Biogas production from Chinese kitchen waste

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Abstract

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Abstract

Biogas is a mixture of different gases produced through anaerobic digestion by breakdown of organic matter in the absence of oxygen. The biogas produced from Chinese kitchen food waste was implemented in mesophilic temperature range (40-43ºC). The aim of this thesis was to determine the feasibility of methane production from Chinese kitchen food waste and compare the potential of biogas production from the mixture of Chinese kitchen food waste and garden waste. Another aim was to compare materials potential for biogas production between Chinese kitchen food waste and cow manure. The biogas production from cow manure was tested before and the final result of biogas yield was collected for this study.

Chinese kitchen food waste was collected the Chinese restaurant of Kuopio, Finland (Kiinalainen Ravintola) which mainly contains chicken, vegetables and noodles. Chinese kitchen food waste was calculated in the biogas batch test which contains 33.41% dry matter (TS) and 29.80% organic dry matter (VS). Garden waste was collected from Kuopio garden yard which mainly contains leaves and slim branches. The garden waste was tested which contains 36.55% dry matter and 29.80% organic dry matter.

In this study, Chinese kitchen food waste was tested to determine its potential for biogas production which set zero test and two substrate tests. The zero test was only filled inoculum in 5 liter bottles and conducted two parallel test. The substrate test one was a mixture of Chinese kitchen food waste and inoculum and the VS ratio between sample and inoculum was 0.92. The substrate test 2 was a mixture of Chinese kitchen food waste and garden waste as well as inoculum. The VS ratio between samples and inoculum in substrate test two was 0.97. Each substrate test conducted three parallel test.

From the result, Chinese kitchen food waste proved to be a highly efficient materials for biogas production. Substrate test one with VS-ratio 0.92 produced 95.59 Nm^3 CH_4 from per ton of fresh matter, 286.13 Nm^3 CH_4 from per ton of dry matter and 320 Nm^3 CH_4 from per ton of organic dry matter. The mass reduction in substrate test one was 2.38% and The VS reduction was roughly 6%. Substrate test two with VS-ratio 0.97 has lower methane yield than substrate test one. The mass reduction was 1.52% and the VS reduction was roughly 6%.

Keywords

Chinese kitchen food waste, biogas production, anaerobic digestion, methane yield

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1 INTRODUCTION

1.1 Biogas benefits for society

1.1.1 Renewable energy sources

The current global energy supply is highly dependent on fossil fuel like natural gas, coal and petroleum. With the growth of economy and population, the demands for fossil fuel are still increasing. Figure 1 presents an example of world energy consumption, which shows an increasing trend in fossil fuel consumption in 2010. Fossil oil is considered non-renewable resources, which is formed through a long period and is used up faster than it can be made by nature (*Fossil oil.* WIKIDEDIA). The current big problem is global energy shortage because limited natural resources need to meet the growing energy demand. To overcome this problem, biogas from anaerobic digestion (AD) is an effective way to solve the world energy shortage and provide a versatile carrier of renewable energy.

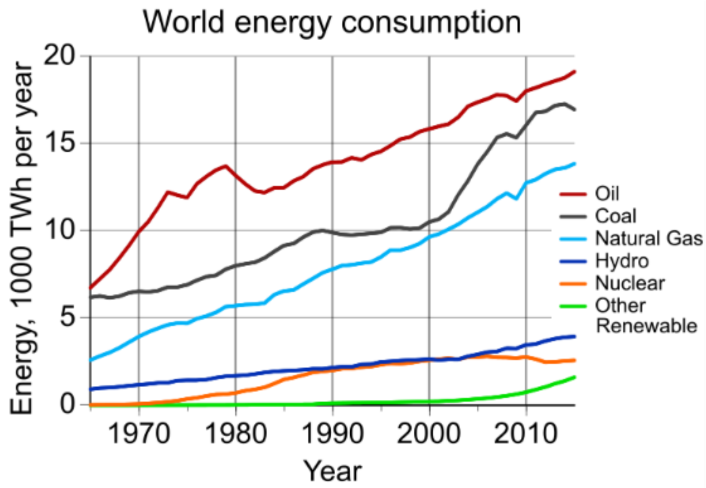

FIGURE 1. World consumption of primary energy by energy source (London, 2012)

1.1.2 Closed nutrient cycle

From the feedstock production to the application of biogas and fertilizers, the biogas production provides idea of sustainable development. Figure 2 shows a closed nutrient and carbon cycle. The biogas from anaerobic digestion is used for electricity or heat and the liquid residue left by biogas production can be used as fertilizers for farmer. The released carbon dioxide return to the atmosphere and up taken by vegetation for photosynthesis (Al Seadi et al. 2008). In a word, biogas production is efficient for recycling of environmental resources and make great contribute to the replacement of fossil fuel used in fuel and heating areas.

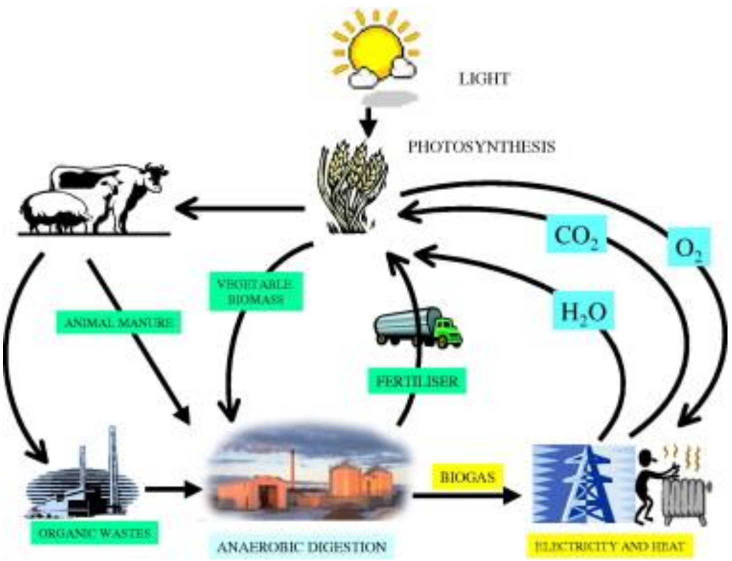

FIGURE 2. The sustainable cycle of biogas from anaerobic digestion (Al Seadi 2008)

1.2 Biogas production in Europe and China

1.2.1 Current situation in Europe

Europe is a big producer of biogas because it has well-developed technique. Currently biogas is produced in 15 European and injected into natural gas grid in most of them. Figure 3 shows biogas plants in Europe. Altogether there are 200 upgrading plants in Europe (Sabine Strauch, Joachim Krassowski, Ankit Singhal, 2013). The produced biogas is mostly fed into a gas grid and used for heat and power purposes as well as its application as a transport fuel (*EBA's BIOMETHANE fact sheet.* European Biogas Association). In Sweden, biogas as a fuel has already overtaken compressed Natural Gas with a market share of 57% (Mattias Svensson, 2013). In Germany, the share is doubled only within one year (2012) from 6% to 15% (*EBA's BIOMETHANE fact sheet.* European Biogas Association). The biogas production and utilization contribute to European climate targets by reducing CO2 emissions and improving air quality.

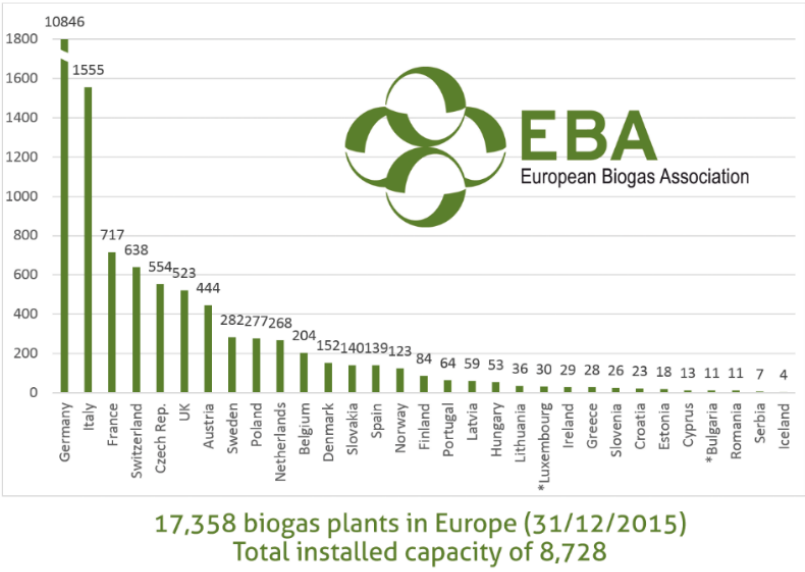

FIGURE 3. Biogas plants in Europe 2015 (European Biogas Association 2015)

1.2.2 Biogas production in China

Biogas production has a long history in China, with the first biogas reactor in the world being created at the end of 19th century. Over 30 million households in China have biogas digester that converts waste into clean-burning fuel and the household digester produces biogas used as daily energy supply in most rural areas. By the end of 2011, the total number of biogas users in China was over 41 million which includes 39 million more that have household biogas digester (Zuzhang Xia, 2013). The household biogas digesters are generally 6 m^3 to 10m^3. In China, the basic household biogas system involves an anaerobic digester (usually underground) with an inlet pipe, an outlet pipe, and a tube for biogas collection (Figure 4.). The feedstock through inlet pipe into digester is a combination of plant and animal waste, plus water. Crop residues as well as tree litter and weeds are suitable, and the manure from pigs, cows, chickens, humans ferments in the digester tank to produce biogas which contains 50-70 methane (CH_4). Both liquid sludge from the outlet pipe and sediments in the bottom of tank are beneficial to farmer as fertilizers.

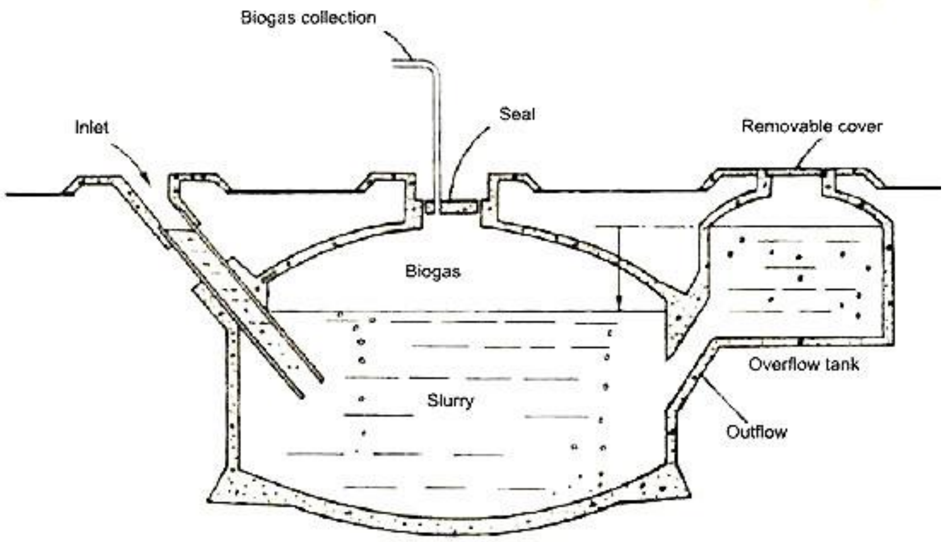

FIGURE 4. Basic biogas digester (Kangmin and Ho 2006)

In China, there are kinds of typical biogas production model linked by household biogas. The basic biogas production model in rural place is called ``three-in-one digester`` in which the biogas reactor underground is made up of cement and bricks (Figure 5.). The digester tank is normally connected to a pigsty and a toilet as feedstock supply for anaerobic digestion through inlet pipe. The residue from biogas production is collected in outlet pit for farm fertilizers. The produced biogas is straightly transported through underground pipe to family used for energy supply. In the south of China, the "four-in-one" energy ecological model (Figure 6.) is built with a combination of biogas reactor, pigsty, toilet and greenhouse. A sunlight green house is set in the rural courtyard and the biogas tank is under a pigsty which is close to the toilet. For the south of china, the "pig-biogas-fruit" energy ecological model which is built by integrating biogas tank with livestock, poultry houses and toilet. It contributes to a courtyard economy system linking breeding, biogas and planting [Li Kangmin, 2006].

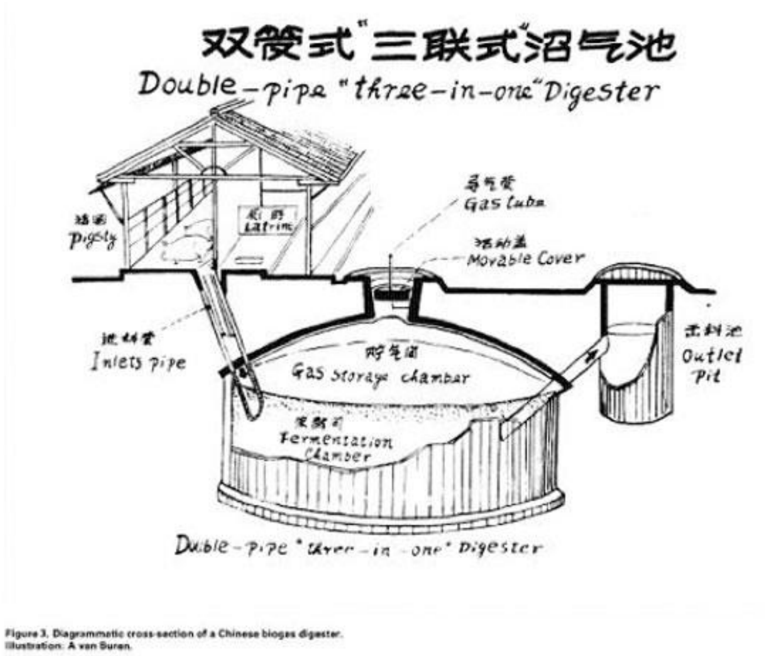

FIGURE 5. Three-in-one model (Van Buren 1980).

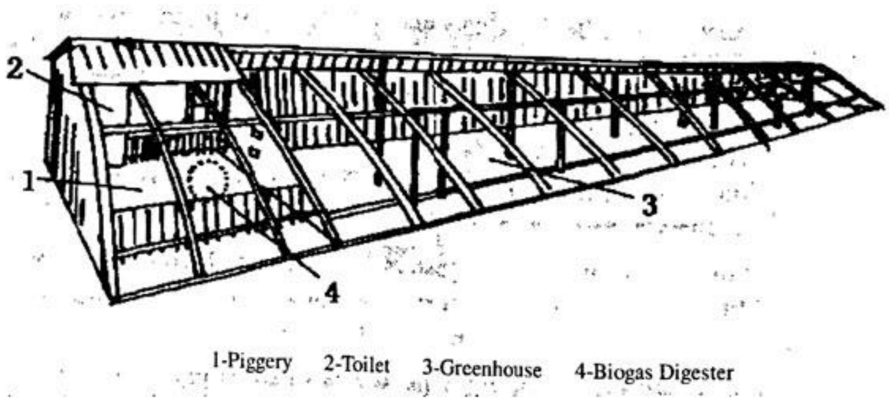

FIGURE 6. Four-in-one model (Wang 2004)

1.3 Chinese kitchen food waste

1.3.1 Current situation of Chinese kitchen food waste in China

Kitchen waste refers to the garbage arising from food processing, catering services and other activity in the daily and the main sources are from family kitchen, restaurant, cafeterias and other food process industries [*Kitchen waste*. Baidu].With the development of economy and improvement of living standard, the increasing of food waste is becoming a new problem in China, which cause harmful effect on city environment quality and residents health. According to the 2017 - 2022 Chinese food waste disposal industry development prospects forecast and investment strategic planning analysis report, in 2014, the food waste production is more than 8000 million tons and the average daily output reaches 230,000 tons / day [Sha Deng, 2016].

1.3.2 Treatment method of kitchen food waste

Chinese kitchen food waste are characterized by its high fat content, high salt content and easily biological degradation in a short term. Improper disposal can cause secondary contamination. The figure below (Figure 7) shows flow of food waste. Currently, regular management system for the food waste treatment technology has not been established in China, which is hard to achieve the dispose of food waste safely. The traditional way of food waste treatment is to landfill with other urban garbage or be transported to farm used as fertilizer. Food waste is the main component of urban organic waste and the common ways for urban organic waste treatment are landfill, incineration, aerobic composting technology, feeding technology and anaerobic digestion technology.

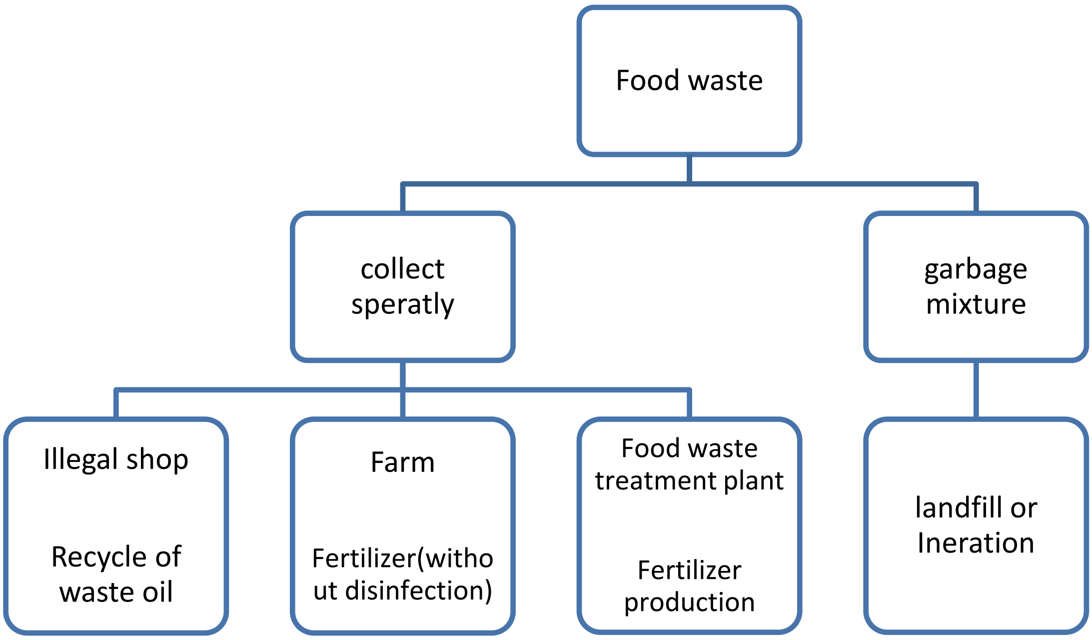

FIGURE 7. The flow of food waste

Landfill

Landfill is the main method of municipal solid waste disposal in the world. Landfill is the biochemical process that the garbage is degraded underground by aerobic microorganisms, facultative anaerobic microorganisms and anaerobic microorganisms [Youcai Zhao, Qingshan Zhu, 1999]. The advantage of landfill is its simple operation and huge processing capacity with low cost. However, with the decrease of land resources and the development of urbanize process, the strong demands for landfill result in increasing high cost. In addition, landfill for food waste treatment is easy to cause groundwater and soil irreversible secondary pollution because of landfill percolate and produce odor by anaerobic or aerobic digestion, which fails to carry out harmless disposal of food waste.

Incineration

Incineration is a waste treatment process that involves the combustion of organic substances contained in waste materials and converts waste materials into ash, flue gas and heat [*Incineration,* WIKIPEDIA]. The heat generated in the incineration process can be used to generate electric power and the incineration with energy recovery is called waste to energy technologies. However, Incineration for food waste treatment still has some disadvantages. Because high water content in food waste is more than 70% which result in low calorific value for burninng so that it can reduce the utilization of heat and increase the processing cost of additional fuel consumption. In addition, due to high oil content in food waste, the combustion process may cause the formation of dioxin catalyzed by the heavy metal and result in serious secondary pollution in improper treatment [Qingfang Zhang, Linhai Yang, Dandan Zhou, 2012]. In recent years waste incineration has caused controversies among administration officials as well as residents because of its adverse effects on environmental protection and public health issue.

Aerobic composting technology

Aerobic composting is decomposition of organic matter by microorganisms in presence of oxygen, which is one of the most effective harmless treatment to deal with municipal solid waste. The output produced by aerobic composting is rich in humus, N, P, K and other nutrient elements and can be used as farm for fertilizer and soil conditioner [Yang Yanmei, Zhang Xiangfeng, Yang Zhifeng, 2006]. However, The optimum moisture content of aerobic composting process is 50% to 60% and the water content in Chinese kitchen food waste is over 60%. In that way, the temperature of the aerobic composting reactor is hard to rise so that the waste decomposition is extremely slow [Youcai Zhao, Lijie Song, Hua Zhao, Jiaren Hu, 2002]. As well, Aerobic composition is mainly for green plant waste like straw which is rich in fiber. In that way, complicated composition in Chinese kitchen food waste like harmful organic matter, grease, heavy metal as well as high water content make it difficult to aerobic compositing.

Feeding technology

Feeding technology is a biodegradation process in which food waste go through solid-liquid separation treatment and take the solid content for sterilizing by high temperature and the organic matters are degraded into biological feed by adding moderate fungi [Zheng Liang, Yong-hua Yang, Hong Fan, 2004]. The feeding technology for food waste treatment is a good way because of high resource utilization. However, there is a disadvantage that the organic feed processed from feeding technology returns to food chain and it would eventually return back to human body and take a risk of leading to homology pollution. Therefore, Feeding technology for food waste used for fertilizer is not permitted and Chinese government decided to withdraw the permission of feed production of food waste.

Anaerobic digestion technology

Anaerobic fermentation or digestion is a biological process in which microorganisms break down biodegradable material in absence of oxygen and convert biomass into biogas [Xiaojun Xu, Xijun Guan, Yijin Yang, 2007]. As anaerobic digestion for food waste treatment can save power consumption and produce clean energy, a lot of country give great attention to the anaerobic digestion technology. Anaerobic fermentation process has different types. According to the different fermentation temperature, it can be divided into normal temperature, medium temperature and high temperature fermentation; according to the feeding operation, it can be divided into continuous and batch Type fermentation; according to the amount of solid content in the fermentation material, it can be divided into wet and dry anaerobic fermentation [Qingfang Zhang, Linhai Yang, Dandan Zhou, 2012].

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1.4 The objectives of the study

The aim of this thesis is to determine the feasibility of methane production from Chinese kitchen food waste and compare the potential of biogas production by using different doses of material mixtures. Another aim is to compare materials potential for biogas production between Chinese kitchen food waste and cow manure. The biogas production from cow manure was tested before and the final result of biogas yield was collected for this study. The specific objectives of the research are as followed:

- To determine biogas yield or potential from Chinese kitchen food waste
- To compare biogas yield from different doses of Chinese kitchen food waste
- To determine biogas potential from the mixture of Chinese kitchen waste and garden waste
- To determine Chinese kitchen food waste degradation and mass reduction
- To compare materials potential between Chinese kitchen food waste and cow manure

2 THEORETICAL REVIEW

2.1 The characteristics of biogas

Biogas is a mixture of different gases produced through anaerobic digestion by the breakdown of organic matter in the absence of oxygen. The biogas mainly contains methane around 50% and CO_2 around 25% as well as a small amount of N_2, H_2 and H_2S. The Table 1 shows typical composition of biogas [*Biogas*, WIKIPEDIA].

The main component of methane is ideal for use in gas fuel, because of its colorless and tasteless, which is burning immediately by mixing with the right amount of air. Per cubic meter of pure methane produce heat 34000 KJ. Per cubic meter of biogas produce heat about 20800-23600 KJ, which is equal to heat provided by 0.7 kg anthracite. Compared with other fuel, methane is a kind of high efficient clean energy [Xiujing Zhai, Kuiren Liu, Qing Han, 2005].

TABLE 1. Typical composition of biogas [*Biogas*, WIKIPEDIA]

Compound	Formular	%
Methane	CH_4	50-70
Carbon dioxide	CO_2	25-50
Nitrogen	N_2	0-10
Hydrogen	H_2	0-1
Hydrogen sulfide	H_2S	0-3
Oxygen	O_2	0-0.5

2.2 Anaerobic digestion

Anaerobic digestion is a biochemical process in which complex organic matter is decomposed by various types of anaerobic microorganisms in the absence of oxygen. The process of anaerobic digestion occurs in many natural environments such as marine water sediments and the stomach of ruminants or peat bogs. In biogas lab and plant installation, the main product is biogas and the by-product is residue. The process of biogas formation is a result of linked process steps, in which the initial materials are continuously broken down into smaller units. The Figure 8 shows the simplified diagram of anaerobic digestion process and highlights four main process steps: hydrolysis, acidogenesis, acetogenesis, and methanogenesis [Al Seadi, et al. 2008].

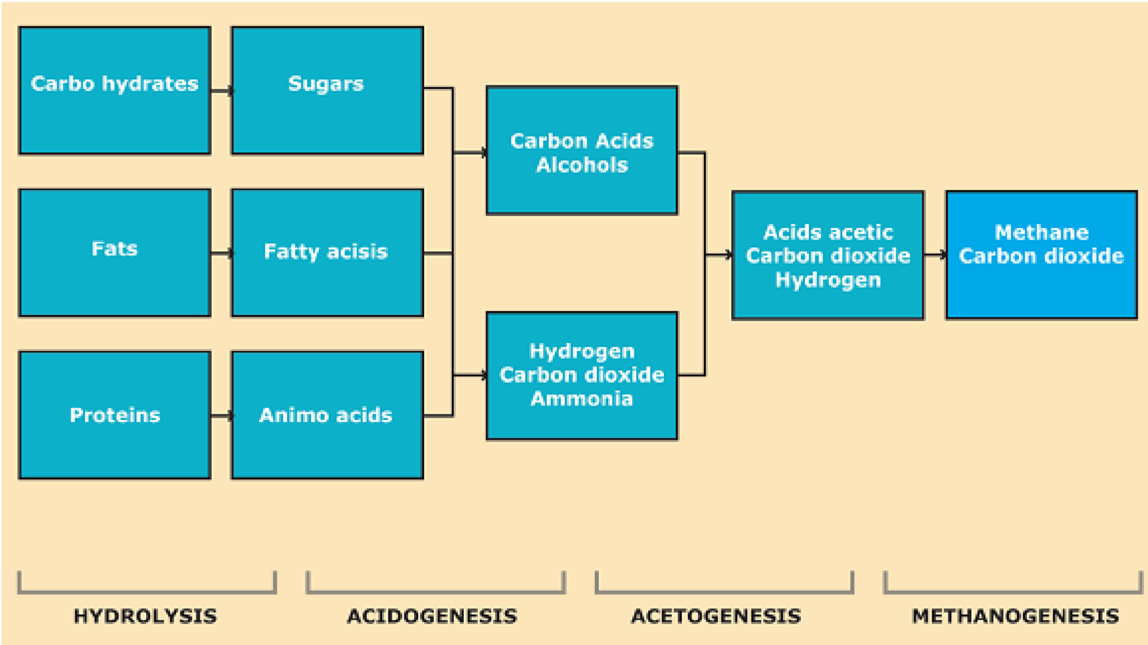

FIGURE 8. Basic stages of anaerobic digestion (Al Seadi 2001)

2.2.1 Hydrogenesis

Hydrolysis is the first stage of anaerobic digestion where the large and complex organic compounds are decomposed into smaller units. During hydrolysis, carbo hydrates, lipids and proteins are converted into sugars, fatty acids and amino acids. Hydrolytic microorganisms excrete enzymes and convert biopolymers into simpler and soluble compounds as it is shown below [Al Seadi, et al. 2008].

$$\textit{Lipids} \xrightarrow{\text{lipase}} \textit{fatty acids, glycerol}$$

$$\textit{Polysaccharide} \xrightarrow{\text{cellulase, cellobiase, xylanase, amylase}} \textit{monosaccharide}$$

$$\textit{Proteins} \xrightarrow{\text{protease}} \textit{amino acids}$$

2.2.2 Acidogenesis

In the acid forming process, the end products of the hydrolysis are decomposed by a large diversity of facultative anaerobes and aerobes. The products from hydrolysis like simple sugar, amino acid and fatty acids are degraded into acetate, carbon dioxide (CO2), hydrogen (H2) and alcohol as well as organic-nitrogen compounds and organic-sulphur compound. The created main products are acetic acid and acetate [Gerardi, Michael H, 2003].

2.2.3 Acetogenesis

Products from acidogenesis which cannot be directly converted into methane by methanogenic bacteria are converted into methanogenic substrates during acetogenesis. Volatile fatty acids and alcohols are oxidized into methanogenic substrate like acetate, hydrogen and carbon dioxide. The production of hydrogen increases the hydrogen partial pressure. This can be regarded as a “waste product” of acetogenesis and inhibits the metabolism of the acetogenic bacteria. During methanogenesis, hydrogen is converted into methane. Acetogenesis and methanogenesis usually run parallel as symbiosis of two groups of microorganisms [Al Seadi, et al. 2008].

2.2.4 Methanogenesis

Methane is formed at the fourth stage in which methane-forming bacteria degrade a relatively small number of substrates (Table 2) to form methane. 70% of the formed methane originated from acetate, while the remaining 30% is produced from version of hydrogen and carbon dioxide. The following equations show the fundamental reaction of methane conversion [Al Seadi, et al. 2008].

$$\textit{Acetic acid} \xrightarrow{\text{methanogenic bacteria}} \textit{methane} + \textit{carbon dioxide}$$

$$\textit{Hydrogen} + \textit{carbon dioxide} \xrightarrow{\text{methanogenic bacteria}} \textit{methane} + \textit{water}$$

TABLE 2. Substrate Used by Methane-forming Bacteria [Gerardi, Michael H, 2003]

Substrate	Chemical Formula
Acetate	CH3COOH
Carbon dioxide	CO2
Carbon monoxide	CO
Formate	HCOOH
Hydrogen	H2
Methanol	CH3OH
Methylamine	CH3NH2

2.3 AD parameter

The efficiency of anaerobic digestion is influenced by some critical parameters, thus it is crucial to ensure appreciate conditions for anaerobic microorganisms. The growth and activity of anaerobic microorganisms are significantly influenced by conditions such as constant temperature, PH value, and nutrient supply. The methane bacteria is fastidious anaerobes so that the presence of oxygen into anaerobic digestion must be strictly prohibited.

2.3.1 Temperature

Temperature is one of the critical factors that effects methane-forming bacteria activity. An acceptable and uniform temperature should remain throughout anaerobic digestion to ensure bacteria activities. Variations in temperature of even a few degrees effect almost biological activities including inhibition of anaerobic bacteria, especially methane-forming bacteria. Most methane-forming bacteria are active in three kinds of temperature range: psychrophilic (below 25°C), mesophilic (30°C-42°C) and thermophilic (43°C-55°C). There is a direct relation between temperature and retention time (Table 3). The thermophilic with high temperature has higher growth rate of methanogens (Figure 9), which proves experimentally to have higher methane yield in anaerobic digestion process [Al Seadi, et al. 2008].

TABLE 3. Thermal stage and typical retention time

Thermal stage	Temperature °C	Minimum retention time
Psychrophilic	5-25	70 to 80 days
Mesophilic	30-42	30 to 40 days
Thermophilic	43-55	15 to 20 days

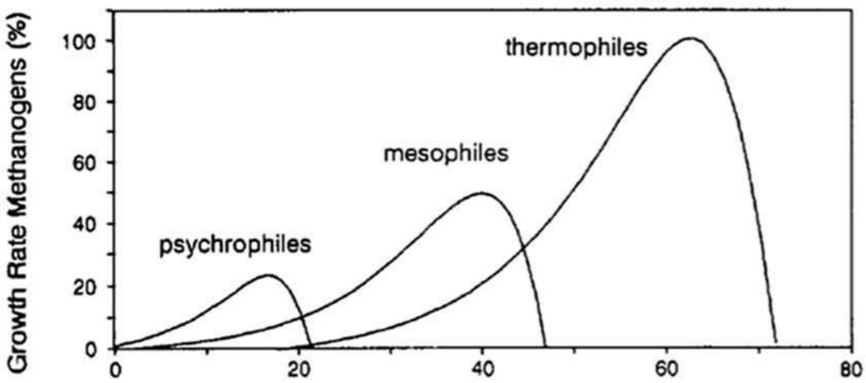

FIGURE 9. Relative growth rates of methanogens (Anglidaki 2004)

2.3.2 Hydraulic retention time (HRT)

An important parameter for biogas production is the hydraulic retention time. Hydraulic retention time is the average time when substrate is degraded inside the digester. The generation time of methane-forming bacteria is relatively long compared with other anaerobic bacteria, typically taking 3 to 30 days. Because HRT value effects the rate and extent of methane production, the HRT for anaerobic digestion is recommended not less than 15 days (Table 3).

2.3.3 Organic loading

Organic loading is an important operational parameter, which indicates how much organic dry matters can be fed into digester, per volume and per day as it is shown below. Obtaining the maximum biogas yield would require a long retention time of substrate inside digester and a correspondingly large digester size.

$$Br = m * c / Vr$$

Br organic loading (kg/d*m^3)
m mass of substrate fed per day (kg/d)
c concentration of organic matter (%)
Vr digester volume (m^3)

2.3.4 PH and Alkalinity

The PH-value is the measure of acidity or alkalinity of a solution and is expressed in parts per million. The PH value of the AD substrate influences the growth of methanogenic microorganisms and affects the dissociation of some compounds such as ammonia, sulphide and organic acids. The optimum PH interval for mesophilic digestion is between 6.5 and 7.8 and the process is severely inhibited if PH value decreases below 6 or rises above 8 (Table 4). Acceptable enzymatic activity of methane-forming bacteria performs within a PH range of 6.8 to 7.2. Alkalinity serves as a buffer that prevents rapid PH changes. Digester stability is enhanced by a high alkalinity concentration, because the decrease of alkalinity usually causes drastic change of PH and completely inhibits anaerobic digestion process. For this reason, a stable and uniform PH and a high level of alkalinity is important to ensure anaerobic digestion process running successfully (Al Seadi, et al. 2008).

TABLE 4. Optimum growth PH of some methane-forming bacteria [Gerardi, Michael H, 2003]

Genus	PH
Methanosphaera	6.8
Methanothermus	6.5
Methanogenium	7.0
Methanolacinia	6.6-7.2
Methanomicrobium	6.1-6.9
Methanospirillium	7.0-7.5
methanothrix	7.1-7.8

2.3.5 Volatile fatty acids (VFA)

The stability of the anaerobic digestion is reflected by the concentration of intermediate products like the VFA. The volatile fatty acids are the intermediate compound produced during acidogenesis with a carbon chain of up to six atoms. An efficient of biogas process is independent on the balance of bacteria. If there is an imbalance, volatile fatty acids produced by acid forming bacteria rise which performs a sharp drop of PH and leads to the instability or inhibition of anaerobic digestion process.

2.3.6 Macro- and Micronutrients

Nutrient requirements for anaerobic digestion are available to methane-forming bacteria. Macronutrients like carbon, nitrogen, phosphor, and Sulphur are needed to satisfy anaerobic bacteria activity and remain acceptable digester performance. The optimal ratio of C: N: P: S is considered as 600:15:5:1 which ensures proper degradation of substrate. Another nutrient is micronutrients (trace element) like iron, nickel, cobalt, selenium, molybdenum or tungsten are equally important to the growth and survival of microorganisms. The insufficient or unbalanced of nutrients and trace elements may cause inhibition and disturbance in the AD process [Gerardi, Michael H, 2003].

2.4 Biogas potential and inhibition effects

2.4.1 Biogas potential

The potential methane yield is one of the important criteria of evaluation of different anaerobic digestion substrates. It is noticeable that food waste for anaerobic digestion can produced considerable biogas. The Figure 10 shows the methane yield of food waste is 400 Nm^3CH_4/t DM which can produce 400 Nm^3 CH_4 from per ton of dry matter. The methane yield of cow manure is nearly 200 m3 CH4/t DM and the literature value of methane yield from cow manure is 250 Nm^3CH_4/t VS which can produce 250 Nm^3CH_4 from per ton of organic dry matter [Al Seadi, et al. 2008].

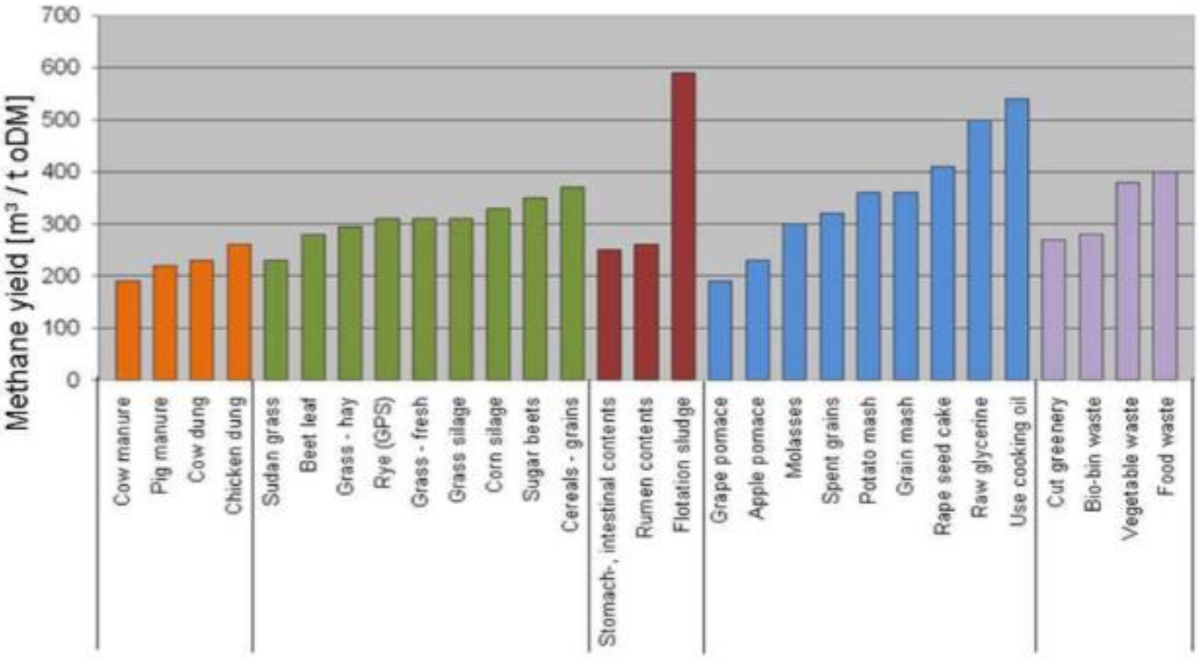

Figure 10. Benchmarks for specific methane yield (Prabl 2007)

2.4.2 Inhibition effects

Inhibitors are harmful factors that decrease methane production or stop it totally. There are two kinds of inhibitors. Possible inhibitors are caused by anaerobic digestion process itself and another inhibitors are from feeding stock.

Fatty acid

Inhibitors from anaerobic digestion process like fatty acid production, a high rate of volatile fatty acid production during acidogenesis stage leads to PH value and the concentration of alkalinity descending, which makes methane-forming bacteria activity is inhibited. In that way, if hydraulic retention time is over 5 days, the methane-forming bacteria begin to consume the volatile acids and the PH value increases and then stabilizers. If the feed stock is easily degradable, the fatty acids in the beginning stage are formed easily and it also results in inhibition of methanogenesis [Gerardi, Michael H, 2003].

Hydrogen sulphide (H_2S)

Bacteria need soluble sulphide as a growth nutrients to satisfy its need. However, excessive concentration of sulphide and dissolved hydrogen sulphide (H2S) cause toxicity. Soluble hydrogen sulphide toxicity occurs because sulphide inhibits the metabolic activity of anaerobic bacteria. The PH is an important factor effecting hydrogen sulphide toxicity. If the PH value declines causing high concentration of H^+, it would accelerate the formation of hydrogen sulphide (H_2S) so that hydrogen sulphide toxicity occurs according to the equation as followed [Gerardi, Michael H, 2003].

$$H_2S \leftrightarrow HS^- + H^+$$

Ammonia (NH3)

Ammonia iron (NH_4^+) and ammonia-nitrogen (NH_4^+-N) are formed by degradation of organic nitrogen compounds. Nitrogen exists in two forms including free ammonia (NH3) and ammonia iron (NH_4^+). Free ammonia has dual effects which are determined by value. If PH value increases leading to H^+ concentration decreasing, the amount of free ammonia will increase according to the equation as followed. If the free ammonia concentration exceeds 1500 mg/g, it can cause inhibition in anaerobic digestion because of the rapid accumulation of volatile fatty acid [Gerardi, Michael H, 2003].

If the feed contains a high amount of nitrogen (chicken manure), the amount of ammonia can be raised into inhibition level.

$$NH_4^+ \leftrightarrow NH_3 + H^+$$

TABLE 5. Effects of ammonia in an anaerobic digestion [Gerardi, Michael H, 2003]

Dissolved ammonia (NH3, N)	Effect
50-200 mg/l	Beneficial
200-1000 mg/l	No adverse effect
1500-3000 mg/l	Inhibition

C/N ratio

In general, the optimal C/N ratio for anaerobic digestion process ranges from 15 to 30. If the C/N ratio is too high, resulting in low concentration of N, the PH is easily lower than uniform value by the unstable buffer ability. If the C/N ratio is lower than optimal value, microorganism can transfer excess N to NH_3 forming ammonium bicarbonate (NH4HCO3) that can increase buffer capacity. However, the accumulation of ammonium salt can easily lead to inhibition to fermentation reaction [Shengtao Fu, Shuili Yu, Xiaoju Yan, 2006].

3 MATERIALS AND METHODS

3.1 Biowaste used in the study

3.1.1 Chinese kitchen food waste

Chinese kitchen food waste in the present study was collected from the Chinese restaurant of Kuopio, Finland (Kiinalainen Ravintola). The restaurant serves three meals a day, which produces roughly 0.05 ton of kitchen food waste per week. The food waste in the restaurant is collected and sorted in different garbage containers. One garbage container is for raw material waste and another is for gathering all of food waste from the dining-table. The Chinese food waste used in anaerobic digestion is originated from the container collecting food waste from dining-table, which is characterized as high oil content including chicken, noodles, meet and vegetables. In the beginning test, Chinese kitchen food waste was calculated in biogas batch test which contains 33.41% total solid (TS) and 29.80 % organic dry matter (VS).

The typical Chinese food waste mainly consists of rice, vegetables, meat and bone. The average water content of Chinese kitchen food waste was extraordinarily high (69.85%), because food waste contains many high moisture components like vegetables and fruit peel. Chinese kitchen food waste cantains elements such as C, N, O, H which follows the sequences: C>O>H>N>Cl>S. The table 6 shows the chemical components and the content of kitchen food waste. The average C content is 47.22%. The average H content is 7.04% and it greatly varies with samples from 3.10% to 18.45%. The N content is as high as 3.86%, because of high protein content in meats, fruits and vegetables. The calculation of the C/N ratio from the table 6 in Chinese kitchen food waste is12.2 [Hui Zhou, Aihong Meng, et al. 2014].

TABLE 6. The chemical composition and content of kitchen food waste [Hui Zhou, Aihong Meng, 2014]

Component	C	H	O	N	S	Cl
Maximum (%)	59.95	18.45	59.93	7.75	1.10	2.50
Minimum (%)	32.81	3.10	26.54	0.82	0.13	0.12
Average (%)	47.22	7.04	41.15	3.86	0.49	1.06

3.1.2 Garden waste

Garden waste was collected from Kuopio garden yard. It mainly contains leaves and slim branches. In the beginning test, the garden waste was calculated in biogas batch test which contains 36.55% total solid (TS) and 29.80% organic dry matter (VS).

3.1.3 Inoculum

Inoculum was taken from Luke´s biogas plant and collected straightly from plant outlet pipe. The inoculum was mixed with food waste in test bottle in order to get the anaerobic digestion process started properly. According to the test, the inoculum was tested in original TS and VS calculations which contains 5.69% dry matter and 4.33% organic dry matter. The inoculum PH was 7.682.

3.2 Methods

3.2.1 The TS and VS determination

The biogas batch test begins by determining dry matter (TS=Total solid) and organic dry matter (VS=Volatile solid) concentrations of the samples. The original TS and VS concentrations are needed for the proper bottle doses calculations and also for the final results calculations like degradations of organic dry matter in the samples. Basic steps to determine dry matter content and organic dry matter content are shown in Figure 10. The following steps involve two important steps which are drying and burning. Drying materials should be carried in the dry oven and set the temperature at 105^{o}C for 20 hours. Burning the dry materials in a muffle kiln set at the temperature of 550^{o}C for 2 hours. Calculating the dry matter and organic dry matter concentrations are expressed as a percentage of mass or grams per kilogram using the following equations [Teija Rantala, Maarit Janhunen, Sanna Hyvonen, 2014].

$TS= (m_3-m_1) / m_w$

$Ash= (m_4-m_1) / m_w$

$VS= TS-Ash$

Where:

m_w= is the mass of fresh matte in grams

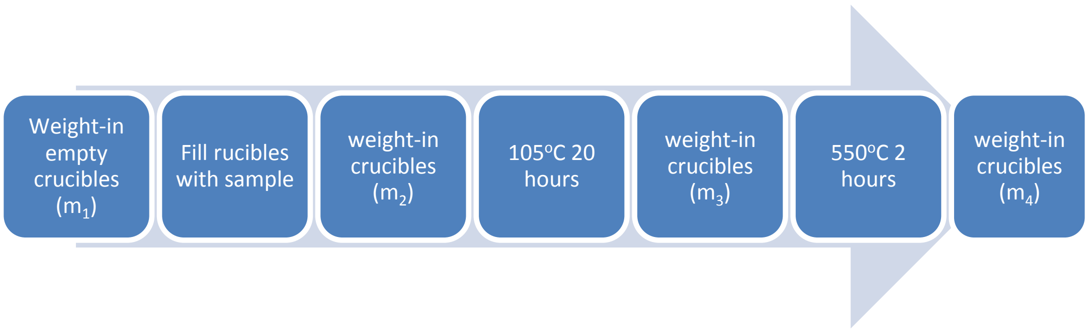

FIGURE 11. Steps for dried matter (TS) and organic matter (VS) determinations

3.2.2 The bottle dose calculations

The biogas batch test is tested in 5 liter glass bottles which are used for loading sample. The total doses of the sample and inoculum together in the test bottle are recommended to be around 3500 g. The amount of inoculum used in test bottle is roughly the half of the test bottle filling volume, which is typically 1500 g. The precise loading ratios of inoculum and substrate in the test bottle are based on initial organic dry matter concentrations of samples and organic dry matter ratios used in the test bottle. There are two kinds of mix test for organic dry matter ratio calculations. If the test is a mixture of one sample and inoculum, the organic dry matter ratio is 50:50 in the test bottle. If the test is a mixture of two samples and inoculum, the organic dry matter ratio is 50:50 in the test bottle. 50% of organic dry matter content is from inoculum and another 50% is totally from two different samples which have divergent organic dry matter ratios [Maarit Janhunen, 2014].

3.2.3 Calculations of methane yield potential

Calculation of methane yield is based on biogas measurement. The measured biogas volume and concentration are collected to calculate the methane yield. It is suggested that the gas volume has to be normalized under conditions of temperature T=273.15 K and pressure P=101325 Pa according to the following formula [Maarit Janhunen, 2014].

$$V_o = V * [(P-P_w) * T_o] / (P_o * T)$$

Where V_o is the dry gas volume in Nml. V and T are the measured gas volume in ml and the temperature in k. T_o and P_o are standard temperature and pressure. P_w is the water vapors pressure at measured temperature.

The final results should be given in such terms which are Nm^3CH_4/ t FM, Nm^3CH_4/ t TS and Nm^3CH_4/ VS. It shows how much methane is produced from per ton of fresh matter, dry matter and organic dry matter. The calulations of methane yield is only from sample without inoculum. The mass reduction and organic dry matter reduction of sample are also need for final results.

4 OPERATING PROCESS

4.1 Planning the test

4.1.1 Operating apparatus

The biogas batch test was tested in different apparatus and the below lists show laboratory equipment and apparatus.

- Drying oven

  Used for drying fresh matter in the stage of TS and VS determination at a temperature of 105^{o}C
- Muffle kiln

  Used for burning dry matter in the stage of VS and TS determination at a temperature of 550^{o}C
- Desiccator

  Used for cooling down hot crucibles after burning in the stage of determination of VS and TS
- Heating cabinet

  Used for heating the test bottles and the storage of biogas anaerobic digestion process at a temperature of 40^{o}C
- GA2000 Plus analyzer

  Used for measuring gas components and their concentrations
- Water-sealed container

  Used for measuring gas volume connecting with GA2000 Plus
- 5 liter glass bottle
- numbered gas bags
- gas tight corks
- pure nitrogen gas
- PH measurement

4.1.2 Determining material mixture

In biogas batch test, Chinese kitchen waste was tested to determine its potential for biogas production by mixing with garden waste and inoculum. The continuous anaerobic digestion test was conducted under the mesophilic condition with a temperature of 43^{o}C. Table 7 shows two different kinds of mixtures in biogas batch test. Each kind of substrate mixture do two or three parallel test. The sample

1 with VS-ratio 1 set two test bottles and only filled inoculum in the test bottle, which is called zero test. The sample 2 with VS-ratio 0.92 arranged three test bottles, which is a mixture of Chinese kitchen food waste and inoculum. The sample 3 with VS-ratio 0.97 has three test bottles, adding garden waste as a supplyment mixed with Chinese kitchen food waste and inoculum, which is called substrate test bottle as well as the sample 2.

TABLE 7. Characteristics of substrate mixtures

Substrates	*Inoculum VS, g*	*Sample VS, g*	*VS-ratio %*	*Bottles*
Chinese kitchen waste &inoculum	65	59.59	0.92	3
Chinese kitchen waste &garden waste	65	63.35	0.97	3

4.1.3 Calculations of bottle dose

Based on the TS and VS determination of Chinese kitchen food waste, inoculum and garden waste, the precise ratios of each sample for loading test bottles were calculated in order to gain optimal biogas production (Table 8). Total loading for each test bottle was 3500g in 5 liter bottle and the amount of inoculum used in biogas batch test was roughly the half of the test bottle volume, which was typically 1500g in substrate test bottles. The first test was bottles 3 to 5 with a VS-ratio 0.92, which load 200g Chinese kitchen food waste and 1500g inoculum. The second test was bottles 6 to 8 with a VS-ratio 0.97 which load 100g garden waste and 100g Chinese kitchen food waste as well as 1500g inoculum.

TABLE 8. Bottle dose of zero batch test and substrate batch test

Bottles	*Inoculum, g*	*Kitchen waste, g*	*Garden waste, g*	*Water, g*	*VS-ratio*
VS	*4.33*	*29.80*	*33.55*		
3-5	1500	200		1800	0.92
6-8	1500	100	100	1800	0.97

4.2 Pre-treatment of the substrate

About 5 kg of Chinese kitchen food waste was collected and stored in cooling room for one night before pre-treatment. The Chinese kitchen food waste was collected from Chinese restaurant in

Kuopio, Finland which contains chicken, vegetables, and noodles. Chinese kitchen food waste was cut into smaller pieces by knife. Garden waste for biogas batch test was crushed by mixer grinder.

4.3 Filling bottles

The test need to prepare 8 test bottles and 8 gasbag and mark them in corresponding order by masking tape. Two parallel test bottles for loading inoculum were marked 1.0 and 1.1. For the substrate batch tests, three parallel test bottles were marked 2.0; 2.1; 2.2 for loading a mixture of kitchen food waste and inoculum. Three parallel test bottles were marked 3.0; 3.1; 3.2 for loading a mixture of kitchen food waste, garden waste and inoculum. The PH value of all test bottles after filling and mixing was measured range from 7.37 to 7.94 which is required within the PH level from 6 to 8. The final step was to remove oxygen from the bottle´s air space with nitrogen and place 8 sample bottles to heating cabinet.

4.3 Biogas measurement

The biogas volume and concentration produced from test bottle were measured weekly or even often if needed. The weekly biogas measurement recorded the date, time, temperature and pressure as well as gas volume and concentration. The continuous anaerobic digestion for biogas batch test took three weeks and the biogas measurement of each test bottle was roughly five to six times totally by using GA2000 Plus analyzer and water-sealed container. GA2000 Plus analyzer determined the methane (CH_4), carbon dioxide (CO_2), oxygen (O_2) and other gases (BAL) concentration as well as hydrogen sulphide (H_2S) and ammonia (NH_4). The water-sealed container determined the biogas volume. Methane yield should be calculated and altered to match normal conditions (NTP). The methane yield determination was based on the total methane output in each test bottle which was formed as Nl CH_4. The final results were calculated by determining how much methane produced from per ton fresh mass (FM), dry matter content (TS) and organic dry matter content (VS) without inoculum.

5 RESULT AND DISCUSSION

5.1 Results

5.1.1 Mass reduction

The biogas batch test ended up with the final calculations of TS and VS from the residue as well as the final weight of the residue. The average mass reduction during anaerobic digestion for three kinds of test bottles were 1.71%, 2.38% and 1.52% (Table 9). The highest mass reduction was 2.38% in Bottles 3 to 5 which represents high efficiency of material biodegradation in anaerobic digestion. Compared to Chinese kitchen food waste for biogas production, cow manure for biogas production shows a higher mass reduction which were 9.79% and3.78% (Table 10). The highest mass reduction from cow manure was 9.79% which was four times as high as mass reduction from Chinese kitchen food waste.

TABLE 9. Mass reduction from Chinese kitchen food waste for biogas production

mixture	*Bottles*	*Average mass reduction %*
Chinese kitchen waste VS-ratio 0.92	3-5	2.38
Chinese kitchen waste VS-ratio 0.97	6-8	1.52

TABLE 10. Mass reduction from cow manure for biogas production

Savonia´s methods test	*Average mass reduction %*
cow manure VS-ratio 0.55	9.79
cow manure VS-ratio 25:75	3.78

5.1.2 TS and VS reductions

Biogas production is based on biodegradation fraction of organic dry matter (VS) in the sample. The VS reduction in Chinese kitchen food waste VS-ratio 0.92 test was 5.96% and in VS-ratio 0.97 test was 5.94%, nearly 6.0% (Table 11). The dry matter reductions in two different VS-ratio test were 6.92% and 6.91%.

Compared to TS and VS reduction from Chinese kitchen food waste for biogas production, The TS reduction from cow manure was roughly 3.40% and the VS reduction was roughly 3.10%, which were approximately two times lower than the TS and VS reduction from Chinese kitchen waste for biogas production (Table 12).

TABLE 11. TS and VS reduction from Chinese kitchen waste for biogas production

Mixture	*Dry matter (TS) reduction %*	*Organic dry matter (VS) reduction %*
Chinese kitchen waste VS-ratio 0.92	6.92	5.96
Chinese kitchen waste VS-ratio 0.97	6.91	5.94

TABLE 12. TS and VS reduction from cow manure for biogas production

Mixture	*Dry matter (TS) reduction %*	*Organic dry matter (VS) reduction %*
cow manure VS-ratio 0.55	3.41	3.10
cow manure VS-ratio 25:75	3.47	3.14

5.1.3 Methane yield

The figure 11 below shows the comparisons of methane yield from Chinese kitchen food waste. The test one with the VS-ratio 0.92 had the highest methane yield, which produced 95.59 Nm^3CH_4 from per ton of fresh matter, 286.13 Nm^3CH_4 from per ton of dry matter and 320 Nm^3CH_4 from per ton of organic dry matter. The test two with the VS-ratio 0.97 which was a mixture of Chinese kitchen waste and garden waste had a lower methane yield which produced 76.66 Nm^3CH_4 from per ton of fresh matter, 229.47 Nm^3CH_4 from dry matter and 257.28 Nm^3CH_4 from organic dry matter.

The figure 12 below shows the methane yield from cow manure for biogas production. The higher methane yield was the test which the VS-ratio was 25:75. It produced 20.40 Nm^3CH4 from per ton of fresh matter, 218.46 Nm^3CH_4 from dry matter and 251.41 Nm^3CH_4 from organic dry matter. Comparing methane yield from Chinese kitchen food waste and cow manure for biogas production, Chinese kitchen food waste for biogas production behaved higher efficiency and potential than cow manure.

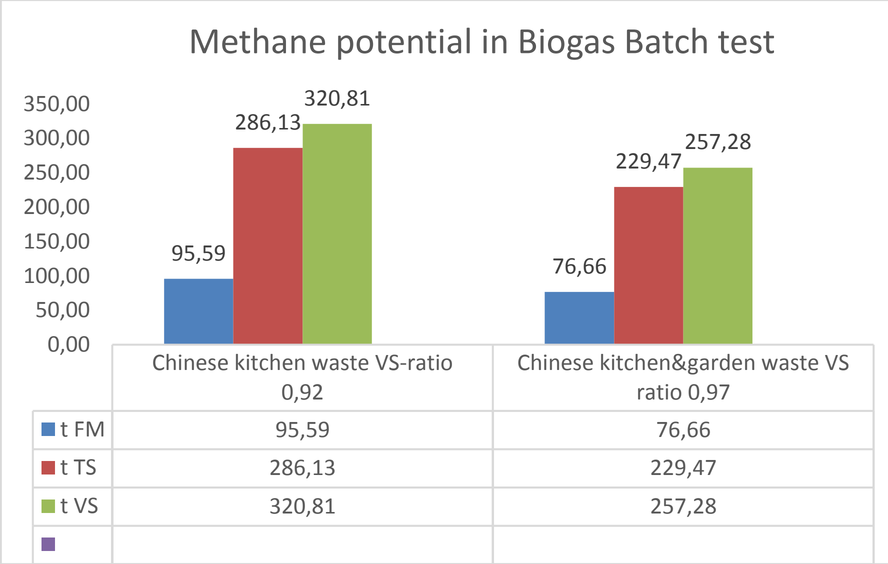

FIGURE 12. Methane potential of Chinese kitchen waste

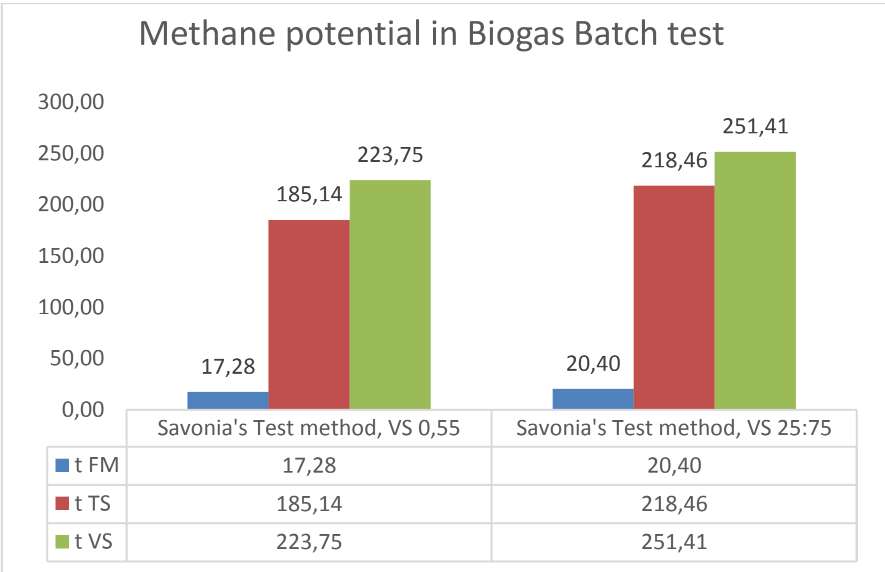

FIGURE 13. Methane potential of cow manure

5.2 Discussion

The anaerobic digestion is a complicated process which has four stages to produce methane including hydrolysis, acidogenesis, acetogenesis and methanogenesis. The experiment had some new discoveries in this study and the lists can be concluded as follow:

- In the beginning biogas measurement, a strange phenomenon occurred that the test bottles produced a huge amount of biogas in the gasbag, but the methane concentration has only roughly 10% and the concentrations of carbon dioxide (CO_2) and other gas (BAL) reached to 60% and 30%. The reason why the methane concentration was low was because of the inhibition of the methane-forming stage. According to inhibition factors, a high rate of volatile fatty acid production during the beginning stage of anaerobic may lead a sharp decrease of PH value, which makes methane-forming bacteria activity is inhibited. After one week, the second biogas measurement showed the methane concentration returned to a normal level ranging from 40% to 60%. If the hydraulic retention time is over 5 days, the methane-forming bacteria begin to consume the volatile fatty acid and the whole anaerobic digestion stages automatically return to normal.

- From the results, it can be seen that the test with the VS-ratio 0.92 which was a mixture of Chinese kitchen food waste and inoculum produced more biogas than the test with the VS-ratio 0.97 which was a mixture of Chinese kitchen food waste and garden waste. In the anaerobic digestion process, the test bottles with a mixture of Chinese kitchen food waste and garden waste produced very small amounts of biogas and nearly entered a period of stasis during the final two weeks. The result showed the adding of garden waste in the test bottles is not efficient to biogas production. A possible inhibition factor is that leaves in garden waste contain lignin which is a class of complex organic polymers that form impotant structural materials in the support tissues of vascular plants and some algae. According to the theory part, lignin protects the plant cell wall so that garden waste may decompose slowly and reduce the biogas production potential.

6 CONCLUSION AND RECOMMENDATIONS

6.1 Conclusion

The study focus on determining potential of Chinese kitchen food waste for biogas production. According to the result of methane yield and the comparison with Savonia´s method test using cow manure as substrate, Chinese kitchen food waste proves to be a highly efficient materials for biogas production. It detects no other inhibitions except high amount of biogas with a low methane concentration in the beginning stage. The result can be concluded as follows:

- Chinese kitchen waste has high potential for biogas production. A mixture with VS-ratio 0.92 produces 95.59 Nm^3CH_4/ t FM, 286.13 Nm^3CH_4/ t TS and 320 Nm^3/ t VS.
- Adding Garden waste did not give significant effect to biogas production. A mixture of Chinese kitchen waste and garden waste with VS-ratio 0.97 produces 76.66 Nm3CH4/ t FM, 229.47 Nm3CH4/ t TS and 257.28 Nm3CH4/ t VS.
- Mass productions in two kinds of VS-ratio of the Chinese kitchen waste are 2.38% and 1.52% and organic dry matter (VS) reduction reaches roughly 6%.

6.2 Recommendations

It is recommended to use Chinese food kitchen food waste as a substrate for anaerobic digestion because of its high potential for biogas production. The mixture of Chinese kitchen food waste and garden waste as a substrate for biogas production should be exemplified further based on the optimal ratio for bottle filling. In terms of an experimental operation, it is suggested to measure the PH every day in the beginning stage to avoid inhibition and shake the bottle twice a day to react perfectly. The sampling of Chinese kitchen food waste used in the study is not typical which contains only several kinds of food waste, so it is proposed to sample in different Chinese food restaurant and take the mixture as a substrate for biogas batch test.

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