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Bioenergy project 7.5 hp

Biogas project development: Design of a small communal biogas facility in Västerbotten VB

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Abstract

The energy issue has been a fairly topical issue in recent years. The development of renewable energy sources is a requirement to be able to achieve the environmental goals that have been set. Thus, several energy sources have been developed. An example is biogas production via anaerobic digestion AB. Biogas' production via AD has been around for many years, while development and research on improvement continue. In this project, a biogas plant for biogas production is designed with the help of AD for placement in Västerbotten, Sweden. After literature studies and literature search, it was decided how the facility should be run. Many operational factors, separately or in combination, may impact anaerobic digestion's efficiency in terms of biogas or digestate production and quality maximization. The best strategy for optimizing an anaerobic digestion plant frequently depends on how carefully key parameters like pH, temperature, organic loading rate and hydraulic retention duration are set. Given the resumed design and implementation of innovative technologies, as well as the introduction of increasingly complex systems, it is necessary to update current knowledge on control factors and their role on operational ranges and flexibilities in actual anaerobic digestion systems. As a result, the current investigation analyzes the significance of operational parameter choices in existing technologies and its influence on biogas output. This study specifically addresses the general categories of feedstock usage (substrate, codigestion, and pretreatment), process condition (pH, temperature, and reactor design), reactor control (HRT and OLR), and inhibition (VFAs). In the end, it was most appropriate with two series-connected CSTR reactors where one works under mesophilic conditions and the other under thermophilic conditions. During winter and cold, both reactors will operate under mesophilic conditions to reduce heating consumption. The substrate will mainly consist of food waste (90 %) and lipid contents (<10 %) and run at a pH around 7. Biogas production of these substrates has great potential in relation to the waste that is extracted every year in Västerbotten. Therefore, it is considered that a biogas plant for biogas production via AD is environmentally good. The gas produced will eventually be upgraded to pure methane gas for resale.

Contents

1 Aim

The aim of this project is to investigate the launch of a plant that will produce renewable methane gas in Västerbotten. There are several ways to produce methane gas. This project is based on methane gas production through digestion of fats and food waste from restaurants, schools and food producers in Västerbotten. Several points must be analyzed to fulfill the purpose of this project, such as location, production method, use of the product and inspection of relevant parameters. In connection with the project work, a biogas production is carried out on a lab scale to gain a better understanding of the biogas production. Information on bioenergy in general on a global level with future prospects will also be part of this work.

2 Goal

The goal of this project is to deliver a design for a biogas plant located in Västerbotten.

3 Method and implementation

This project is largely based on literature study and research articles. An in-depth search into the development of biogas production gave the results of what this project looks like. It is a very large area with many parameters that play a role and affect what a biogas plant looks like. Therefore, only important parameters have been addressed in this work. A lab for biogas production was also carried out at Umeå University to get a better picture of how biogas is produced and what any calculations might look like. At the end, a compilation was made of what bioenergy looks like on a global level and own views on the future of bioenergy.

4 Introduction

4.1 Background

Natural gas is becoming increasingly important as a source of energy. It's used for power generation, mechanical and household heating, as a chemical feedstock, and it's becoming more popular as a transportation fuel (CNG). Biofuels are made from biomass, either directly or indirectly, and are one of the most important renewable energy sources due to its abundance and uniform distribution over the globe. In 2016, the amount of energy generated by biofuels accounted for almost 10% of total vital energy supply [1]. Naturalgas can be produced from food-, industrial- and forest wastes in form of biogas. There are also other production sources such as wastewater treatment and sludge. This work is based on biogas production from food and industrial waste. Biogas consists mostly of methane and a small amount of carbon dioxide. To produce biogas from these sources, Anaerobic digestion (AD) is used. Anaerobic digestion (AD) is a microbial process that decomposes organic materials without oxygen. Many natural ecosystems, such as swamp or ruminant stomachs, have this mechanism. The AD process is used to decompose organic biodegradable waste in airtight reactor tanks, also known as digesters, to create biogas using an engineering technique and regulated design. The anaerobic degradation process uses a variety of microorganisms to produce two major products: energy-rich biogas and nutrient-rich digestate [2]. The deployment of commercial and industrial scale biogas facilities using AD has been rapidly growing in all regions of the world with the goals of meeting future energy demands and reducing global warming. In Germany alone, the EU country with the most biogas facilities, installed capacity of biogas to power plants topped 8900 MW in 2015 [3]. For the last several decades, China, one of Asia's largest biogas producers, has seen a rise in biogas generating appliances, mostly for household-scale uses. However, significant investment and public initiatives on novel techniques and technologies have aided the transition of many of these small-scale uses into large-scale technologies, including a massive increase in biogas-to-electricity conversion. As a result, China's biogas to power installation capacity reached 5500 MW in 2015, and it was expected to reach 30,000 MW by 2020 [4]. As far as the Nordic countries are concerned, Sweden, Denmark and Finland have a fairly stable development of biogas production [5].

4.1.1 Anaerobic digestion AD

Anaerobic microorganisms dominate the AD process, which is responsible for converting organic-rich waste material into two important products: methane and nutrient-rich digested/effluent. The four key processes in the anaerobic decomposition of complex organic waste biomass are (i) hydrolysis, (ii) acidogenesis, (iii) acetogenesis, and (iv) methanogenesis. The four steps are presented in figure 1.

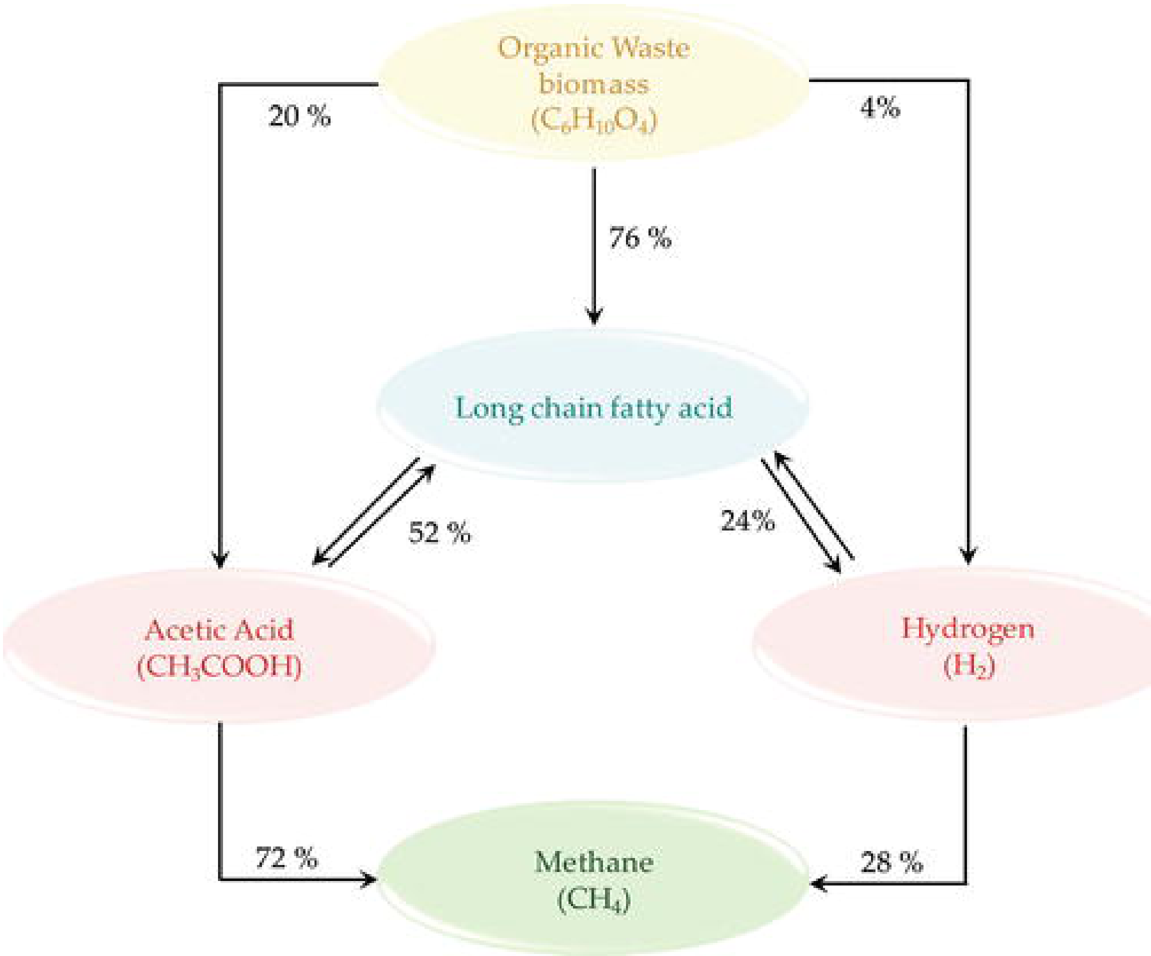

Figure 1: Schematic biodegradation steps of complex organic matte [6].

Complex organics ($C_6H_{10}O_4$) like protein, carbohydrate, and fat are reduced to simple digestible amino acids, monosaccharides, and fatty acids during hydrolysis. The reaction happens during the hydrolysis phase, as described in Eq. (1), when enzymes transform the complex organic substrate into simple monomers ($C_6H_{12}O_6$) and hydrogen (H_2), as illustrated below:

$$C_6H_{10}O_4 + 2H_2O \rightarrow C_6H_{12}O_6 \tag{1}$$

Acidogenesis is the second phase in the AD process, during which acidogenic bacteria convert hydrolyzed organics to ethanol (C_2H_5OH), acetate (CH_3COO), hydrogen (H_2), carbon dioxide (CO_2), and other acids (propionic, formic, lactic, butyric, succinic acids). Amino acids may lead to the production of ammonia in rare instances. As indicated in Eqs. (2)–(4), the process happens during the acidogenesis phase:

$$C_6H_{12}O_6 \leftrightarrow 2CH_3CH_2OH + 2CO_2 \tag{2}$$

$$C_6H_{12}O_6 + 2H_2 \leftrightarrow 2CH_3CH_2COOH + 2H_2O \tag{3}$$

$$C_6H_{12}O_6 \rightarrow 3CH_3CH_2OH \tag{4}$$

The third phase in the anaerobic digestion process is acetogenesis. Acetogenic microorganisms convert long-chain fatty acids, volatile fatty acids, and alcohols into acetic acid (CH_3COOH), hydrogen (H_2), and carbon dioxide (CO_2). As indicated in Eqs. (5)–(7), the process happens during the acetogenesis phase:

$$CH_3CH_2COO^- + 3H_2O \leftrightarrow CH_3COO^- + H^+HCO_3^- + 3H_2 \tag{5}$$

$$C_6H_{12}O_6 + 2H_2O \leftrightarrow 2CH_3COOH + 2CO_2 + 4H_2 \tag{6}$$

$$CH_3CH_2OH + 2H_2O \rightarrow CH_3COO^- + 3H_2 + H^+ \tag{7}$$

The last phase in the anaerobic breakdown of organic waste is methanogenesis. Methanogenic bacteria are in charge of turning acetic acid and hydrogen into methane (CH_4) gas and carbon dioxide (CO_2) in this stage. As demonstrated in Eqs. (8)–(10), the reaction happens during the methanogenesis phase [6]:

$$CH_3COOH \rightarrow CH_4 + CO_2 \tag{8}$$

$$CO_2 + 4H_2 \rightarrow CH_4 + H_2O \tag{9}$$

$$2CH_3CH_2OH + CO_2 \rightarrow CH_4 + 2CH_3COOH \tag{10}$$

5 Location

Västerbotten is the country's second largest county and to the surface slightly larger than one eighth of Sweden's total land area. It consists of a total of 15 municipalities with 273,192 inhabitants where approximately 50% of the inhabitants live in Umeå municipality. This means that the majority of the population lives in Umeå. Umeå is also the resident city of Västerbotten County. [10]. With many companies, schools, restaurants and households, Umeå will be the most attractive part of Västerbotten to implement a biogas plant for biogas production. This means that the availability and delivery of the raw material can be to a greater extent. In short, it is within Umeå municipality that the facility is planned for.

6 Biogas facility - Design

Investigation for the design of a biogas plant comes in the following sections. Several points are discussed such as feedstock material, setup, utilizatoin, by products and economies.

Two important basic points in the design of a biogas plant are the raw material and the reactor type. Feedstock has a direct connection on properties such inoculum type, codigestion, and pretreatment type. The kind of reactor utilized and the biochemical interactions involved have a significant connection to temperature, mixing, retention time, organic loading, volatile fatty acids, pH, and pressure.

6.1 Feedstock

As previously mentioned, the biogas will be produced via anaerobic digestion. Therefore, it is organic waste that will be treated in the planned facility. Organic waste includes a lot of sources. But the main sources that the investigation looks at are food waste from the restaurant and hotel industry, schools, food industries and a proportion of municipal waste.Two experiments were performed in connection with this project on a lab scale:

- Norrmejeri's dairy waste: Dairy waste in the form of whey was used to produce biogas. Substrate was given from Norrmejeri together with sludge for the digestion process.
- Consumed corn oil: Consumed corn oil was used to produce biogas. The sludge used was the same as mentioned above. Why oil was so interesting is because in the restaurant industry, a lot of oil ends up as a waste product. Of course, there are several different types of oil such as rapeseed and sunflower oil, but for that experiment it was corn oil that was available.

More about these experiment in section 7.

6.1.1 The choise of feedstock

Large amounts of food waste occur every year in various forms. Municipal waste, restaurants and other sources account for the largest share of organic food waste. At avfallsverige, you can read about the amount of municipal waste collected per county in 2020, kg per person. For Västerbotten County, 37 kg became food waste per person in 2020 [7]. Other interesting sources for this project are:

- The grocery industry: Approximately 100,000 tonnes of food waste was generated from grocery stores in 2018. This corresponds to 10 kilos per person. Food waste in grocery stores arises mainly because food products have time to become bad, close or reaches the best before-day or passes the last day of consumption. It can be about fruit and vegetables that become soft or stain and are cleaned out or eggs, meat and dairy products that have passed out.
- Commercial kitchen: In 2018, 75,000 tonnes of food waste was generated from commercial kitchens, which corresponds to 7 kilos per person. The commercial kitchens that this compilation touches on are public commercial kitchens and can be found at schools, preschools, nursing homes, hospitals and prisons. The biggest amount of this food waste, close to 51,000 tonnes, was generated in schools and preschools.

- Resturantes: In 2018, 73,000 tonnes of food waste was generated from restaurants in Sweden. This corresponds to 7 kilos per person.
- Households: Most food waste, 71 percent, occurs in households. In 2018, around 917,000 tonnes of food waste came from Swedish households, which corresponds to 95 kilos per person.

These statistic is for the Sweden consumption [8].

Although these numbers do not relate to Västerbotten alone, it still provides a point of view for the food waste that arises in Västerbotten. There is a large amount of food thrown away every year. It provides a picture of the great potential that exists to utilize the energy in food waste for biogas production. Figure 2 shows a map of Sweden, which tells about the proportion of food waste generated as goes to biological recycling and the proportion of food waste that is treated biologically so that both plant nutrients and energy is utilized.

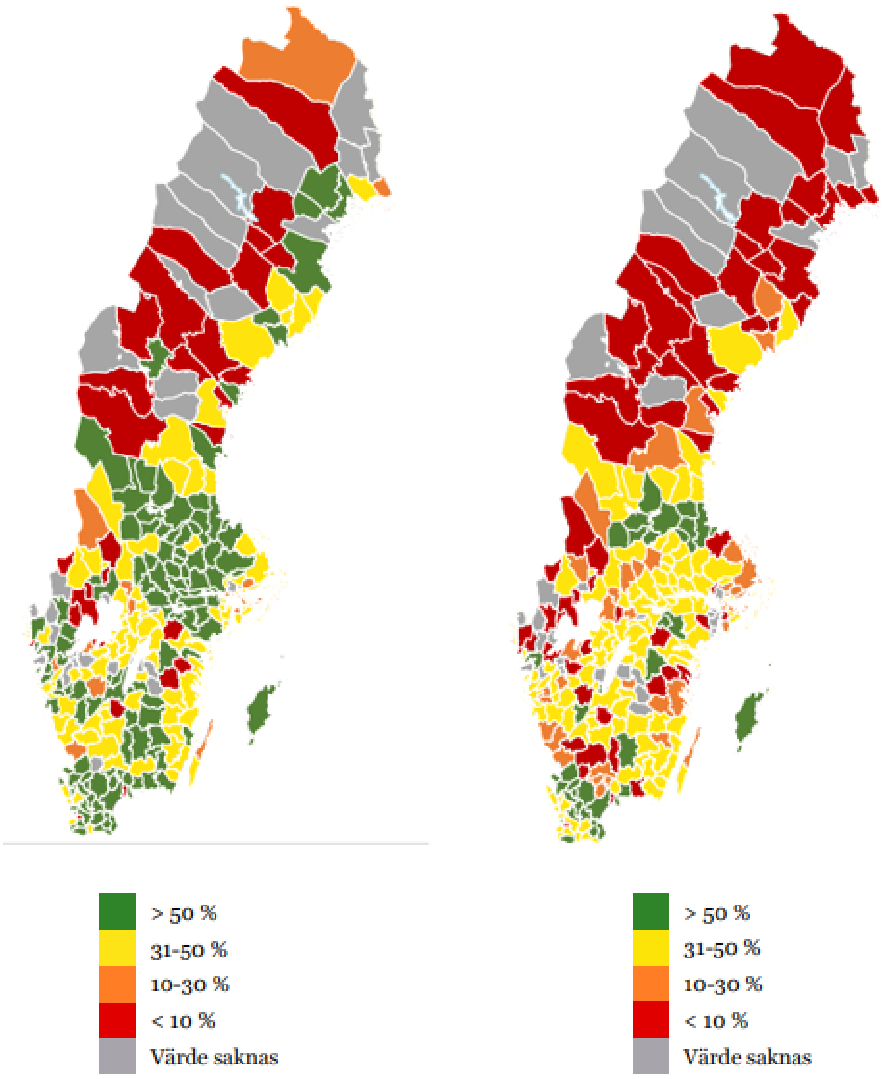

Figure 2: Left: Proportion of emergence food waste that goes to biological recovery. Right: Proportion of generated food waste that is biologically treated by digestion so that both plant nutrients and energy are utilized [9].

The map shows that Västerbotten is less good at treating food waste biologically through digestion. This means that Västerbotten has great potential to develop and extract the energy that food waste contains in the goal of producing biogas. Hence, why it is the following raw material that this project investigates [10].

6.1.2 Substrate and co-digestion

The substrate will be a mixture of food waste FW and grease waste from grease traps arising from restaurants and the food industry. Food waste will be the largest part of the substrate,$>$ 90%, while the rest will consist of fatty waste and process sludge from the food industry. Theoretically, 1 g of glycerol trioleate ($C_{57}H_{104}O_6$), a common lipid in nature, corresponds to 1.08 L of methane at standard temperature and pressure, while 1 g of glucose ($C_6H_{12}O_6$) corresponds to only 0.37 L. Why the amount of fat is much less than the food waste in the substrate is due to the problems that the fat poses to it. Lipid loading is an important element in anaerobic digestion of lipid-containing waste. Due to restricted substrate and product transport, damaged cells, and reduced activity of stressed microbial communities, buildup of long-chain fatty acids (LCFAs), propionate, and acetate can result in a pH drop and even process failure when fat is overdosed. The reason for the digestion of food waste and de-oiled Grease trap waste are an increase in methane yield by about 19% [11].

6.1.3 Pre-treatment

The pretreatment of the substrate is important to increase methane production. There are several ways to pretreat the substrate. In this case, the choice falls on mechanical milling. Particle size of the food waste may play a greater role in the extraction of biogas. Food waste will be digested together with fats as mentioned earlier, but the pre-treatment will only include solid food waste. An adjustment of the particle size takes place with the help of an electrically powered grinder, which grinds the food waste to the desired size. Pretreatment to decrease particle size has two effects: first, comminution of the substrate improves gas generation if the substrate has a high fiber content and weak degradability; second, it might result in faster digestion. Smaller particles provide more surface area accessible to microorganisms, which means more food for bacteria; therefore, anaerobic biodegradability will be more [14]. The effects of particle size on anaerobic thermophilic digestion in FW treatment were studied by Kim et al. (2000). With a drop in mean particle size from 2.14 to 1.02 mm, the maximum substrate utilization rate coefficient doubled, illustrating that particle size is one of the most essential parameters in anaerobic FW digestion [15]. A bead mill (BM) will be used as a grinder to refine the particle size of the food waste. In comparison to typical pretreatment procedures, this device is projected to produce smaller particles and better solubilization, leading to increased methane production rates. The particle size will be based on the experiment performed by K.Izumi (2010), where it was studied how the particle size of the food waste affected methane production. The experiment was performed on several different particle sizes. The article describes in more detail how the grinder was used, which is considered unimportant to address in this project. In the experiment, six types of experiments were performed by changing the rpm number of BM between 300 - 40000 rpm (II-300, III-1000, IV-1000, V-4000, VI-20000, and VII-40000). Figure 3 shows how this affected methane production.

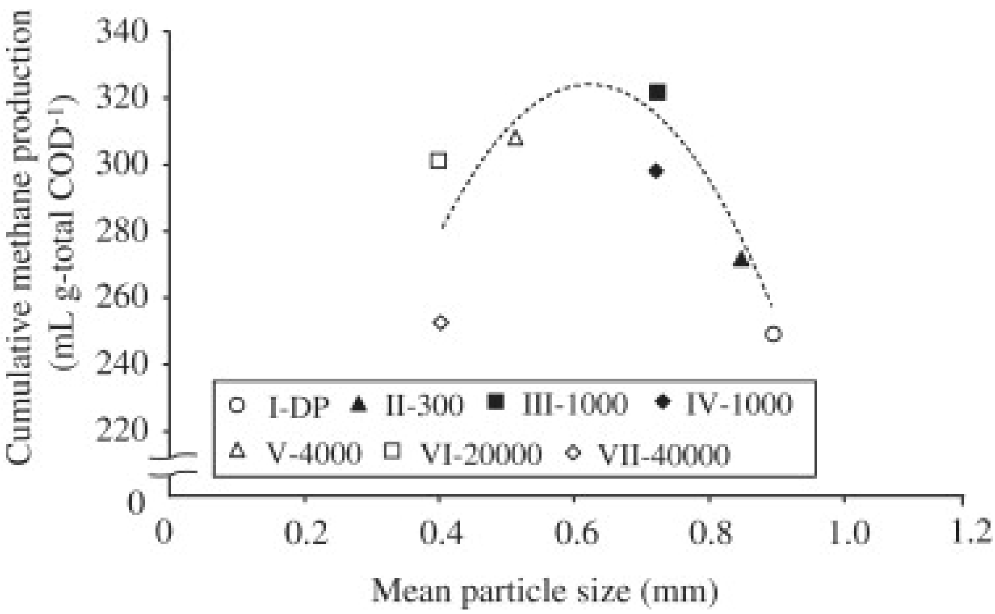

Figure 3: Relationship between methane production and mean particle size of pretreated substrate for each pretreatment condition [15].

These findings imply that in the anaerobic digestion process, size reduction by BM pretreatment efficiently improved solubilization and boosted methane output. At 1000 rotations, smaller MPS increased methane output by 28%.This will form the basis for the pre-treatment in the biogas plant.

6.2 Setup and reactor

There are several different ways to determine how the collection of produced biogas should proceed. Batch, continuous or bacth/continuous setup are common. In everyday reality, it is desirable to get methane out in a continuous way. Therefore, the plant will be a continuous setup. Continuous digestion system can be designed with single or multiple digesters. All processes of microbial degradation, including as hydrolysis, acidogenesis, acetogenesis, and methanogenesis, occur simultaneously in a single reactor vessel in an one stage digestion system. Single stage reactors are still the most popular choice for the majority of anaerobic digestion applications due to its ease of design and low cost [12].CSTR reactor is used for single stage systems. Since this project is about designing a small communal biogas facility, the choice for a single-stage reactor will be prioritized. However, since lipid-rich contents will be digested with food waste, the plant will contain two series-connected CSTR reactors. Lipid loading is an important element in anaerobic digestion of lipid-containing waste. Due to restricted substrate and product movement, damaged cells, and reduced activity of stressed microbial communities, buildup of long-chain fatty acids (LCFAs), propionate, and acetate can result in a pH drop and even process failure when lipid-rich waste is overdosed [12]. Due to enhanced capacity to breakdown LCFAs and a smaller scum layer, thermophilic conditions (55 ° C) for lipid-containing waste are preferable to mesophilic conditions (35 ° C). Because higher diffusion coefficients and lipid solubility in aqueous solutions with rising temperature, lipid becomes more accessible to microorganisms and their lipolytic enzymes under thermophilic conditions [13]. Therefore, the system will contain two reactors operating under two different conditions, mesophilic and thermophilic conditions. A simplified name for this system is TPAD-R, temperature-phased anaerobic digestion with a recycle system. Recirculating the process liquid back into the reactor results in higher methane production, therefore it is desirable to include it in the system [12]. Figure 4 represents how the system is intended to be structured.

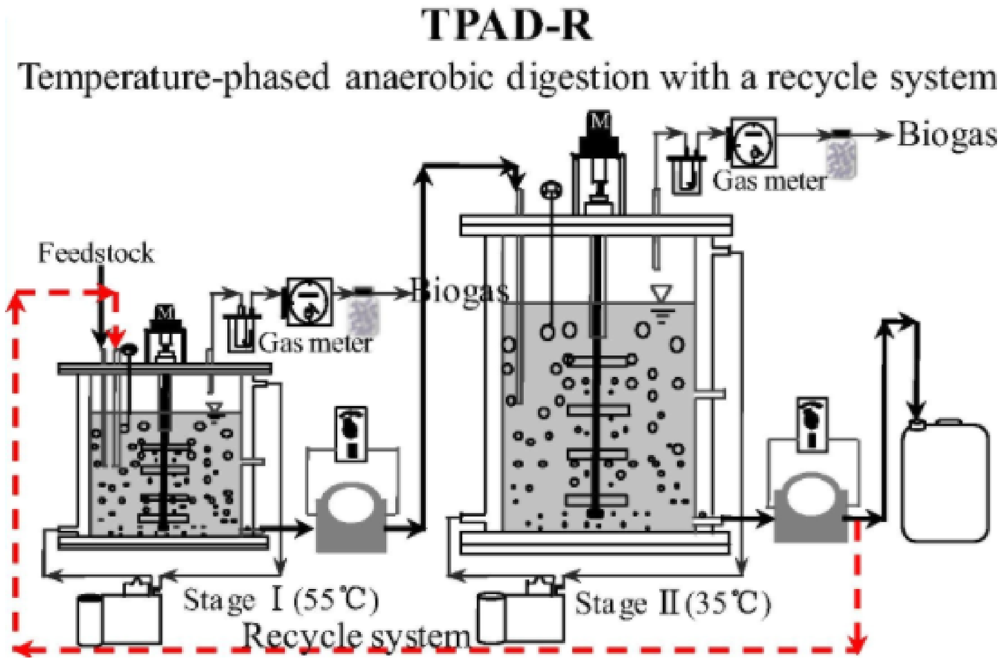

Figure 4: Scheme of setup for TPAD-R [11].

The idea is to be able to use as simple a system with an high efficiency as possible. Using two single-stage reactors reduces the risk of downtime if the lipid content reaches undesirable amounts. In addition, the degradation of LFAC becomes easier at higher temperatures so that the microorganisms can utilize the components that are released. Biogas production can take place with a single reactor both in mono-digestion and co-digestion during mesophilic conditions. During co-digestion, the lipid content may be significantly lower.

6.2.1 Temperature

The AD temperature is classified as psychrophilic, mesophilic, thermophilic, or extremophilic based on the microorganisms' tolerance to temperature ranges of 4–25 °C, 30–40 °C, 50–60 °C, and $>$ 65 °C, respectively. Higher temperatures, such as those found between the mesophilic and thermophilic regimes, provide an ideal environment for biological degradation, resulting in high hydrolysis rates and, as a consequence, large biogas outputs. As mentioned earlier, and as shown in Figure 4, the biogas plant will consist of two reactors, one for mesophilic digestion and one for thermophilic digestion. The mesophilic reactor will operate at a temperature at 35 ° C and the thermophilic at 55 ° C. These temperatures are the basis for the start-up of the biogas plant as they are expected to give the best results for co-digestion of food waste together with lipid waste. The choice of these temperatures also depends on another cause. The microorganisms that belong to the different temperature ranges grow best at the so-called maximum temperature, where the death of the cells is caused, see figure 5. If the temperature rises above this point, the cell's proteins and other components become inactive fast, leading the organism to die. The microorganism's maximum temperature fluctuates based on which temperature range it is acclimated to. For the mespophilc case it is at 39 ° C and thermophilc 60 ° C, hence the choice of operating temperature [16].

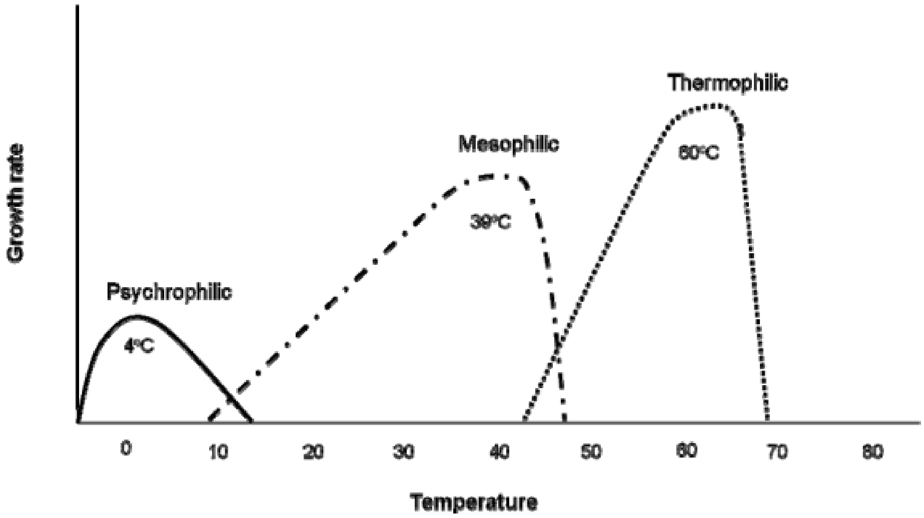

Figure 5: Microorganisms growth at various temperatures [16].

The quantity of methane produced in thermophilic AD is about similar to that produced in mesophilic AD, but higher temperatures enhance the production rate and lower the need for a high operating HRT, allowing the reactor size to be reduced, as illustrated in figure 4. But it is very important to keep a stable temperature. A temperature change of ± 0.5 ° C. Temperature changes make methane producers more susceptible than other microbes in the process. Using some type of agitation to maintain a constant temperature in the digesting tank is the easiest way to do so. It is also necessary that the digesting tank be well insulated [16]. Keeping the temperature constant is important. The ambient temperature can have a great influence on the temperature in the reactor. During the winter, the outdoor temperature in Umeå can reach low temperatures within about -20 °C. Therefore, the temperature in the reactor must be checked. The temperature can be controlled using one or more thermometers connected to the reactor. There are other parameters that also affect the temperature in the container, such as the substrate temperature that is constantly being fed. The input must be regulated in a good way so that there is no temperature drop during input caused by a temperature difference between substrate and mixture. To make it simple and flexible, a PID regulator can be connected to the CRST reactor where it can control the temperature in the reactor. The reactor must be equipped with a temperature controller when purchased. When there are temperature changes, the PID controller can regulate the temperature back to normal temperature.

Temperature during cold times

During the cold times of the year, several measures must be taken to be able to handle the large temperature drop. In Umeå it will be quite cold during the winter time, <0 C. In the following sections, the measures will be represented to overcome the temperature problem in the best possible way during the winter:

- Insulation: Insulation may be used to reduce heating demand or heat losses. The use of insulation can be a very good alternative. By choosing a good material, with a low heat transfer coefficient, and investing in it at a very early stage, large heat losses can be saved.

- Maintaining the SRT: Sedimentation of solids tends to take place in digesters. This means that SRT and HRT becomes lower over time. As a result, as the next longitudinal research will show, the retention time must be maintained by frequent cleaning. The majority of studies are completed in a very short amount of time; however, digesters are meant to function for considerably longer periods of time. As a result, a ten-year longitudinal research was established to investigate the influence of temperature on the methane production of a Janata fixed dome in India's mountainous terrain (Kalia and Kanwar 1998). In the winter, when ambient and digester temperatures were 11-12 ° C and 13-14 ° C, respectively, compared to 25-26 ° C and 22-23 ° C in the summer, they discovered a drop in gas production. As a result, the digester was able to balance out the excessive temperature swings. More intriguingly, they discovered a steady decline in gas output over season, with a 34 percent fall in summer and a 13 percent decrease in winter in five years. This was due to sediments settling in the digesters, which reduced the effective digester capacity and, as a consequence, the SRT and HRT. After cleaning the digester, the gas output increased to the maximum level seen throughout the study's initial years (Kalia and Kanwar 1998). To offset the impact of low temperatures on biogas generation, digesters should be cleaned at regular intervals to maintain the retention duration and keep the digester operating at full efficiency [18].

- Operation: The biogas plant will consist of two series-connected reactors. One works at 35 C while the other at 55 ° C. Maintaining a temperature of 55 ° C during the winter will cause major problems and high electricity consumption during electric heating. Therefore, the thermophilic reactor will be adapted to a mesophilic environment to operate at a lower temperature. Operation at even lower temperatures than 35 ° C during the winter will be carried out to reduce electricity consumption. This will lead to higher HRT instead.

- Dehygienisation: Because there are regulatory requirements that hygiene be carried out in order for the position of animal by-products to occur, dehygienisation is carried out (Swedish Board of Agriculture, 2015). The spread of infection associated with the handling and use of substrates and digestate in the biogas process is prevented as a result of this. The most frequent way is to heat the substrate for one hour at 70 degrees Celsius (Jarvis Schnürer, 2009) [19]. An utilization of the heating can take place in two different ways:
  1. The hot dehyginated substrate can be used as a kind of "heat exchanger" to cool by preheating the next substrate to be dehygienated.
  2. Dehyginated substrate can be cooled to the desired temperature, 50-60 ° C in summer, and 40-50 ° C in winter. This is to have a sufficiently high temperature on the substrate instead of heating it by electric heating. With good insulation, the temperature will be kept at a reasonably stable level for a longer period of time. Note that the temperature of the substrate will be studied carefully so as not to damage the microorganisms in the incolum.

6.2.2 pH

The pH range of 6.5–7.5 is ideal for a generally stable AD process and good biogas output. In contrast to the methanogenic phase (pH 6.5–8.12), the hydrolysis and acidogenesis processes occur at acidic pH levels (pH 5.5–6.5) during digestion. To ensure acceptable buffering capacity, an alkalinity level of around 3 000 mg/L must be present at all times [2]. A change in pH of 0.5 may cause a significant shift in microbial metabolism, altering reaction kinetics and generated gas production. Although anaerobic digestion is possible between the pH of 5.5 to 8.5, methanogens are very sensitive to pH changes and perform best at a pH of about 7. A pH of less than 6.3 or more than 7.8 might have a negative impact on methanogenesis, leading to process failure.

Modern biogas facilities often include an automated pH controller to manage pH variation and keep the AD process operating within the appropriate pH range. The controller's principal goal is to assist in the balancing of the system buffer (alkalinity) by supplying an appropriate neutralizing agent at a suitable concentration as needed. Strong bases (e.g., NaOH) or carbonate salts (e.g., Na_2CO_3 and $NaHCO_3$), as well as acids (e.g., HCl), are the most common chemicals used to raise or lower pH [12]. The biogas plant will primarily use ORL control to regulate the pH value. In contrast, since the digestate, which is rich in buffer agents, is periodically refluxed back into the system in a digester with digestate recirculation, system alkalinity may be greater than in a digester without digestate recirculation. The high alkalinity may neutralize an increased quantity of hydrion, which is useful for keeping the pH in the ideal range for methanogens; as a result, the digester's OLR rises [17]. A second way to regulate the pH value is the use of basic and acidic substances depending on the situation. When the pH of an AD system becomes excessively acidic, lime is usually employed to increase it. Sodium bicarbonate, on the other hand, may be used to modify the pH. Lime is generally substantially less expensive, and leftover lime solutions from local industries may be available for free. When lime is utilized in excessive amounts, it may cause precipitation and clogging of pipes. Sodium bicarbonate and sodium hydroxide are both totally soluble and do not normally precipitate, however they do contribute to greater expenses [2].

The plant will test a new method for an increase in methane production with the help of good pH regulation. In a study, conducted by M.Novias (2018), biomass fly ash-based geopolymer spheres were used to control the pH in anaerobic digesters. In contrast to conventional alkaline materials, the utilization of waste-based geopolymeric spheres with high buffer capacity might be a suitable alternative for promoting sustained pH control in the AD of highly biodegradable waste streams. It is well acknowledged that methanogenic digestion of these substrates is difficult. The suggested technique has the potential to improve system stability, efficiency (for example, methane yield), and simplicity (prevent the need for continuous pH adjustment). The research was done on a batch-regulated reactor. The biogas plant will consist of CSRT, which needs data for several experiments beforehand. The raw manufacturing cost of the geopolymer spheres was assessed and compared to that of the commercial buffer solution ($NaHCO_3$ and $KHCO_3$) used to enhance pH control in AD to further analyze their potential as pH regulators in the AD process. 4g/L commercial buffer solution costs between 0.09 and 0.20 € depending on the provider, whereas 28g/L FA-based geopolymer spheres (highest quantity utilized in larger size batch experiments) costs approximately 0.10 €. The results show that the suggested approach is cost-effective, which is important for industrial use. Figure 6 shows the cost of different buffer substances in kg price [17].

	Material	Cost (€/kg)	Reference
Commercial buffer solution	Sodium bicarbonate	17.9	(Fisher Scientific website, 2017b)
		32.6	(Sigma Aldrich website, 2017b)
	Potassium bicarbonate	25.93	(Fisher Scientific website, 2017a)
		69.6	(Sigma Aldrich website, 2017a)
Geopolymer spheres production	Fly ash	0.033	(McLellan et al., 2011)
	Metakaolin	0.132	
	Sodium silicate	0.264	
	Sodium hydroxide	0.132	
	Sodium dodecyl sulfate	222.0	(ThermoFisher website, 2017)

Figure 6: Kg-prices for different substances [17].

This is considered an idea to be cost-effective and to use by-products from other businesses where ash treatment can be difficult.

6.2.3 HRT

The retention time is an essential parameter in anaerobic digestion design and optimization. Hydraulic retention time (HRT) and solid retention time (SRT) are two types of retention time. The HRT stands for the liquid phase retention time, whereas the SRT stands for the microbial culture retention time in the digester. The HRT equals SRT in an anaerobic reactor system when the feedstock and microbial mixed cultures are present at the same time. HRT is essentially SRT in the case of food waste, kitchen waste, and municipal solid waste, and vice versa in the case of waste activated sludge and primary sludge, whereas the interaction between solids and microbial cultures is biphasic in the case of waste activated sludge and primary sludge, making HRT and SRT different. HRT is described by Equation 11.

$$HRT = V/Q \tag{11}$$

Where V (m3) is the reactor volume and Q (m3/day) is the volume flow rate of the influent. HRT will vary depending on the reactor and the season. The thermophilc reactor will have a lower HRT than the mesophilic reactor. During the winter, HRT will increase. Usually, HRT lasts between 10 and 25 days. But during the winter, an HRT of between

50 and 100 days may be necessary [12]. Deciding what HRT should be is early. Several parameters such as load, temperature and substrate type affect biogas production, and an adjustment of HRT can provide a good solution for which HRT to have based on different situations. Therefore, several trials and experiments must be done where different HRTs are taken into account.

6.2.4 OLR

The Organic Loading Rate (OLR) is a measurement of the AD system's biological conversion capability. It denotes the amount of substrate injected into the reactor volume in a certain amount of time. Overloading causes a considerable increase in volatile fatty acids, which may lead to acidification and system failure, as stated above. OLR is a particularly critical control parameter in continuous systems. Organic input rates of 4–8 kg VS/m3 reactor and day have been reported in studies of anaerobic treatment of biowaste in industrialized countries, resulting in VS elimination of 50–70%. (Vandevivere et al., 2003). This is perfect for reactors that are constantly agitated. OLR is described by equation 12 [2].

$$OLR = C/HRT \tag{12}$$

where C is the feed concentration in g·VS/L. In most anaerobic digester applications, a high operating OLR is preferable since it allows for enriched bacterial species, smaller reactor sizes, less heating, and cheaper investment costs. It will be experimented with whether the load will take place in the reactors. Since the plant will have two reactors operating under different conditions, the ORL will differ between them. It is important to be careful with VFA acclimatization so that it does not destroy biogas production. The OLR will in any case be higher for the thermophilic reactor than the mesophilic reactor because the thermophilic can handle larger amounts of load and VFA [20].

6.2.5 VFA

VFA stands for volatile fatty acids and consists of acetic acid/acetate, propionic acid/propionate, butyric acid/butyrate, valeric acid/valerate, caproic acid/caproate, and enanthic acid/enanthate. These components form part of the intermediates that occur during anaerobic digestion. The bulk of VFAs decompose to acetate and then to methane through the acetoclastic and hydrogenotrophic routes of methanogenesis. In an AD process, a higher VFA conversion efficiency is normally preferable since it allows for better methane production stability and balance at various phases. Several factors affect VFA production, such as raw material, reactor type, temperature, pH and OLR [12]. To increase the conversion of VFA to methane gas, it is important to process these parameters in order to achieve a maximum conversion of VFA into methane gas. In previous sections, it has been discussed how the various parameters should be optimized individually to handle, for example, VFA. There are many parameters that come into the picture, so trials and experiments must be done to find a good starting point to start from. It is not easy to be able to satisfy all parts, such as reduction of VFA accumulation, maximum biogas production, maintaining a normal pH and more. Examples of what is intended to be done in the facility to reduce the acclimatization of VFA:

- Co-digestion: Lipid-rich content is co-digested together with food waste, which results in less VFA acclimatization.

- Reactor type: The choice of reactor can play a role in how VFA is handled. A multi-stage reactor is in this case better than a single-stage reactor for treating VFA as previously mentioned.
- Temperature and pH: These two parameters may make a difference in the VFA accumulation. Many studies have been done around these with varying results. Therefore, the plant will need to perform various tests to find a good equilibrium between temperature, pH and VFA consumption and development.
- OLR: As mentioned in the paragraph before, OLR will be taken into account to inhibit VFA accumulation [12].

6.3 Utilization of produced methane

The idea is that the biogas will be used as a vehicle fuel. For a small biogas plant like this, this may be the most suitable, flexible, and cost-effective solution. The biogas can be used in other ways such as for heat and electricity production, but this requires advanced equipment with a number of other factors that must be maintained as a connection to the electricity grid and so on. Therefore, the produced biogas will undergo a separation process in the end. The biogas will be released from all the carbon dioxide it contains to increase the energy density of the gas. This will be done using water scrubbers.

6.3.1 Biogas upgrade

Biogas is made up of 50-70% methane (CO_4), 25-45% carbon dioxide (CO_2), and the rest is made up of H2S gas and other elements. Methane (CH_4) gas, which may be utilized as a fuel in the combustion process, is the major component with a very high energy content. However, due to the enormous amount of carbon dioxide (CO_2) present, the percentage of methane and other gases is relatively low. Because of the properties of carbon dioxide, which can diminish the heat value and impede with the combustion process, this can become a concern. The water-scrubbing method is one of the options for lowering carbon dioxide (CO_2) levels. One technique to increase the quality of biogas is to scrub it with water. The approach is based on the physical effects of dissolving gas in liquids in the presence of water. Carbon dioxide (CO_2) and hydrogen sulfide (H_2S) in the biogas will be collected by the water throughout the process since these gases are more water soluble than methane gas (CH_4). The water-scrubbing technique employs a column in which the absorption process takes place. A regulated flow of water is streamed from the top of the water scrubber column while biogas is injected at high pressure from the bottom of the scrubber column, resulting in a contra-flow scrubbing process. Working at a high pressure instead of at atmospheric pressure has advantages. Because of the increased pressure, the solubility of CO_2 in water will increase. As a consequence, the quantity of water utilized is reduced. The carbon dioxide separation from the biogas with the help of water scrubbers has other advantages such as cost efficiency, environmentally friendly and high efficiency in the absence of heat supply [21].

7 Biogas production on labscale at Umeå University

A laboratory was performed for the production of biogas associated with this project to provide a better understanding.

7.1 Introduction - Biogas production lab

Anaerobic digestion produces biogas, which is a renewable energy source for those who wants an additional energy source. Organic waste (waste water sludge, agricultural and food waste, animal and human manure) is converted into energy using anaerobic digesters. More about AD, *read* 4.1.1.

The aim of this laboratory was to investigate and analyze the composition of biogas production from different sources using gas chromatography. To be able to do that, a small set-up was built for biogas production, see figure 7. The set-up was made for lab scale and for the production of a small amount of biogas. Note that it was a batch setup because it was the analysis of the biogas composition that was the most interesting in this case. Two different substrates were used to make this laboratory successful. The first substrate was dairy residues in the form of whey used. These dairy residues were given from Norrmejeri and were used during the laboratory as a "reference point" because it was certain that this substrate would work for biogas production and give good results, together with the sludge, which was also given from Norrmejeri's biogas plant.

Biogas is considered a renewable energy source. In general, all renewable energy sources are important for achieving the climate goals for a friendlier environment. The need for energy increases with increasing population and industry. At the same time, the use of fossil energy sources is coming to an end. Therefore, other environmentally friendly energy sources must cover these needs. In addition, biogas production is not only environmentally friendly in its form, but it solves a lot of other problems. When it comes to biogas production from food waste, a problem that arises in many countries is handled. The food that is wasted contains a large amount of energy that would be lost. By taking care of these wastes, which may cost a lot to treat, you create good conditions for energy production and solutions to important problems in society. Therefore, this is an important research area and an interesting topic to develop to solve important societal issues.

7.1.1 Hypothesis

For Norrmejeri's substrates, a good and qualitative exchange of biogas is expected. This is because Norrmejeri themselves have sponsored with sludge and substrate that they use for their facility. When it comes to the oil consumed, a higher methane density is expected in the biogas than the whey substrate because the oil is lipid-rich, which is energy-rich. But there are several factors that can affect the outcome.

7.1.2 Calculations

To calculate the biogas production [mol sample/h] the following equation was used:

$$n = \frac{area_{sample} * K * Vol_{reactionchamber} * 100}{h_{reactionhours} * Vol_{sample}} \tag{13}$$

where $area_{sample}$ is the area detected from the chromatograph, $Vol_{reactionchamber}$ is 490ml, $h_{reactionhours}$ is 1h, Vol_{sample} is 10ml and K is:

$$K = \frac{Vol_{calibration} * Concentration_{calibration}}{24.2 * area_{calibration}} * 10^-3 * 10^-6 \quad (14)$$

where $Vol_{calibration}$ is 10ml and $Concentration_{calibration}$ is 990000 ppm.

7.2 Material

- Thermostated water bath set to 37°C
- Magnetic stirrer-hotplates
- Laboratory stands with adjustable clamps
- 250 ml plastic measuring cylinders with gas sampling septum
- 1l glass beakers
- 500 ml glass bottles with Suba Seal cap
- Long and short blunt-ended 14G (2mm OD) needles
- PVC and silicon rubber tubings, plastic connectors and taps
- Gas chromatograph Shimadzu GC-8AIT with Thermal Conductivity Detector (TCD)
- Bacteria sludge (obtained from Norrmejerier)
- Whey (obtained from Norrmejerier)
- Consumed corn oil

7.3 Method

1. An arrangement shown in figure x was assembled for biogas production. Each side of the array represents a biogas reactor. The reactor was placed in a water bath to monitor the temperature.

2. To obtain an oxygen-free environment, nitrogen was flushed into the reactor from one end and out of the other where it carried the oxygen. An airtight lid was fitted to maintain an oxygen-free environment.

3. The biogas reactor was connected to a 250ml cylindrical tank that stood upside down in a water bath suspended adjustable clamps. The cylinder was completely filled with water. They were connected via a pipe and a pipette where the gas was sent from the reactor to the cylinder and collected at the top of the cylinder where it forced the water down into the water bath. The amount of gas was measured in the top of the cylindrical tank.

4. 490ml of bacteria sludge was incubated in 37°C water bath. This step was done by the tutor.

5. The sludge was placed into the reactor.
6. A magnet was placed into the reactor and the reactor was placed on magneti stirrer-hotplates.
7. The experiment was done during mesophilic conditions so heat was added to the mixture until it reached 37°C.
8. The temperature was measured through an IR therometer and the pH value was measured by using indicator paper.
9. After the reactor was placed in a water bath on magnetic stirrer hotplate, a 10ml of norrmejeri's substrate was added. Thereafter, production of the biogas began, which lasted for 1 hour.
10. During the time waiting for the biogas production, the gas chromatograph was calibrated by injecting pure methane gas (99%) into it. The data that showd up on the screen was noticed, such as time and integrated area for the different peaks. This step was done twice to get a better result.
11. After 1h, sampels was token from each inverted cylinder with a syringe.
12. The sampels was injected into the Gas chromatograph Shimadzu GC-8AIT where the biogas was measured.
13. To produce biogas from the consumed corn oil, the sludge with bacteria was changed. After that, the same steps above was repeated expect step 10.

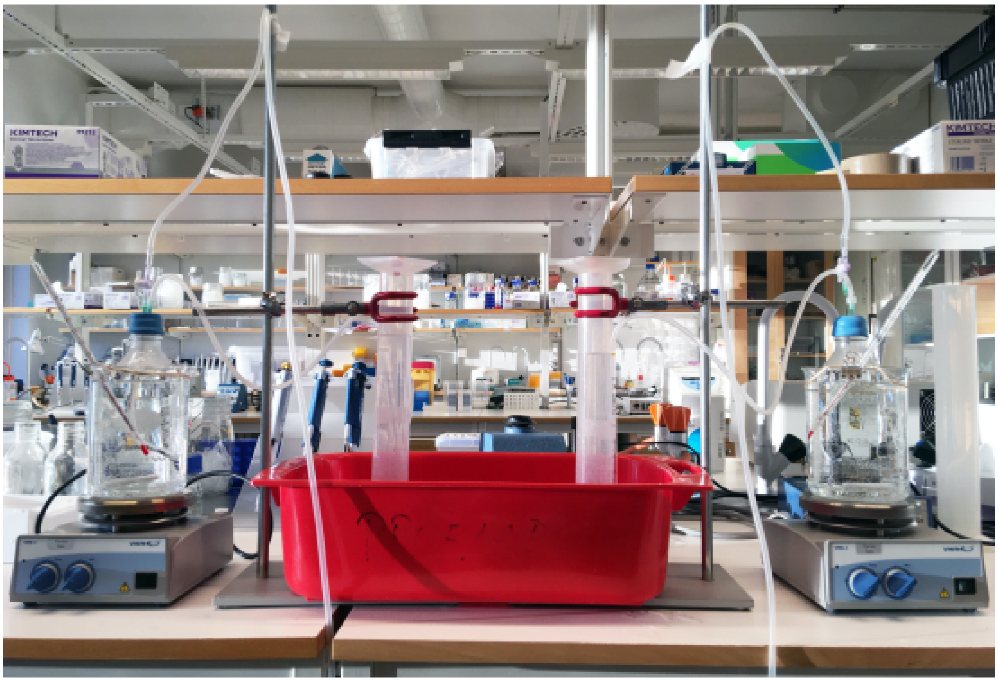

Figure 7: The setup for the biogas production on labscale at Umeå University.

7.4 Results

The result for biogas production will be presented in the following section:

Norrmejeri's whey - test 1:
n: 8,37 mol sample/h **Biogas produced** :100 ml/h **pH** : 7

10 ml of the whey substrate was added to the sludge and the production of the biogas was started for 1 hour. After one hour, 100ml biogas was produced. A sample of the biogas was collected from the inverted cylinders and injected into the chromatograph to analyze the data and measure the integrated area. This step was done 3 times, and an average of the area was further used for calculations.

Norrmejeri's whey - test 2 :
n :10,21 mol sample/h **Biogas produced** :78 ml/h **pH** : 7

In the second test, a smaller amount of biogas was produced during one hour, but the methane density was higher. The chromatography analyze was done 3 times and an average of the area was further used for calculations. 10ml of substrate was added to the sludge in this step.

Consumed corn oil - test 1 :
n :7,71 mol sample/h **Biogas produced** :25 ml/h **pH** : 7

10ml of consumed oil was added to the the sludge and 25ml of biogas was produced. Like in the earlier steps, the gas chromatography analyze was done 3 times and an average of the area was further used for calculations.

Consumed corn oil - test 2 :
n :9,72 mol sample/h **Biogas produced** :30 ml/h **pH** : 7

In this step, 10ml of corn was added without any sucess for biogas production. The production was on about 20h without results. So 10ml more of corn oil was added until the results above was reached.

7.5 Discussion

The process performed was a batch operation for biogas production. As this was on a lab scale and in order to gain a better understanding of biogas production, this was preferable for the sake of simplicity.

Producing biogas via AD is a very complicated process where many parameters play a role, just as described in section 5.2. As the results show, the whey substrate performed best when based on the same conditions, apart from consumed corn test 2, which was expected as this would be our reference point. During implementation, biogas started production for the whey substrate fairly quickly, it took 5-7min until it started producing biogas. Norrmejeri's whey substrate and the sludge used came from their biogas plant and therefore it was expected that it would produce good biogas. As the results show, the experiment did twice and in both cases the results were quite similar. In the first experiment, more biogas was produced, but less methane gas, while in the second case, less biogas was produced with a higher amount of methane.

When it comes to used corn oil, the case was different. Treating fats for biogas production via AD is usually more difficult and complicated, while the energy content is expected to be more. But in order to succeed in getting the high energy content out, the several parameters discussed in previous sections need to be controlled in a more detailed way, which was not possible during this process. Biogas' production of corn oil took quite some time before it started. It took about 15-20 minutes before the biogas started to be produced in the first case. In the second test, no biogas was produced until we had to add 10ml more of the corn oil. After that, it took about 20-25 minutes before the biogas began to be produced. Why it was not produced directly as the first test may be due to many factors. But this gives a sign that the amount of substrate may play a role in how biogas production will be.

We can also see that the methane content was higher in the second test of corn oil, which may be due to the fact that twice as much oil was digested. We can still see that the methane content of the two substrates was quite similar. Although much less biogas was produced from the corn oil, the methane content was quite close to the whey substrate.

8 Bioenergy on the international market

8.1 Bioenergy production methods

Bioenergy is a renewable energy source where you can utilize that energy in many different ways. There are several ways to access bioenergy. Several conversion pathways, including chemical, thermal, and biological processes, can be used to generate energy from solid or wet biomass. As detailed below, biomass resources utilized for this purpose might come from the forestry, agricultural, industry, or trash sectors:

- By-products from the forrest (wood blocks and chips)
- forestry with short rotations (e.g., willow, poplar, and eucalyptus)
- ligno-cellulosic herbaceous crops (e.g. miscanthus)
- agricultural leftovers and by-products (e.g., straw, animal manure)
- residues from industry (for example, from the food and paper sectors)
- waste wood (wood processing waste, construction residues)
- Municipal solid waste organic fraction and garbage sewage sludge

Biomass-to-electricity conversion methods, for example, may be categorized into three parts: thermo-chemical conversion processes (combustion, Char, pyrolysis, and gasification), biological conversion processes (anaerobic digestion) and physical-chemical conversion processes [22].

8.2 Market and current trends - International level

Europe is promoting the use of biomass for power production and CHP generation. Austria, Germany, the United Kingdom, Denmark, Finland, and Sweden are in the forefront of this process, generating bio-electricity and MGW in co-generation facilities mostly from wood wastes. Power plants in the timber and wood pulp (paper and chipboard panels) industries account for a major portion of these yields. Internally, waste products such as black liqueurs, wood debris, bark, or sawdust are handled in large-scale CHP power facilities, which may utilise biomass alone or in combination with other fuels. They create excess power that may be sold to the grid in addition to supplying the electricity, heat, and steam required for industrial activities. Between 2006 and 2007, both the primary output of biogas and the gross power generation from biogas rose by over 18% across the EU. Germany accounted for the majority of this expansion, and German biogas businesses extended their operations in 2008, despite increasing feedstock prices. Small-scale electricity generation is one of biogas's strong suits, since this co-generation is particularly efficient in terms of heat and power ratio. Recent technological advancements have enabled parity in energy production, resulting in 1kW electric for every kW [22].

But when it comes to biofuel production from biomass, there are a lot of challenges left to overcome. Biomass resources have a number of problems that must be addressed before they can be completely used for biofuel and other applications. The feedstock selection for value-added processes is heavily influenced by availability, abundance, and needs for growth, growth rate, and other characteristics. Furthermore, the quantity of cellulose, hemicellulose, and lignin in biomass materials, as well as their accessibility within biomass structures, play important roles in biomass breakdown and biofuel synthesis from hydrolysate. To address moisture, storage, and handling issues, biomass material should be densified. For optimal conversion of a certain product, biomass feedstocks supplied to a bio-refinery from various sources should be standardized [23].

Biomass energy consumption ranges from a few percent of national energy supply to considerable proportions (15–25 percent in Finland, Sweden, and Brazil, for example). Imported biomass already accounts for a major portion of overall biomass consumption in several European nations, including Belgium, Finland, the Netherlands, Sweden, and the United Kingdom (between 21 percent and 43 percent). Canada, Finland, and (to a lesser degree) Brazil and Norway now export wood pellets, whereas Sweden, Belgium, the Netherlands, and the United Kingdom import them. Pellet imports currently account for a significant portion of overall renewable power output in the Netherlands and Belgium.

Another example of a fast expanding worldwide business is bio-ethanol trade. Exports from Brazil and other countries to Europe are projected to grow as a result of the EU-wide objective of 5.75 percent biofuels for transportation in 2010 (and the newly stated target of 10 percent in 2020). Large resource potentials and comparatively cheap production costs in producing nations like Canada and Brazil, as well as high fossil fuel prices and numerous legislative incentives to encourage biomass usage in importing countries, are major drivers for international bioenergy commerce in general.

However, there are certain roadblocks to the market's development: (1) To access higher physical biomass quantities and reach other (i.e. smaller) end-consumers, both exporting and importing nations must create the necessary logistic infrastructure. (2) To track the expanding trade volumes, improved data and methodologies must be established. (3) Policy measures still influence a major portion of trade flows, and policy shifts may cause trade patterns to shift swiftly. (4) Actions must be implemented to guarantee the long-term viability of biomass production [24].

The yearly worldwide harvest of biomass (agricultural, forest) for all purposes, including food, feed, materials, and bioenergy, is appreciated to be approximately 5,374 Mtoe, or around 10% to 20% of global net primary production (NPP). Bioenergy accounts for 25% of total annual human biomass harvest, but it also includes cascaded applications of biomass that were previously employed for material reasons. Bioenergy makes up around ten percent of total primary energy supply (TPES). Since the previous decade, modern bioenergy applications have grown at a fast rate. These mostly include efficient heating systems in buildings, such as wood pellet stoves, large-scale industrial bioenergy usage in manufacturing (14 percent), transportation (9 percent), and electricity and district heating (8 percent + 8 percent). In addition, the (non-energy) use of biomass for the manufacturing of biobased chemicals and polymers contributes 1% (600 PJ, 14 Mtoe) to current biomass consumption [25].

8.3 Future possibilities

Modern bioenergy applications are generally geographically far from areas of biomass supply, unlike traditional biomass uses, which are mostly local within the producing area. Modern bioenergy deployment, which is now at 270 Mtoe, has already established worldwide bioenergy markets, with countries becoming net bioenergy exporters. In the IRENA Remap 2030 scenario, primary biomass might rise from 1342 Mtoe (56 EJ) now to 2484 Mtoe (104 EJ) in 2030. International commerce might reach 549 Mtoe (23 EJ) in this scenario. In global energy system models (TIMER, Poles) and the forest sector model GFM, similar trading ranges have been reported. Interregional commerce accounts for 14 percent to 26 percent of total primary biomass consumption in 2030, according to optimistic scenarios. Despite the fact that worldwide commerce in solid and liquid biomass has risen dramatically in the past decade, the majority of biomass is still obtained locally. According to these optimistic scenarios, liquid biofuel trade would expand by a factor of 70 and solid biofuel commerce would increase by a factor of 80 between 2010 and 2030, based on current trade proportions. However, these models lack precise characterization of the logistic infrastructure (collection, pre-processing, transportation, handling, and storage) as well as limitations on infrastructure upscaling over time [25] as mentioned before.

8.3.1 Own views of current trends and future opportunities

In recent years, the energy issue has been a hot and highly topical issue. In order to reduce dependence on the fossil energy sources, great efforts have been made to find other equivalent energy sources that can supply today's needs. One of these is bioenergy, which, according to the above, has a promising future as long as political decisions do not complicate it. A large investment in renewable energy sources is good, but this will, in my opinion, lead to major competitions between the various energy sources. A lot of money, resources and time is invested in coming up with new solutions, which I think will affect how energy conversion will look in the future. It is difficult to know what the future of bioenergy will look like today, as there are many other energy sources that are in a development phase that competes with bioenergy. Bioenergy comes in many different forms, and several of these forms will surely have great potential in the future, just as they have now. For example, the use of pellets and the incineration of waste, which will always be available and secure the availability of an energy source, as well as solving other problems such as waste management. Comparable to sun and wind, we can not rely on them. This is because they can affect, for example, the price of electricity on windless days and not secure the supply for today's needs. In summary, I believe that bioenergy will solve a large part of our energy needs. We can see this in the development that is taking place today, and the increasing use of biomass energy at the same time as international laws are leaning towards more bioenergy use. But as long as the political decisions do not complicate it, it looks promising.

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