Biogas Production from the waste of the shrimp manufacture in Sisimiut

Arctic Technology 11427 – Spring 2009

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Preface:

This report is the result of one month of analytical test in the laboratory of environment in DTU and 3-week field work in collaboration with the Royal Greenland in Sisimiut from the 25 of May until the 15 of June 2009. It has been supervised by Marianne Willemoesgade Jørgensen and Arne Villumsen and it has an academical worth of 15 ETCS of special course.

This project is part of the course "Arctic Technology (11427)", taught in the Civil Engineering Department of DTU and coordinated by Arne Villumsen and Pernille Erland Jensen.

Handed in the 25th of June 2009;

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Abstract:

This report describes the study of the viability of implementing a biogas plant in Royal Greenland Sisimiut plant, using its shrimp waste as the substrate of the digestion. The study is divided in two parts, the first one is focus on the shrimp waste experimental analysis and the second part is about the future biogas plant characterization.

From the experimental work was concluded a potential biogas around 200 Nm^3 CH_4/Tn VS; due to some incoherence in the experimental results, its value of biogas potential was no used to characterize the biogas plat. Moreover, it was observed big difference between the laboratory and the real scale plant, regarding the optimal volatile solid concentrations. Anyway, it was observed that this kind of waste has a big potential for the biogas production.

Regarding to the biogas plant implementation, the required dimensions and the design of each unit has been done, adapting them to the Royal Greenland Sisimiut requirements and limitations. Due to the lack of some of the information needed to make a deep analysis of the biogas plant, the present report is only a draft of a future biogas plant assessment. At this moment, it could not be realized because of the short project duration as well as the long waiting time for the supplier companies' replies.

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1. Introduction

Nowadays, Sisimiut community is living mainly from the incomes of the local fishing and fishery industry. This factory, known as the Royal Greenland Sisimiut s.a., needs large energy (electricity to supply all the machines of the factory and oil to produce heat for the production process) and water requirements; moreover it produces huge amounts of waste which are poorly treated before being released into the sea.

This industry could become more environmentally sustainable if it could use some renewable energy instead of the traditional fossil fuels. One possibility could be using its own waste as a biomass source of energy. This innovation is promoted from the government by the means of some incentives, like the elimination of taxes for renewable energy source. Furthermore, if the industry waste becomes the energy source of the factory, the last will be energetically self-sufficient; it will not need any external energy supplier. Moreover, it will be less dependent from the oil price fluctuations.

Figure 1: Sisimiut landscape [9.1]

As it has been mentioned above, the current waste is being released directly into the sea, without any kind of treatment. Thus the Sea is receiving the process water with big quantities of shrimps and crabs shells. In previous Arctic projects, it has been concluded that these releases cause some variations in the marine environment.
The water discharged in the surrounding sea would be cleaner if the main part of the waste could be retired to be used as biomass.

The purpose of this project is to study the implementation of a biogas generation plant from the shrimp waste of the Royal Greenland Sisimiut Plant.
The project is divided into three main parts. The first one takes place in the Technical University of Denmark, where some shrimp samples are analyzed to measure the potential biogas produced by the shrimp waste of the Royal Greenland.
The second part focuses on the fishery plant analysis; this part is located in Sisimiut, where the compilation of the required data is carried out. Mainly, the needed data are waste amounts, energetic requirements, plant distribution and so on.
The third and last part is the biogas plant design. From the collected data, a roughly design and an economical study are done for a suitable biogas generation plant.

2. Background

2.1. Greenland

Figure 2: Greenland map [9.2]

Greenland is the largest island in the world and it belongs to the Kingdom of Denmark.

As it can be observed on the left image [Figure 2] it is surrounded by the Arctic and the Atlantic oceans, between Canada and Iceland.

It hosts a total population of 57.000 people, in an area of 2.166.086 km^2 of which 81% of it is covered by ice.

Nowadays, the main sources of income are fishing and fish exportation, representing 95% of the Greenlandic exportations [9.3]. Besides, the hydrocarbon and mineral exploration are being developed. Since, minerals like gold, iron, diamonds and rubies are found in abundance [9.4].

Figure 3: Royal Greenland image [9.5]

2.1.1. Fishing and fisheries industries

The fish market evolves fishing and fishery industry. Fishing can be carried out by local fishermen in near coast with small boats and also offshore fishing with larger trawlers, as Royal Greenland [9.3].

Royal Greenland plays the main and sole role in the Greenlandic fishery industry. It has many market points all over the world, see right figure [Figure 4], and its largest production is located in Greenland, with more than 20 factories in the West coast.
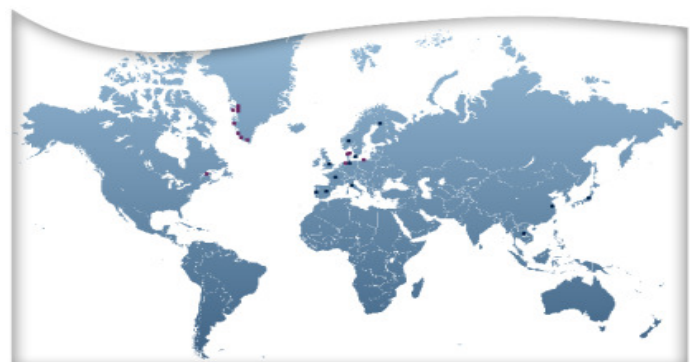
Figure 4: Map of production sites and sales offices of Royal Greenland [9.6]

2.1.2. Energy and environment

In order to meet with the Kyoto Agreement, Greenland has to eliminate 8 % of its emissions of greenhouse gases (carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs) and sulphur hexafluoride (SF_6)) before 2012. To deal with this reduction, the Greenlandic politicians are trying to reduce fossil fuel imports by the means of increasing the use of clean energies, as hydropower [9.7].

The first hydroelectric power plant was built in Buksefjorden in 1993; new plants are planned in a close and in a far future. Nowadays, the company Nukissiorfiit has three hydroelectric plants which supplies Nuuk, Tassiilaq, Qaqortoq and Narsaq, and another plant under construction in Sisimut.

Today, Sisimiut is supplied with a power plant which generates electricity from imported diesel oil with a capacity of 8.2 MW. In 2010, this plant will be replaced by a hydroelectric one with a capacity of 15 MW.

Figure 5: Greenland map [9.8]

The International Maritime Organization is a specialized agency of the United Nations. The 24th of March 2006, it was reached the Protocol to the Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter, entry into force in 1996. It regulates the use of the sea as a depository for waste materials, dumping is prohibited, except for approved materials, like waste fish and material resulting from industrial fish processing operations [9.9]. According to this, Royal Greenland Sisimiut can throw its waste directly into the sea.

2.2. Current situation of Royal Greenland S/A

'Royal Greenland is one of the world's leading groups on the seafood market' [9.3], as it has been mentioned above; there are more than 20 factories around the Greenlandic west coast. Moreover, it owns smaller fishing vessels and factory trawlers which treat the raw material and freeze the product in the open sea.

2.2.1. Main numbers

During 2008, the Royal Greenland Sisimiut plant was supplied by 8 boats and the factory trawlers with annual amount of 20,180 Tons of shrimps, being the amount of shrimps treated per month around 1,680 tons. This amount was more or less constant during all the year; when the raw material fished was bigger than this amount; they kept frozen the rest of the material for using it in other period with less fishing to keep the production constant. The final product sold during all the year was around 6,019 Tones. Thus, the quantity of waste produced and released to the sea results in 14,161 Tons of waste, mainly made up of shells and head of the shrimps.

The direct waste discharge started six years ago, when the Greenlandic Government allowed the factory to release all its waste to the sea. Previously, the shells and the heads of the shrimps were converted into shrimp dust and sold it. This waste transformation was really costly, while the price of the dust was quite low, thus the process was not profitable. This was the reason for obtaining the permission for untreated sea discharges.

2.2.2. Water consumption

Royal Greenland Sisimiut plant uses huge volumes of water in its production chain; it is not only used in the 18 working hours, since 60% of its consumption takes place during the cleaning hours, from 1 a.m. to 7 a.m.
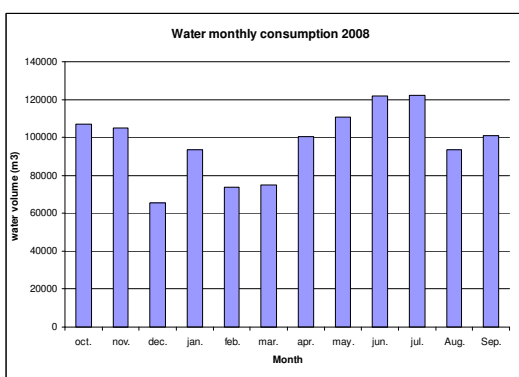
Figure 6: Monthly water consumption of Royal Greenland in 2008.

On the left graph [Figure 6] it can be observed that the water consumption is monthly dependent. The minimum volume of water used is in December, being a good period due to the lack of spawns that have to be removed.

On the opposite, June and July are the months which need more water volume because it is the reproduction period of the shrimps, thus their spawn has to be taken out. During this period the cost of the process grows because of this increase in the water consumption.

The total waste cost in 2007 was around 747,000 € and in 2008, 826,000 €. This increment of the water consumption during 2008 was due to the increase of shrimp production during this year [Appendix 1.a].

2.2.3. Energy requirements

Besides the high water consumption, there is also a huge energy requirement.

The electricity in the plant is used to supply all the production equipment, and the oil is used to produce steam, and with it, to warm water. The consumption of electricity and oil during the years 2006-2007 and 2007-2008 can be seen in appendix 1.b, being the amount and the money spent shown in the below table [Table 1]:

	Electricity (KWh)	Oil (L)	total cost electricity (€)	total cost oil (€)
2006-2007	3,710,330	1,799,522	462,381.3	1,044,119
2007-2008	4,349,208	2,102,450	541,998.3	1,219,884

Table 1: Electricity and oil consumption

If Royal Greenland would like to substitute these two energy sources with biogas, the required biogas annual volume is shown in the following table [Table 2]:

Values of 2008	Consumption	Biogas equivalent* (m^3/u)	Biogas required (m^3)
Electricity (kWh)	4,349,208	0.56	2,435,556
Oil (kg)	2,102,450	1.83	3,847,484
* Reference[9.10]			6,283,040

Table 2: Biogas required replacing both electricity and oil

Thus, if Royal Greenland is able to produce almost 6 millions of cubic meters of biogas, all the fuel cost will be saved. This means saving around 13 millions of Danish crowns; it is explained later on in the economical section.

2.2.4. Waste characterization

The discharge of the Royal Greenland in Sisimiut has a fraction of 7% of shells and 93% of water (experimental test and calculation in the Appendix 2). The solid waste is mainly shrimp shells, with an expected moisture content of approximately 80%. The dry part is mainly composed of proteins (30%-40%), chitin (17%-20%), calcium carbonate (30%-40%) and a small fat fraction of around 5%.

2.2.5. Environment effects

Royal Greenland has permission for discharging its waste into the sea, since it is not considered harmful to the environment. But, in the basin where the last pipe is discharging, water has a red color due to the shell discharged.

Figure 7: Discharged site waste
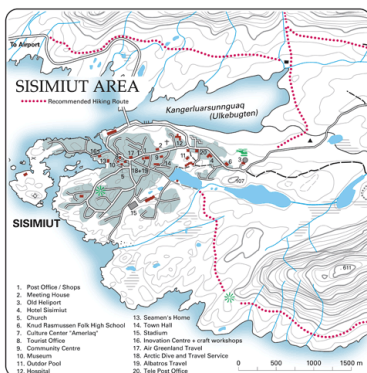
Figure 8: Sisimiut area map [9.11]

In 2006, Brogaard & Jørgenson analyzed the sediments in the fjord Ulkebugten (see Figure 8). It was concluded that the sediments close to the Royal Greenland discharge point contain high amounts of organic matter as well as heavy metals (cadmium and copper).

Heavy metals have a tendency to bind in the organic matter, which later on will be the marine organism food. The degradation rates of these metals are really low, thus they persist in the food chain.

Moreover, it was concluded that there is an oxygen depletion of the sediments, affecting the marine environment of the fjord. [9.12]

2.3.   Biogas

2.3.1. Definitions

Biogas is a combustible gas that is generated by the biological breakdown of organic matter. It is produced by anaerobic digestion of organic matter such manure or sewage, municipal waste (food waste, kitchen waste, farm waste), green waste and energy crops.

The composition of final biogas depends on many factors, such as the composition of the initial organic matter, the operation conditions of the digester and so on. But roughly the fractions are shown in the following table [Table 3]:

Matter	%
Methane, CH4	50-75
Carbon dioxide, CO2	25-50
Nitrogen, N2	0-10
Hydrogen, H_2	0-1
Hydrogen sulfide, H_2S	0-3
Oxygen, O_2	0-2

Table 3: Biogas typical composition

To calculate the composition of the biogas produced by a specific substrate, there is a formula created by Buswell and Bolye. It is expressed in the next equation and it describes the molar composition of biogas depending on the chemical composition of the initial substrates of the anaerobic digestion [9.12].

$$C_aH_bO_cN_dS_e + \left(a - \frac{b}{4} - \frac{c}{2} + \frac{3d}{4} + \frac{e}{2}\right)H_2O \Rightarrow \left(\frac{a}{2} - \frac{b}{8} + \frac{c}{4} + \frac{3d}{b} + \frac{e}{4}\right)CO_2 + \left(\frac{a}{2} + \frac{b}{8} - \frac{c}{4} - \frac{3d}{8} - \frac{e}{4}\right)CH_4 + cNH_3 + dH_2S$$
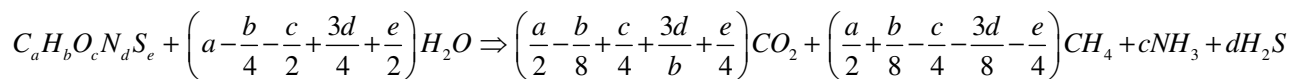
The following table [Table 4] shows some examples of different biogas compositions depending on the substrate used:

Substrate	Input (%)		Output (%)			
	Substrate	**H₂O**	**CO₂**	**CH₄**	**NH₃**	**H₂S**
$C_5H_7NO_2$ (Protein 1)	25.0	75.0	36.2	35.4	28.4	0.0
$HO_2CCH(NH_2)CH_2SH$ (Protein 2)	40.0	60.0	29.8	20.6	33.0	16.5
$CH_3(CH_2)_{10}COOH$ (Fat)	16.7	83.3	25.0	60.7	14.3	0.0
40% Protein 1 + 5% fat	40.8	59.2	36.3	39.0	24.7	0.0
40% Protein 1 + 5% fat	54.1	45.9	31.5	28.5	27.7	12.3

Table 4: Biogas composition depending on the substrate

The calculation of the values that appears in the table is explained in the Appendix 3.

2.3.2. Obtaining

The conversion of organic matter to biogas by the means of anaerobic digestion is made up by several steps, in which microorganisms break down biodegradable material in the absence of oxygen. After that, the biogas obtained must be treated to exploit the methane for renewable energy generation, generating electricity and heat.

During the chemical process there are many kinds of bacteria involved in the degradation of the organic material, as acetic acid-forming bacteria (acetogens) and methane-forming archaea (methanogens). These required bacteria are fed in the initial feedstock, at the same time, and they bring under a number of different processes (four steps) converting the organic waste into biogas. These steps are as follows:

- Hydrolysis, where enzymes convert large molecules/polymers such as polysaccharides and proteins into smaller compounds (peptides, glycerol, alcohol and the simpler sugars), to make easier their degradation for the bacteria.
- Acidogenesis (fermentation), where the conversion of small compounds to Volatile Fatty Acids (VFA) by using microorganisms takes place. Moreover, enzymes are produced, which can be used to hydrolyse the complex components remaining from the hydrolysis part.

- Acetogenesis, in which volatile fatty acids are converted into acetic acid, carbon dioxide, and hydrogen, by using acetogens.

- Methanogenesis, where methanogenic bacteria converts the products of acetogenesis into methane and CO_2. These bacteria are the most sensitive to the operation conditions (pH, residence time, temperature).

The 4-steps process explained above is represented in the figure below [Figure 9].
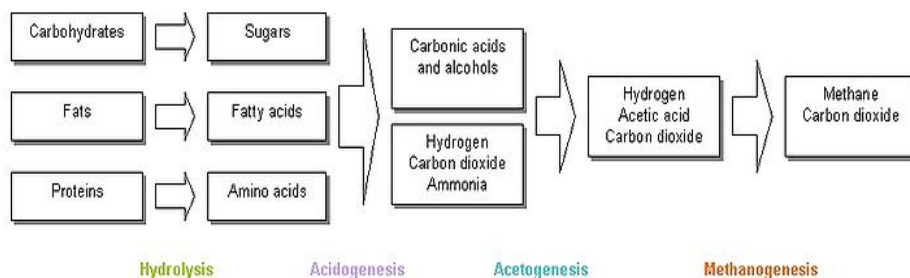
Figure 9: Steps for the degradation of the organic material [9.14].

The better all the phases merge into each other, the shorter the digestion process is, thus the best option is put together all the required bacteria for the entire process.

The digestion can be carried out by different **types of methanogenic bacteria** according to the temperature in the digester:
- Phychrophilic bacteria degrade at low temperature, between 10 to 20 ºC
- Mesophilic bacteria work at medium temperature, between 20 to 35 ºC
- Thermophilic digestion takes place when the temperature of the digester is in the rank 50 – 60 ºC.

The methane content of the formed biogas is highly dependent on the digestion temperature, low one produces biogas with high methane content, but low quantity of biogas because the bacteria need longer time to digest.

As it has been said before, the methanogenic bacteria are really dependent on the operation conditions. They are sensitive to both high and low pHs, being the **optimal pH** neutral value, between 6.5 and 8.

The **retention time** is an important parameter to characterize the digester, it is the period spent by the feed matter inside the digester. It is chosen by economic criteria, but usually:
- Phychrophilic bacteria need around 100 days of retention time.
- Mesophilic bacteria approximately 20 days.

- Thermophilic digestion last around 8 days.

Degradation is faster at higher temperature, but to get this temperature, more heat energy input is required, so an energy balance of the system must be done.

If the residence time is short, the methane concentration in the formed biogas is lower than 50% and it is not longer combustible.
The residence time also depends on the amount and type of feed material, the configuration of the digestion system (one-stage or two-stage).

The income **slurry** should have fluid properties to make it easier for the methane bacteria to contact with feed material, thus it makes the digestion faster. For continuous operation, solid contents of the slurry around 5 to 10% are optimal for the digestion.
The slurry composition has high carbon and nitrogen fractions; the ratio between its fraction is another important parameter to characterize the digestion. The most favorable **C/N ratios** are from 20/1 to 30/1.

At the end of the process, the solid remaining of the initial input material that are non-digestable, it is which the microbes cannot use, constitutes the digestate, and it is recovered at the exit. It contains mineralized remains of the dead bacteria, and also ammonia, which can be oxidized to nitrates during maturation or composting stage after digestion, making possible its use as fertilizer. Water obtained after digestion from both the moisture of the initial waste and the produced during the process must be separated from the digestate [9.10]

The process described above produces suitable biogas for energy production; it can replace fossil fuels and at the same time reduce the gas emission into the atmosphere as well as the volume of the input material. All these facts decrease the environmental impacts in relation with waste management.

The sketch on the right side [Figure 10] shows how all the procedure explained above takes place in a real biogas plants, going from the biodegradable waste to the energy generation:
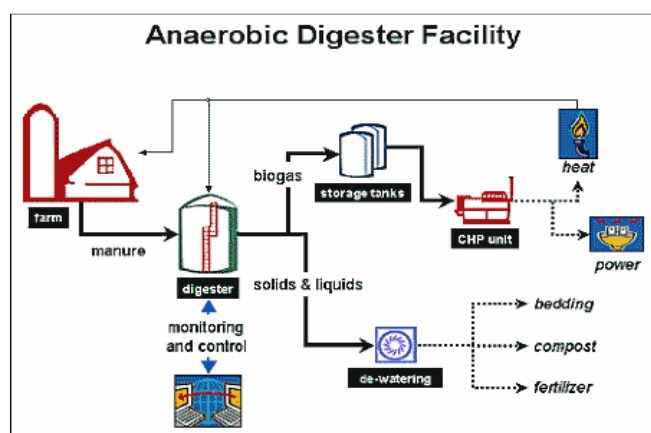
Figure 10: Sketch of a complete biogas plant [9.15]

The complete process in biogas plant is the following one:
First, the treated substrates are introduced into the digester system by dosing equipment, that regulates the process, and makes that the microorganisms are fed in small amounts several times. In the digester system, the fermentation process takes place.
The first digester often is metallic, horizontal, and with mechanical agitation. The secondary digester is used to store the gas, it is also called gas holder.

The biogas energy produced is converted into electricity and heat in a CHP station (cogeneration unit), where fuel releases its energy with a chemical reaction, such as combustion, or nuclear (fission and fusion). In cogeneration plant thermal energy is used, reaching an efficiency of up to 89%, whereas that in a conventional power plant most of this heat is lost as excess heat (efficiency of 55%). The efficiency of a CHP station depends on where the heat is going to be used. If it has to be transported over longer distances, the efficiency decreases and insulated pipes are needed, becoming the freight expensive. The low pollution permits to build the plants near to the city, using the heat and electricity generated very close where it is used. It reduces the amount of energy lost in the transmission, and the size and number of power lines constructed.

2.3.3. Biogas applications

Biogas is a clean environment friendly fuel, as any other combustible gas, it produces energy that can be stored and be discharged when it is needed.
Its calorific value is about 6 KWh/m^3 (equivalent to half a liter of diesel oil) and its air requirement during the combustion is 5.7 m^3 air/m^3.

- Biogas direct applications

Biogas can be used as a low-cost fuel for heating purpose, such as cooking, replacing the use of fuel wood or oil. It leads to a cleaner and safer way to cook. Biogas can also be utilized to run heat engine generating either mechanical or electrical power, applying it in domestic appliances.

There are some risks that can appear if biogas is directly used; when biogas is mixed with air in the proportions of 1:20, highly explosive detonating gas forms, so leaky gas pipes in enclosed spaces are dangerous. In addition, biogas cannot be liquefied, so gas pipes may be made of steel, copper, rubber or plastic. Moreover, the hydrogen sulphide in the biogas can form corrosive acids, being water appliances at risk. For this reason, the combustion chambers and burners should be made of steel. One solution for removing H$_2$S can be the use of filters, but with large volumes of gas, they must be replaced very often.

Some characteristics of the biogas, like its high ignition temperature or its slow burn make it necessary to mix it with diesel fuel in order to run a diesel engine. Engines of less than 2000 rpm are the best choice for using biogas [9.10].

Regarding to CO_2, it is an acid gas that is corrosive when it is combined with water, causing destruction in equipment and pipelines, decreasing their capacity. Furthermore, carbon dioxide reduces the heating value of biogas from 9.94 KWh/m^3 to 5.96 KWh/m^3 [9.16]. Environmentally, CO_2 has been proven to be a greenhouse gas, helping to increase the earth's surface temperature and promoting long term climate changes. So, with the Kyoto Conference, a lot of countries are aware of the reduction of its emissions into the atmosphere. For this, it is very important to separate and treat this CO_2 [9.17].

Referring to H_2S, it is toxic at a concentration above 100 ppmv. Some bad aspects to stand out are its odor and the safety risk involved when it is combined with CO_2 and water vapour, causing corrosion in the equipment. In addition, its combustion generates SO_2, which reacts with water to form H_2SO_4, a highly corrosive acid. For these reasons, H_2S must be removed from biogas. With H_2S removal, less maintenance and more energy efficiency are achieved, resulting in cost savings [9.18].

- Biogas energy transformation

The biogas could be converted into electricity and heat in a CHP (combined heat and power, cogeneration unit), where fuel becomes electricity producing heat as a by-product. Afterward, this heat is used for heating purposes.

In cogeneration plant thermal energy is used, reaching efficiency up to 89%, whereas in a conventional power plant most of the heat created is emitted to the environment through different units, like cooling towers or flue gas (efficiency of 55%).

- Methane extraction

Another option is to extract methane from the biogas, since methane energetic proprieties are better than the biogas ones. With this method, some of the mentioned problems like the risk produced by the hydrogen sulphide presence are solved.

Some treatment techniques like absorption or membrane separation must be applied to remove CO_2 and H_2S from the biogas and to achieve pure methane.

   o Membrane

Membrane systems have major advantages over more-traditional methods of CO_2 removal, as:

• **Lower capital and operating costs**: Installation costs are significantly lower than alternative technologies, especially for remote areas. Moreover, membranes units do not used additional facilities. The only major operating cost is its replacement, but it has to be done few times, since membranes have long useful life.

• **Simpler operation and higher reliability:** Membrane systems have no moving parts, being the most complexity part the addition of a recycle compressor.

• **Good weight and space efficiency:** Its dimensions can be chosen depending on the space available, and multiple elements can be inserted into tubes to increase packing density. So this space efficiency is used for offshore environments.

• **Adaptability:** Membrane system is extremely adaptable to various gas flows, CO_2 concentrations and product-gas specifications, and turn-up/turndown increments can be set during the design phase. By adjusting process parameters such as operating temperature, the designer can further reduce the sales-gas CO_2 content.

• **Power generation:** The permeate gas from membrane systems can be used to provide fuel gas for power generation, either for a recycle compressor or other equipment.

• **Environmentally friendly:** Membrane systems do not involve solvents or adsorbents, neither their periodic removal, and permeate gases can be flared, used as fuel, or reinjected into the well.

Many of the factors make membrane systems ideal for remote and difficult locations. Furthermore, solvents storage and trucking, water supply, power generation or extensive infrastructure is not required.

The way to separate CO_2 from methane using this technique consists in the principle of solution-diffusion through a nonporous membrane. It separates based on how well different compounds dissolve into the membrane and then diffuse through it. The gases that dissolve and diffuse quickly through the membrane are called fast gases (carbon dioxide, hydrogen sulphide, and water vapour) and they separate from the slow gases (methane), which take more time to dissolve and diffuse [9.16].

The only commercially viable membranes used for CO_2 removal are polymer based, for example, cellulose acetate, polyimides, polyamides, polysulfone, polycarbonates, and polyetherimide [9.16]. In order to select a membrane, permeability and selectivity have to be taken into account; high permeability leads to less membrane area required and lower system cost; high selectivity leads to a better separation between the elements, therefore lower losses of hydrocarbons (methane) in

the rich CO_2 flow. So, it is desirable to keep high both parameters, but when one of them is increased, the other decreases, so a compromise must be reached. Both of them are influenced by the operation conditions:

- **Flow rate**: An increase in flow rate produces a directly proportional increase in membrane area requirement, keeping constant the percentage hydrocarbon losses (hydrocarbon losses ÷ feed hydrocarbons). So, hydrocarbons losses also increase proportionally with the flow rate.

- **Feed temperature**: An increase in feed temperature increases membrane permeability and decreases selectivity.

- **Feed pressure**: An increment in the pressure decreases both membrane permeability and selectivity, but creates a greater driving force across the membrane that increases the permeation through the membrane and drops the area requirement.

- **Permeate pressure**: The effect of permeate pressure is the opposite of the effect of feed pressure, being desirable a low permeate pressure in order to get a low membrane area requirement. In addition, losses of hydrocarbons decrease when permeate pressure becomes lower
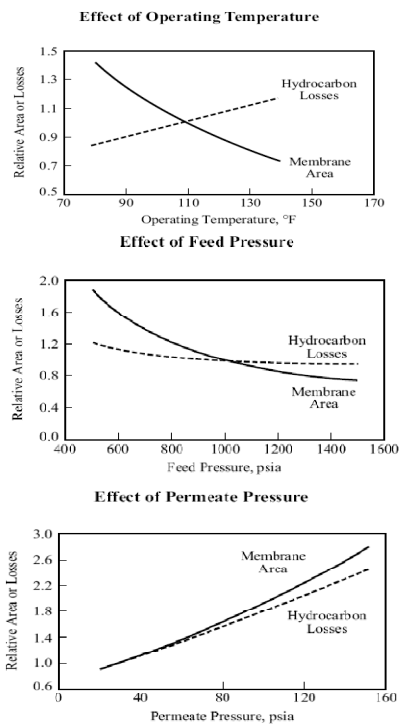
The process inside the membrane can be divided into different steps. First, the mist eliminator removes the possible liquid in the feed gas, because it causes swelling of the membranes and destruction of membrane integrity if it is not removed. Secondly, there is a heater which superheats the gas to make sure that liquids will not form within the membranes themselves, by condensation of the gas when it cools down. It also maintains constant operating temperature.
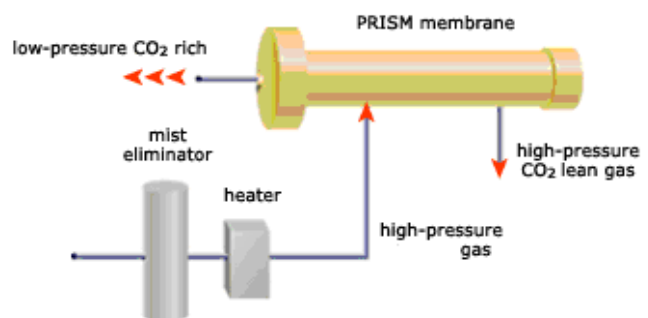
Figure 11: Sketch of all the element for a membrane system

Thirdly, the feed gas at high-pressure enters along the side of the membrane and passes through the envelopes. As the gas travels between the envelopes, the highly permeate compounds (CO_2, H_2S, water vapour) permeate into the envelope. They travel within the envelope to the permeate tube through holes in the tube, while low permeate and high-feed pressures compounds are

transported by the driving force to the side opposite the feed position, leaving the membrane [9.16].

The low-pressure CO_2 flow must be liquefied to be transported and stored. For transportation in pipelines, ambient temperature and 140 bars pressure must be reached. However, for transportation in ships, which is the case of this project, the optimal pressure and temperature are 6 bar and -50 ºC, so a cycle with intercooled compression stages must be used. [9.17]. The high-pressure methane obtained has to be treated to produce energy.

2.3.4. Biofertiliser

On the other side, the biogas production process has another product as important as the biogas; it is the non-digested matter in liquid phase, called biofertilizer. The non-digested matter settles out in the digester as a liquid sludge. Its composition depends on the raw matter as well as the digestion conditions, but it mainly contains many essential elements for the flora, as nitrogen, phosphorus, potassium and trace quantities of metallic salts.

The digested sludge is used as soil conditioner and fertilizer; it feeds the plant while it also improves the soil proprieties, increasing the water-holding capacity and beneficiating its structure.

One of the most important elements of the fertilizer is nitrogen; it has a vital role in nutrition and growth of the plants. The digestion converts nitrates and nitrites of the organic waste to ammonium. Usually the fresh digested sludge has to be let for few weeks in an open tank or some months in a closed one, in order to decrease the ammonia contain, which in high concentrations could become toxic for the plants [9.19].

3. Experimental biogas production

3.1. Procedure

In this project, the aim of the experimental part was to obtain the amount of methane that can be produced from the shrimp waste of Royal Greenland, in Sisimiut. A wet sample of prawns´ shells and head was send from Greenland to DTU in order to be treated and analyzed in the laboratory.

For the transportation of the sample by plane, it was frozen to conserve the same properties as in the beginning. The concentration of the initial sample was 129 g VS/Kg, so it was diluted to obtain the range of different concentrations that were required to study the production of biogas and to select the optimal concentration.

During the calculations for obtaining the different samples, inoculums must be taken into account, due to the fact that it contains the necessary bacteria to carry out the anaerobic digestion. Every

test sample has a volume of 100 mL, and it contains the substrate, inoculums and water. The amounts to obtain the blank solution, the control solution, and the different concentration samples are as follows [Table 5]:

Masses (g)	Inoculums	Substrate	Water	Total
Blank	70.00	0	30.00	100
Control	70.00	0.10	29.90	100
Test solution 5 gVS/L	70.00	3.88	26.12	100
Test solution 10 gVS/L	70.00	7.75	22.24	100
Test solution 20 gVS/L	70.00	15.50	14.40	100
Test solution 35 gVS/L	70.00	27.13	2.87	100

Table 5: Amounts required for the different samples

Calculations:

Mass of substrate: $m_{initial\ sample} \cdot C_{initial\ sample} = m_{final\ solution} \cdot C_{final\ solution}$

Total mass fixed at 100g and inoculums at 70g.

Example of calculation:

$$m_{initial\ sample} \cdot 129\,\frac{g\,VS}{kg} = 100\,g \cdot 5\,\frac{g\,VS}{kg} \xrightarrow{\ density\ of\ the\ final\ sample \approx 1kg/l\ } m_{initial\ sample} = \frac{100\,g \cdot 5\,\dfrac{g\,VS}{kg}}{129\,\dfrac{g\,VS}{kg}} = 3.88g$$

Three samples for each different concentration were made in order to contrast information and make sure that the results are correct, and to have enough data, in case of some mistake in the subsequent measurements.

The real quantity of each product introduced in each bottle is showed in the table of the Appendix 4.

All these samples must be introduced in the chromatograph in order to obtain different peaks for each one. With the area, it is possible to calculate the amount of methane that is produced every time. To make these measures, the chromatograph must be calibrated each time that it is used, with a standard gas of 40% CH_4. Approximately every two days, the CH_4 produced by the samples is measured. In this way, it is possible to analyze the evolution of the production of methane with time, guessing the optimal retention time. When percentage of methane within the bottle is bigger than 30%, it is necessary to take out some methane of the test solution, to decrease the pressure, and to encourage the production of more methane. Measuring the amount of methane before and after the removal, it is possible to calculate the removed methane, which has to be taken into account in the calculations.

3.2. Methane measured

The methane produced is calculated through the standard gas. Each time, at the beginning of the laboratory work, the standard gas is prepared. It is measured several times until the results are very similar between them, and an average of the area is taken. Then, the peaks of the samples with different concentrations as well as the blank and the control are obtained. Being known the area and the percentage of methane in the standard gas (40 % CH_4), it is easy to calculate the percentage of CH_4 that has been produced in the sample, with the following equation:

$$\%CH_{4,\,sample} = 40\% \cdot \frac{Area_{sample}}{Area_{s\tan dard}}$$

In Appendix 5 can be seen the percentage of methane that has been produced in each bottle with the time.

To obtain the amount of methane produced in volume (mL), the following calculation must be done:

- Total volume recipient = 321 mL (volume measured through the difference of weight between the recipient empty and full of water)
- Active volume≈100 mL (substrate + water + inoculums)
- Headspace = Total volume – active volume ≈221 mL
- $ml\, CH_4 = \dfrac{\%CH_4 \cdot 221mL}{100\%}$

The volume of methane obtained in each bottle is also expressed and represented vs. time in Appendix 4.

At this point, the objective of studying the experimental data is to discover at which concentration, and at what time the amount of biogas produced by 1g VS has the biggest value. These conditions will be the optimal ones to operate in the anaerobic digester. For this, the mL of CH4 produced/g VS must be calculated. It is done using the following equation:

$$\frac{ml\, CH_4}{g\, VS} = \frac{ml\, CH_4\ produced\ by\ the\ waste}{g\ substrate \cdot \dfrac{12.9\ g\, VS}{100\ g\ substrate}}$$

Where:
   mL CH_4 produced by the waste=mL CH_4 produced by the test solution –mL produced by the blank

All this results are collected in Appendix 4, and the representation of these values vs. time is shown in the below graph [Figure 12]:
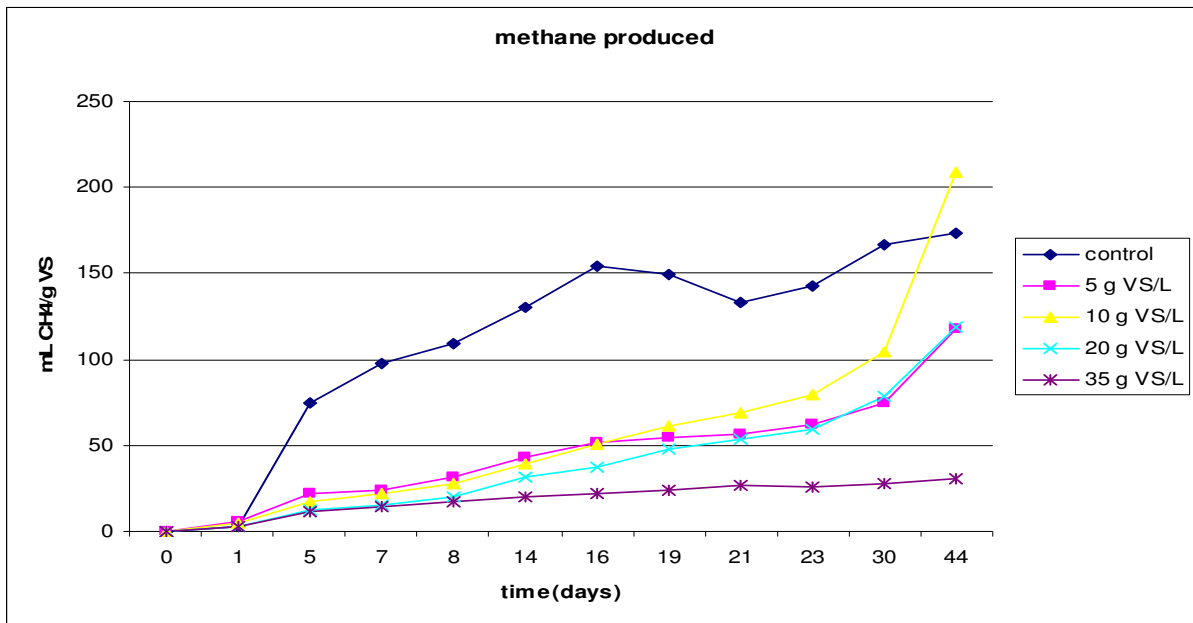
Figure 12: Methane produced (mL CH$_4$/g VS)

This graph is useful to calculate the biogas potential of the shrimp samples, but not to figure out the optimal conditions in the digester (operation time, concentration…) because this experiment was made in a laboratory scale closed system, and in real scale reactor the conditions will change.

Looking at this graph [Figure 12], it can be seen that the biogas potential of the sample (when the amount of CH$_4$ generated per g VS seems to keep constant) is around 200 ml CH$_4$/g VS,. This value must be constant for all the concentrations, but it is lower at 35 g VS/L. It is due to the fact that at high concentrations, the amount of NH$_4$-N is also high, and it inhibits the process of degradation of organic matter, causing a decrease in the amount of methane produced.

The control sample shows the theoretical biogas potential of the sample, being around 174 mL CH4/g VS the result obtained.

4. Biogas plant design

In order to produce the biogas from the waste of the Royal Greenland in Sisimiut, a biogas plant must be designed. It will consist of many different parts, being the most important one the digester, where the chemical reaction to convert organic material (shells of shrimps) into biogas takes place. Before the digester, the waste must be treated to meet with the optimal operation conditions within the digester. Once the biogas has been produced, the CO_2 must be removed, in order to make it possible the use of pure methane (95%) as combustible, instead of oil, and generate heat with it.

4.1.   Digester conditions

As it has been mentioned previously, the solid content in the slurry must be between 5 and 10% of solids in order to make the digestion easier for the bacteria. Dry shrimp shells have 12.8% of volatile solid, thus they have to be mixed with water in order to get fluid properties. This mix should be done in a mixer before the digester.

The shells which are going out of the Royal Greenland factory are quite big pieces, they must be crushed before being mixed with water in order to increase their specific area and facilitate the attack of bacteria. This crushing is easier when the material is dry, so the shells must be separated from the water process, be crushed and afterward be mixed with hot water in the mixer.

4.2.   Waste Treatment before digester

As has been mentioned before, six years ago it was not allowed to throw the waste into the sea, so there was a specific equipment to convert the waste into dust of shrimp shells, instead of flinging it directly.

Left side figure [Figure 13] shows the room where the conversion of waste into shell shrimp dust was carried out 6 years ago.

The room roughly dimensions are 10 m x 10 m (see Appendix 6)

Figure 13: Room where the waste conversion was carried out 6 years ago.
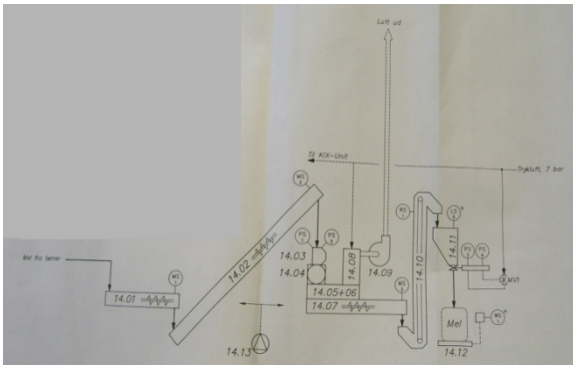
Figure 14: Sketch of the machinery required to convert the waste into shrimp shells dust.

On the left figure [figure 14] shows the flow diagram which used to follow the waste.

The main units are: the filter which separates the shells from the water of the process production, a crusher which grinds the shells and finally a ventilator that dry the dust; all these machines are communicated by conveyors.

For the current project, the operations that must be done before the waste comes into the reactor are quite similar to the past one, so it would be possible to use that installation for this treatment process, making some modifications.

The old installation consisted of a filter (Figure 15:) that separated the water from the shells, settling the shells on the bottom, and throwing the water into the sea. The waste from the factory arrived through the upper pipe (Picture 1), while the water went into the sea through the bottom pipe (Picture 1).

The shells were transported through the first conveyor (Picture 3) to a tank with a second conveyor (Picture 4).

Picture 1: External side of the filter.

Picture 2: Internal side of the filter.

Picture 3: Lateral side of the filter and first conveyor.
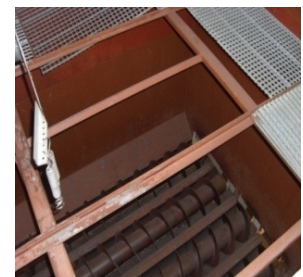
Picture 4: tank with the second conveyor.

Figure 15: Pictures of the primary filter with the conveyor incorporated.

The second conveyor is connected to the crusher by the means of a pipe, shown on the right pictures [Figure 16]
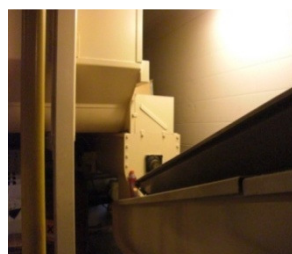
Picture 1: Connection tank-pipe

Picture 2: Connection pipe-crusher

Figure 16: Royal Greenland connections between

the tank and the crusher

In the crusher [Figure 17], the shells grinded into small pieces, becoming dust. Afterwards, a filter with a ventilator dries completely the dust. This final product was carried by another conveyor to the balance, where it was weighed, and finally sold.

Picture 1: Crusher + ventilator

Picture 2: Crusher

Figure 17: Royal Greenland Sisimiut crusher images

4.2.1 New working conditions of the old machinery

In the new project, the output product of the crusher will be mixed with water in a mixer and afterwards the mix will go inside the digester. So, part of the process explained before (from the filter to the crusher) could be reused, although some modifications are needed. The second filter and the ventilator are not useful in the new application; the digestion does not need really small particles, and they must not be dry, due to the fact that the digester needs a wet waste.
In the table below [Table 6:] are listed the old characterizations of all the required machinery:

	nr.	Capacity (t/h)	Energy consumption (KW)	Length (m)	Weight (Kg)	Speed (rpm)
Conveyor 1	14.01	0.8	1.1	1.23	155	1400/33
Conveyor 2	14.02	0.8	1.1	6.55	405	1400/85
Crusher	14.04	1.23 (m^3)	45			2955

Table 6: Old characterization of the required machinery.

To adapt this machinery to the new process, some studies must be done. As it has been mentioned before, the production during the year is quite independent of the season, because Royal Greenland always treats approximately the same amount of shrimps and they freeze the excess, but there are some fluctuations. During 2008, the month with larger production was April, its main numbers are shown in the following table [Table 7:]:

	Tn/April 2008
Raw material	2118
Final meat	646
Solid Waste = Raw - Final	1472

Table 7: Production in April 2008

If the monthly solid waste is converted in daily solid waste, 26 working days per month, the daily waste produced is 57 Tons.

Taking some samples from the last pipe of Royal Greenland [Appendix 2], it is known that 93% of the waste thrown directly to the sea is water. So, the total waste (water and shells) that Royal Greenland produced every day is:

$$57 \frac{Tn\,Shells}{day} \cdot \frac{Tn\,total\,waste}{0.07 Tn\,Shells} = 809 \frac{Tn\,total\,waste}{day}$$

With the planned project, all that flow would go to the initial filter that separates the water from the waste. It is considered a filter efficiency of 90% due to some very small particles that can cross the filter, so around 51 tons shells/day would pass through the conveyor 1 and the conveyor 2.

Royal Greenland Sisimiut has two working periods every day; from 7 a.m to 1 p.m, it is production time, and from 1 p.m to 7 a.m all the installation is cleaned.

The conveyor 1 will work only during the production time and during the cleaning time it will be off and all the dirty water will go directly into the sea, so only during the production time (18 h/day) the waste must pass through the first conveyor, thus its flow per hour will be:

$$51 \frac{Tn\,Shells}{day} \cdot \frac{day}{18\,working\,hours} = 2.8 \frac{Tn\,shells}{h}$$

Six years ago, the conveyor had capacity of 0.8 Tn/h, the current required one is 3.5 times bigger, and thus the speed has to be increased, keeping all the other characteristics.

The second conveyor will be used for transportation and also it will be the linkage between the production time (18 hours) and the biogas production time (24 hours). Its input will be the output of the first conveyor, 2.8 Tn/h from 7 a.m. to 1 a.m. and its output will be 2.1 Tn/h, 24 hours per day.

$$51 \frac{Tn\,Shells}{day} \cdot \frac{day}{24\,biogas\,production\,hours} = 2.1 \frac{Tn\,shells}{h}$$

Thus, 2.6 times bigger than the capacity used 6 years ago, 0.8 Tn/h. As a result, the new machinery should have the following features [Table 8:]:

	nr.	Capacity (t/h)	Energy consumption (KW)	Length (m)	Weight (Kg)	Speed (rpm)
Conveyor 1	14.01	2.8	1.1	1.23	155	1400/116
Conveyor 2	14.02	2.1	1.1	6.55	405	1400/224
Crusher	14.04	1.23 (t)	45			2955

Table 8: Old characterization of the required machinery

The crusher has a capacity of 1.2 ton, thus the feed that goes into the crusher is crushed during half an hour, until it becomes small enough. Afterwards, these crushed shells must be mixed with water in a mixer; its characterization is explained in the following section.

4.2.2 Mixer

Royal Greenland Shells has a content of volatile solid around 13%; in order to get the optimal slurry composition (5-10 %), they have to be mixed with water in an adequate proportion.
To get a fraction of 9% of VS, the next equation has been used to calculate the required volume of water.

$$m_{shells} \cdot \frac{13\,g\,VS}{100\,g\,shells} = \left(m_{shells} + m_{water}\right) \frac{9\,g\,VS}{100\,g\,totals} \rightarrow m_{water} = m_{shells} \cdot \frac{13\,g\,VS}{9\,g\,VS} - m_{shells}$$

Thus, the resulted daily numbers are:

	Quantities
Shells	51 Tn
Water	23 m^3
Slurry	**74 m^3**

Table 9: Daily inflows to the mixer

Its hourly inflows (24 hours per day) will be:

	Quantities
Shells	2,1 Tn
Water	1 m^3
Slurry	**3,1 m^3**

Table 10: Hourly inflows to the mixer

The slurry flow is too large to remain in the mixer during one day; thus the mixing time has to be reduced, reducing also the required volume of the mixer.

The mixing time considered is 1.5 hours, so the inflow waste is mixed with the water inflow during one hour and a half before leaving the mixer. It works in continue, so the outflow of the mixer will be 3 m^3/h. So, the capacity of the mixer must be around **4.5 m^3**.

Looking at different companies catalogues, the model **3301 - 5000Ltr Vrieco-Nauta Conical Powder Mixer** has been chosen. 'It consists in a conical mixer that relies on a three dimensional action produced by a turning screw which itself rotates around the wall of a conical vessel' [1.9.20]

Its aim is to mix the shells with the water and homogenize this slurry. Some advantages of using this mixer are the high mixing speed and homogeneity reached, through low power consumption, minimum heat generation and minimum product retention.

Technical features of 3301 - 5000Ltr Vrieco-Nauta Conical Powder Mixer	
Capacity	**5000 liters**
Manufacturer	**Vrieco Zelhem-Holland**
Construction	**Stainless Steel**
Voltage	**415 volts**
Frequency	**50Hz**
Control Panel Dimensions (L x W x H)	**1500 x 300 x 2000 mm^3**
Overall Dimensions (L, D)	**Approx screw dimensions (3600mm, 450mm)**
Power	**20 KW**
Price	**10,000 €.**

Table 11: Technical features of the mixer

The slurry has to go inside the digester around 30 ºC, to work at mesophilic conditions (20ºC-35ºC). The hot water obtained from the boiler is at 65 ºC (Appendix 7) so if this water goes into the mixer, the outflow temperature of the mixer will be calculated with following energy balance:

$$T_{mix} \cdot (C_{shells} + C_{water}) = C_{shells} \cdot T_{shells} + C_{water} \cdot T_{water}$$

Where

$$T_{water} = 338.15\ K$$

$$T_{shells} = 283.15\ K$$

$$C_{shells} = m_{shells} \cdot c_{p,shells[2]} = 2120\left(\frac{Kg}{h}\right) \cdot 3.014\left(\frac{KJ}{Kg \cdot h}\right) = 6389.68\left(\frac{KJ}{K \cdot h}\right)$$

$$C_{water} = m_{water} \cdot c_{p,water} = 960\left(\frac{Kg}{h}\right) \cdot 4.18\left(\frac{KJ}{Kg \cdot K}\right) = 4012.8(\frac{KJ}{h \cdot K})$$

The slurry temperature will be:

$$T_{mix} = \frac{T_{water} \cdot C_{water} + C_{shells} \cdot T_{shells}}{(C_{shells} + C_{water})} = 304.27\,K = 31.36°\,C.$$

Thus, using the water obtained in the boiler, at 65ºC, the slurry at the exit of the mixer will be at 31.36 ºC, more than 30ºC required at mesophilic conditions, so it is a good solution. But some heat losses because of the transportation, lost by conduction, convection and radiation in the isolation will produce a small decrease in temperature [9.21].

In the figure below, it can be observed a sketch of the new process before the waste arrives to the digester; it can be seen bigger in the Appendix 8.
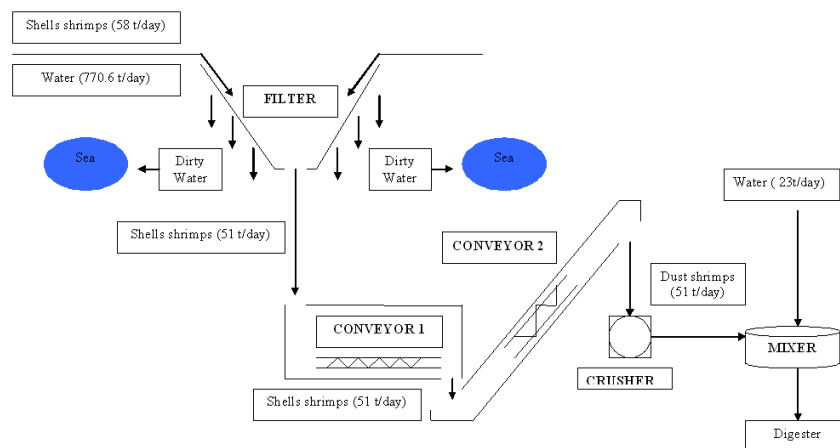
Figure 19: Sketch of the new process before the digester

Once, the shells are well mixed with the adequate volume of water, the slurry comes into the digester, its dimension is explained in the next section.

4.3. Digester

As it has been mentioned before, the fermentation process takes place in several stages; first the fermentation of the treated slurry is carried out in the digester. Secondly, the gas produced is collected and stored in a gas holder, also called secondary digester, while the fermented material is stored in a third tank, where it gets ready to fertilize the fields and absorb all the nutrients.

Figure 20: Image of a Real biogas plant [9.22]

4.3.1. Volume of fermentation chamber:
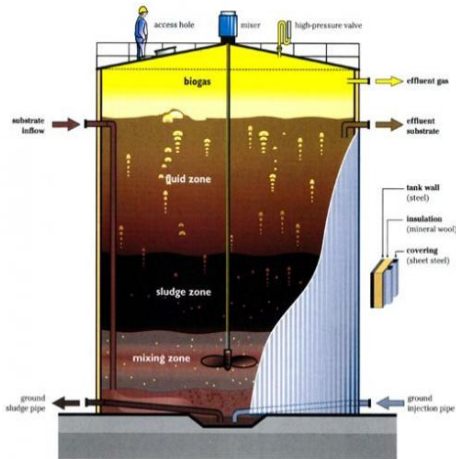
Figure 21: Anaerobic digester diagram [9.23]

From the mixer is coming slurry flow at around 3 m^3/h with a volatile solid content of 9%, and it has to remain 20 days inside the digester, so the required reactor volume is:

$$V_d = 3\frac{m^3}{h} \cdot \frac{24h}{day} \cdot 20days = 1440m^3$$

Adding an extra 20 % of the previous volume for the inoculums and 5% as a safety measure, the volume above is incremented one 25%, thus the final volume of the digester should be:

$$V_d = 1440m^3 \cdot 1.25 = 1800m^3$$

4.3.1.1. Volume of gas storage chamber:

In order to calculate the required volume for the gas storage tank, it is necessary to know the amount of gas produced by the waste by means of the potential biogas.

4.3.1.1.1. Potential biogas calculation

From the experimental work, the methane produced in the optimal conditions was 174 Nm^3/tons VS. On the opposite, the values found in the literature are quite different.

In order to calculate the theoretical biogas potential, some assumptions should be done; First, the chitin degradation is considered negligible, because of its complexity. Secondly, to make simpler and possible the calculations, all the proteins present in the waste are supposed to be $C_5H_7NO_2$, while all the fat is $CH_3(CH_2)_{10}COOH$ and their percentage inside the dry waste are 40% and 5% respectively.

With these assumptions, the theoretical potential biogas of the dry waste will be the following one:

$$ThBG = 0.40 \cdot ThBG_{protein} + 0.05 \cdot ThBG_{fat} = 246\, Nm^3 CH_4 / tons\, VS$$

Where:

Component	Theoretical potential biogas (Nm^3/tons VS) ThBG$_x$
$C_5H_7NO_2$	496
$CH_3(CH_2)_{10}COOH$	952

Table 12: Theoretical potential biogas of proteins and fat

In order to calculate the practical biogas potential from the theoretical value, the last should be multiplied by 0.85, thus the practical potential biogas should be **210 Nm³CH₄ /tons VS.**

As it has been mentioned, the literature and the experimental values are quite different from each other. Some incoherence in the experimental results makes more reliable the literature value, so from now on the project will be base on the literature value.

The gas holder should be dimensioned to store the difference between the daily gas produced and the collected one.
The daily biogas production will be 31.5 Nm³ biogas per ton of slurry, it is calculated like follows:

$$\dot{G} = 210 \frac{Nm^3 CH_4}{tons\,VS} \cdot \frac{1\,Nm^3\,biogas}{0.6\,Nm^3 CH_4} \cdot \frac{9\,tons\,Vs}{100\,tons\,slurry} = 31.5 \frac{Nm^3\,biogas}{ton\,slurry}$$

Figure 22: Real gas holder [9.24]

As a safety measure, it is dimensioned in order to keep the gas produced during 6 hours, thus the produced volume will be:

$$V_g^{6h} = 74 \frac{Tn\,slurry}{day} \cdot \frac{day}{24\,hours} \cdot \frac{31.5\,m^3\,biogas}{Tn\,slurry} \cdot 6\,hours = 580\,m^3\,biogas$$

The volume of gas stored has to be smaller than the gas holder; the ratio between their dimensions (gas holder capacity) has to be around 70%. This is done as a safety measure for possible fluctuations.

Thus, the volume of the gas holder will be: $V_{gh} = \dfrac{V_g^{6h}}{0.7} = 830\,m^3$

4.3.1.2. Volume of fertilizer storage chamber:

Every twenty days, the fertilized material is taken out from the primary digester and transported through a positive displacement pump to another tank, where the digested matter will remain some weeks to decrease its ammonium content. In order to minimize the remaining time, the tank should be an open recipient. This last repository tank of sludge often has a membrane for gas storage, to obtain the maximum extraction of biogas.
The volume of the total slurry will be smaller than the initial one, since the bacteria have degraded it. As a safety measure the volume of the storage tank is chosen as the same as the slurry of 20 days and its respective inoculums (20% more of the slurry):

$$V_d = 3\frac{m^3}{h} \cdot \frac{24h}{day} \cdot 20days \cdot 1.20 = 1728m^3$$

Above, the volume of the fermentation, gas holder and fertilizer storage chambers have been calculated. The dimensions of each can be seen in Appendix 9.

4.4. Biogas treatment design

Previously, it has been mentioned that the biogas is not used directly after the digester; it has to be treated in order to use the methane as a renewable energy.

4.4.1. Membrane

As it has been explained before, CO_2 must be removed from biogas to obtain better energetic conditions; it could be reached with a membrane.

In this case, the inlet flow of the membrane will have the following characteristics:
- Composition: 60% CH4, 40% CO2, with traces of H2S and fractions of water vapour.
- Volume: 97.65 m3/h.
- Roughly Temperature: 30 ºC.

Consulting with the company **Newpoint Gas, LP,** specialists in the design of modular gas treating and gas processing facilities [9.25], a membrane for this application is proposed.

It consists in a two-stage membrane unit operating at 27 bar. A budgetary +/- 20% cost for this system is $950,000 (600,000 €). This price includes inlet filtration and the membrane tubes and elements. It is also included the heater upstream of each stage of membranes to insure that all process streams into and out of the membrane elements remain

several degrees above the dew point at all times.

All of this equipment will come mounted on a single skid with approximate dimensions of 3.66 m x 12.2 m.

Figure 23: Membrane technology for CO₂ removal [9.25]

Approximately 350 bhp of recycle compression will also be required to increase the pressure of the 1st stage permeate stream from 15 psig to 400 psig (not included in the price). The total methane losses in the 2nd stage permeate stream will be approximately 3.5% and the membrane will meet a 2% CO_2 pipeline specification.

 A single stage membrane unit would be lower cost and not require recycle compression; however, methane losses would be approximately 30%, so this option was ruled out.

At the exit, the methane is treated to be burned and to produce steam in the boiler, and the CO_2 is liquefied to be transported.

4.4.2. Carbon dioxide treatment

To liquefy the CO_2 in order to transport it in ships, P=6 bar and T=-50ºC are the optimal conditions. P_{CO2} after the membrane is still unknown (the company Newpoint Gas, LP, is working on it), so the compressor conditions will depend on this value. CO_2 must be cooled to reach -50 ºC, so a cooler is necessary to be included in this process as well.

4.4.3. Methane treatment

Nowadays, Royal Greenland produces hot water burning oil in a boiler. In the new project, pure methane obtained from the biogas production is going to be used to replace this oil and produce energy.

Oil contains potential energy in the form of a heating value, being its net calorific value of 6 KWh/Kg oil. To burn it, oil must be compressed from 0 to 11-15 bar, using a compressor.

Figure 24: Compressor using in Royal Greenland Sisimiut before the boiler.

The function of the boiler situated in the factory is to convert water into steam, in order to use this steam for heating.
In a steam power plant these include fuel (oil in this case) and ash handling, handling of combustion air and the products of combustion, feed water and condensate and steam.
The boiler scheme is as follows:
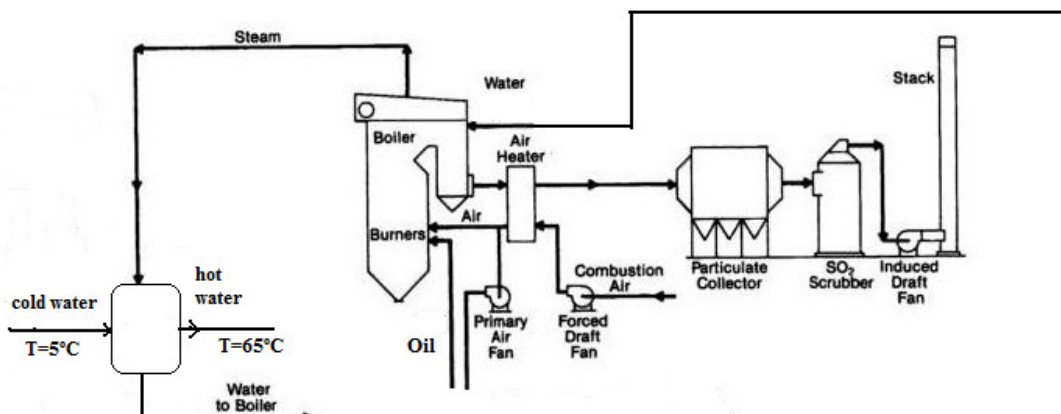
Figure 25: Sketch of the oil-fired [9.26]

The oil is directed under pressure through a nozzle to produce a fine spray. A forced-draft supplies the combustion air to the burners, and this air is preheated in an air heater to improve the efficiency of the cycle.

The oil-air mixture flows to the burners, where it is burned in the furnace portion of the boiler, being ignited by an electric spark. Afterwards, the combustion gases (flue gas) leave the boiler, and pass through environmental control equipment.

Ash and residue are also removed from the scrubber. The boiler recovers the heat from combustion and produces steam under carefully controlled conditions [9.26].

Since heat is continually added, the steam reaches the desired temperature and pressure for the particular application (in this case 160 ºC and 8.5-9 bar).

This steam produced in the boiler is used to heat water from 5ºC to 65ºC in a steam heat exchanger, for cookers, heating of buildings... The steam is condensed and the condenser water returns to the boiler through pumps. This process reaches the required conditions to its re-entry into the boiler, completing its cycle from water to steam and then to water again.

In the new project, methane is going to be used instead of oil, so some of the conditions must be changed to produce the combustion of the fuel. For example, the burner must be adapted to methane, due to the change of the fuel source, and with it, the change of air requirement, that for methane is 9.5 m^3 air/m^3 methane.

One possible solution could be replacing the oil burner with a new biogas burner, but it will need many other auxiliary units, as the biogas pipe with it safety shut-off valves, the combustion air blowers and control panels, thus it is not a simple task the conversion is not so easy.

4.5. Elements localization

In the previous sections of the design, the volumes have been calculated in order to maximize the biogas production.

This section studies possible locations of the elements inside the current plant; there are two options. The first option is to build a second floor on the present building called Ny Rejefabrik, where the entire equipment will be situated. The second one is to locate all the elements in the same level as the existing one, buying or renting some more land to the Greenlandic government.

4.5.1. Possible distribution
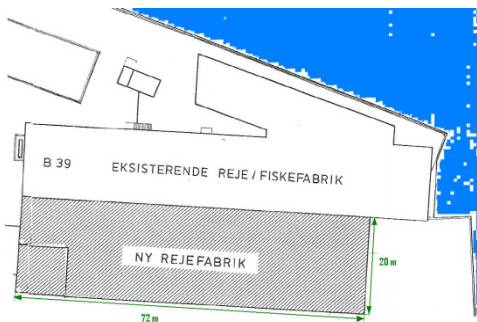
Figure 26: Possible area in Royal Greenland to install the biogas plant.

The more restringing option, talking about space, is the first one, since all the elements have to fit in a fixed space. Thus the biogas plant surface area should be smaller than the actual Ny Rejefabrik area.

As it can be observed on the left figure, the Ny Rejefabrik has an area about 72m x 20m.

The three recipients for the digestion should have diameters smaller than 15 meters in order to fit in the area with their respective covers and isolation, thus the final internals dimensions of the three tanks are:

	Primary digester	Gas holder	Fertilizer storage
Diameter (m)	13.2	10.2	13.2
Height (m)	13.2	10.2	13.2

Table 13: Internal dimensions of the three tanks in the biogas plant.

For this first option, one possible distribution could be the shown in the below figure [Figure 27].
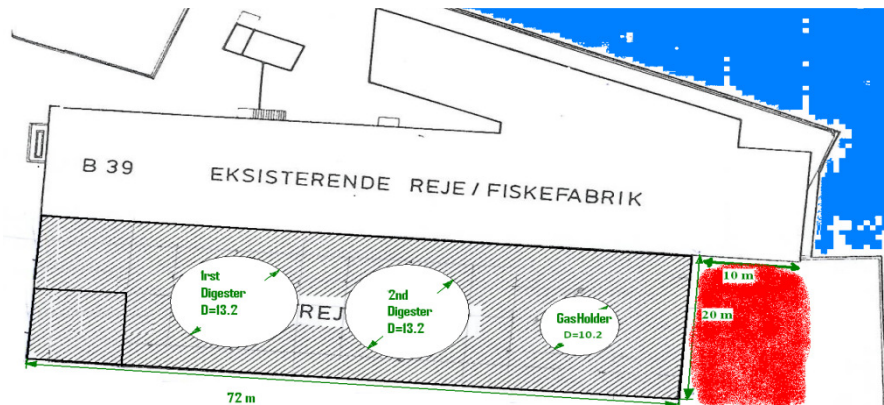
Figure 27: Possible distribution of the biogas plant, building a second floor.

The mixer is located on the left down corner in the first floor (free space in the room of the Figure 13); the mixing is transported through a positive displacement pump to the first digester located in the second floor. The fertilized material is driven to the second digester by means of a second positive displacement pump, while the gas produced in the first digester goes to the gas holder and the same pipe collects the gas formed in the second digester.

Once the entire biogas has been formed, it crosses the membrane. The methane will be separated from the other gases and afterwards treated in order to get the required boiler conditions. The membrane could be located in the 200 m^2 of free land situated next to the gas holder position, which belongs to Royal Greenland (see red part in Figure 27). Moreover, the liquation of the carbon dioxide should be located in the same area.

Regarding to the second option, Royal Greenland could buy or rent the free space surrender that belongs to the Greenlandic Government (yellow part in Figure 28) and build the biogas plant there.
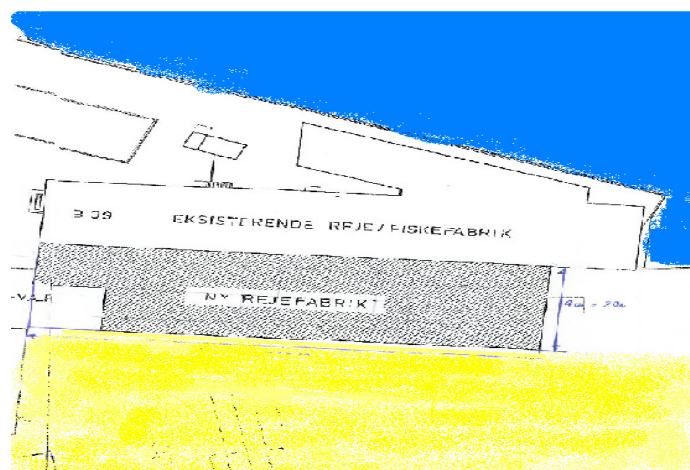
Figure 28: Possible space to build a biogas plant.

The mixer and membrane, as well as the liquation of CO_2 would be located in the same places as in the first option.

In this case, the restriction of space would not be a problem, because this area is big enough to install the biogas plant. The biggest problem of this option would be the restrictions that the government could set, both economical and legal.

4.5.2. Advantages and disadvantages

The construction of a second floor is not a simple task, the current building is not ready to support the weight of a biogas plant in its top and thus all the building must be reinforced. Furthermore, the current roof is full of exhaust pipe from the machinery located in the first floor.

The other solution is the extension of the factory surface. It will request some negotiations between Royal Greenland Sisimiut and the Greenlandic Government, since it has been mentioned previously, the Greenlandic Government is the owner of Sisimiut land.

5. Economical study

The biological and physical viability of implementing the biogas plant from the shrimps waste has been study previously. Assuming a potential biogas of 210 Nm^3 CH_4 per ton of VS, the yearly biogas production could be:

$$BG^{yearly} = 210 \frac{Nm^3 CH_4}{Tn\,VS} \cdot \frac{1 Nm^3 biogas}{0.6 Nm^3 CH_4} \cdot 0.09 \frac{Tn\,VS}{Tn\,Slurry} \cdot 74 \frac{Tn\,Slurry}{day} \cdot \frac{26\,day}{month} \cdot \frac{12\,month}{year}$$
$$= 723,341 \frac{Nm^3 biogas}{year}$$

If this value is compared with the biogas equivalent of the oil consumed to produce steam [table 2], this biogas produced can replace 19% of the oil consumed. It is known that Royal Greenland has two boilers, so the smallest one could be adapted to methane, replacing the oil burner with a natural gas burner. Thus, Royal could use this methane to produce steam.

In this way, the money saved in oil is:

$$Saved\,money \left(\frac{€}{year}\right) = 2,102,450 \frac{liters\,oil}{year} \cdot 0.19 \cdot 4.33 \frac{Kr.}{liter\,oil} \cdot 0.134 \frac{€}{Kr.} =$$
$$= 231,777.9\,€/year$$

The present section is focused on the economical viability, the most important part for the implementation of any project. In order to see if this project is profitable, the extra cost of the implantation of a biogas plant must be calculated and compared with the benefit obtained from it.

Nowadays, Royal Greenland is allowed to throw the shrimp remains into the sea, as well as all the water that they used during the production and the cleaning processes. As it has been mentioned before, six years ago the situation was not like that.

They had to treat the shrimp shells and then to sell them as shrimp dust. The cost of this treatment was really high compared to the benefits of the sale. Finally, Royal Greenland got permission for discharging its waste directly into the sea, so they save the money of the waste treatment process.

If Royal Greenland keeps this permission, the biogas plant is not profitable; the easiest and cheapest way to come off the waste is to throw it directly into the sea. But if this situation changes, Royal Greenland could have two possibilities; treat the shells of the shrimps and sell them as they did six years ago or implant a biogas plant, using the methane produced to obtain steam, replacing part of the oil consumed, and sell the fertilizer and the CO_2 produced.

As it has been mentioned before, this last option is supported by the authorities, through investment grants of the 20% and the users of biogas as energy source are exempted of the Danish state taxes, while the fossil source user are obliged to paid them [1.9.28]

To study which option is more profitable for Royal Greenland, the following roughly economical has been done:

5.1.   Waste treatment

In the treatment process explained before, the investment cost is low, due to the fact that all the required equipment is already in the Royal Greenland Sisimiut plant. Only some modifications should be done due to the increase of the flow, as well as the replacing and purchasing of some pieces. This cost could not be considered in the present study because of the lack of information.

On the contrary the energy cost of all this process is calculated and its value is shown in the following table [Table 14:]:

	Energy consumption (KW)	Cost(Kr/h)	Cost(Kr/day)	Cost (€/day)
Conveyor 1 (18h)	1.1	1,023	18,4	2,47
Conveyor 2 (24h)	1.1	1,023	24,6	3,29
Crusher	45	41,85	1004,4	134,59
Ventilator	1.1	1,023	24,5	3,29
TOTAL	44,94	1071,9	**143,64**

Table 14: Energy cost of the required equipment

The only income of this process is the sale of the shrimps dust; it has been not possible to know the price that Royal Greenland could sell it, but knowing that the daily dust production will be around 51 tons per day, its price should be bigger 2,8 €/ton in order to cover energetic cost.

5.2. Biogas plant

To implement a biogas plant, a lot of aspects have to be taken into account at the time of making the economical study. In order to calculate the cost to design and implement a biogas plant, three parts can be differentiated: the waste treatment before the digester, the digester and the biogas treatment. The information that is available at this moment is not too much, so only a rough economical analysis can be made.

5.2.1. Waste Treatment before digester

The waste treatment before the digester in a biogas plant is very similar compared to the treatment explained before, although some differences can be seen; ventilator is not used in this application, due to the fact that waste before digester must not be dry. Another difference is the use of a mixer; the waste obtained after the crusher is directly introduced in a mixer with water before the digester.

Thus, the investment cost is the same as in the waste treatment explained before (modifications and adaptation of the equipment) with the addition of the mixer, which costs 10,000 €.

The energy cost of all this process is calculated and shown in the following table [Table 15]:

	Energy consumption (KW)	Cost(Kr/h)	Cost(Kr/day)	Cost (€/day)
Conveyor 1	1.1	1,023	18,41	2,47
Conveyor 2	1.1	1,023	24,55	3,29
Crusher	45	41,85	1004,4	134,59
Mixer	20	18,6	446,4	59,82
	TOTAL	62,49	1493,76	**200,16**

Table 15: Energy const of the waste treatment before the digester

As it has been mentioned before, the waste needs to be mixed with water at 65 ºC before going to the digester, in order to obtain the inlet slurry at 30 ºC. The amount of necessary water is 960 Kg/h, so 960 Kg/h must be warmed in the boiler for this application.

The price of water is 5.27 Kr/m^3, so 5.06 Kr./h (0.678 €/h) are spent to get this amount of water. With the amount of litres of oil required in the boiler to heat 1 m^3 water, and the price of the oil (4.33 Kr./L) it would be possible to calculate the cost required to warm this water. Summarizing,

Investment cost=10,000€
Energy cost (€/h) =200.16 €/h + oil cost to warm the water + 0.678 €/h

5.2.2. Digestion

For the economical study of the digestion part, many factors should be considered, but the lack of available information made difficult their evaluation.

Firstly, it has to be considered the construction price of the three main tanks: digester, gas holder and fertilizer storage, and the connections between them, taking into account the working conditions of the plant.

Secondly, the location of tank has to be evaluated. If the digestion takes place in a new terrain, next to the building Ny Rejefabrik [Figure 28], the price will depend on the deal with the Greenlandic government, sole owner of the Greenlandic land. Hopefully, it will be low, because it will be a way to incentive the use of renewable energy.

On the other side, if the digestion process is located in a new floor, built on the current Ny Rejefabrik building, the economical expense will be higher. Since, the current building it is not ready to support the weight of the three tanks, so it should be reinforced or rebuilt. Moreover, all the material transportation from the first to the second floor should be also considered.

5.2.3. Biogas treatment design

After the digester, the biogas produced, as well as the digestrate must be treated.

For the biogas, the CO_2 must be removed using a membrane that costs \$950,000 (600,000 €), so it is the investment cost. The operating cost in a membrane is low, the only major operating cost is membrane replacement, and membranes have a long useful life, so this cost is not taken into account in this evaluation.

After that, the CO_2 must be liquefied, and the cost of this process (compressor, cooler) depends on the outlet flow pressures and temperatures at the exit of the membrane.

The methane must be introduced in the boiler to produce steam, and for this, a natural gas burner, as well as some modifications explained before (see Biogas plant design) must be taken into account to calculate the total cost.

5.2.4. Biofertilizer

In order to give an economical value of the biofertilizer formed, its characteristics and properties have to be studied; it is known that this kind of fertilizer usually has high prices in the market, but

in Greenland, where the agriculture is not an important economic sector, it is not sure that it could be profitable. A detailed study must be done to analyze if all of the obtained biofertilizer can be used or it has to be commercialized outside Greenland.

6. Discussion

The project presented in the current report has many parts which could be improved with a longer time of study.

Regarding to the experimental analysis, carried out in the environmental engineering laboratory of DTU, the results obtained were not the expected ones. This experimental part was supposed to show the biogas potential of the shrimp sample (mL methane/g VS), equal for all the concentrations of VS, but the reality was different. Some differences in the biogas potential could be observed between the different concentrations, being the most significant discrepancy at 3.5 % of VS. It was due to the fact that the experimental rank worked was too wide, and at 3.5% the NH_4-N produces the inhibition of the digestion, decreasing the amount of methane produced.

On the other hand, looking at the literature, the optimal concentration of volatile solid in a digester is between 5 and 10 % of VS, apparently contradictory to the experimental data. So, it can be concluded that the optimal conditions change from laboratory data to large scale.

Moreover, the shrimp waste should be analyzed in order to figure out its composition (proteins, lipids, calcium carbonate). With this data it would be possible to improve the calculation of the theoretical biogas potential, thus in its calculation many assumptions were taken.

In the second part of the project, some collaboration with external companies and experts were missed. Some of them considered Greenland out of its work borders and they did not supply with the required information, dimensioning or/and budget. Other companies are working on it; this is the case of Bentec Bioenergies S.L. or Newpoint Gas, LP. This lack of information about operation conditions and prices of the equipment required made impossible the realization of a complete and deep economical study.

Furthermore, there are also many missing information about the Royal Greenland which could be really useful in the economical study (for example, the price that the Royal Greenland in Ilulissat is selling the shrimp dust).

7. Conclusion

The aim of this project was to study the possibility of obtaining biogas from the shrimps waste produced in Royal Greenland Sisimiut. It would suppose the replacement of fuel sources of energy, like oil, with renewal energies, like biogas in this case, becoming the industry more environmentally sustainable. This use of the waste also involved the treatment of material that now is being thrown into the sea causing variations in marine environmental. All these facts made this project really interesting.

The study was focused on Royal Greenland, who plays the main and sole role in the Greenlandic fishery industry. This company produces a huge amount of waste; the average of waste per day is around 57 Tons shells/day, and this shells, with 12.9 % VS, have a biogas potential of $210 \frac{\text{Nm}^3\text{CH}_4}{\text{Tn VS}}$. Slurry of 9% VS is the optimal concentration for the digestion, and operating at these conditions, $723,340 \frac{\text{Nm}^3\text{biogas}}{\text{year}}$ can be produced if a biogas plant is installed.

Studying the amount of energy (electricity and oil) that the company consumes every year and the biogas required to replace all this external energy used, it can be seen that the biogas produced is not enough to make the company energetically self-sufficient. It could only cover 10% of the total energy required. In this project it was decided to use this biogas to replace around 20% of the consumed oil, being 231,778 €/year the money that will be saved.

The implantation of a biogas plant is biological and physical viable, but to analyze if it is profitable for the company, the economical study presented in this project should be completed and improved. For it, it is necessary the collaboration of external companies, and more detailed information about the Royal Greenland (Sisimiut and Ilulissat plants). If the total cost of the implementation is lower than the annual benefits, the future biogas plant will be profitable for Royal Greenland Sisimiut.

8. Acknowledgements

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Appendix of the project:

Biogas Production from the waste of the shrimp manufacture in Sisimiut

Contents

APPENDIX 1: <u>WATER/ ENERGY CONSUMPTIONS</u>

Water consumption

Month	oct.	nov.	dec.	jan.	feb.	mar.	apr.	may.	jun.	jul.	Aug.	Sep.	Total	cost (Kr./m^3)	total cost(euros)
2006-2007: consumption (m^3)	75915	108270	62117	57070	79505	97370	88130	104667	88547	105054	97837	93529	1058011	5.27	747,146.208
2007-2008: consumption (m^3)	107151	105084	65313	93528	73653	74885	100504	110799	121740	122398	93636	100991	1169682	5.27	826,006.0348

Electricity consumption

Month	oct.	nov.	dec.	jan.	feb.	mar.	apr.	may.	jun.	jul.	Aug.	Sep.	Total	cost (Kr./KWh)	total cost(euros)
2006-2007: consumption (KWh)	329935	419955	234740	294437	276843	149322	67159	333381	423448	377318	413292	390500	3710330	0.93	462,381.3246
2007-2008: consumption (KWh)	385590	365160	256481	359705	283460	321138	362703	388221	399496	449161	366872	411221	4349208	0.93	541,998.301

Oil consumption

Month	oct.	nov.	dec.	jan.	feb.	mar.	apr.	may.	jun.	jul.	Aug.	Sep.	Total	cost (Kr./litres)	total cost(euros)
2006-2007: consumption (liter)	144533	179802	122209	125484	123528	167711	147855	183939	142928	150566	159529	151438	1799522	4.33	1,044,118.655
2007-2008: consumption (liter)	225035	217786	140007	159254	158080	143923	183641	175562	206484	170391	145298	176989	2102450	4.33	1,219,883.539

Electricity monthly consumption 2008

Oil monthly consumption 2008
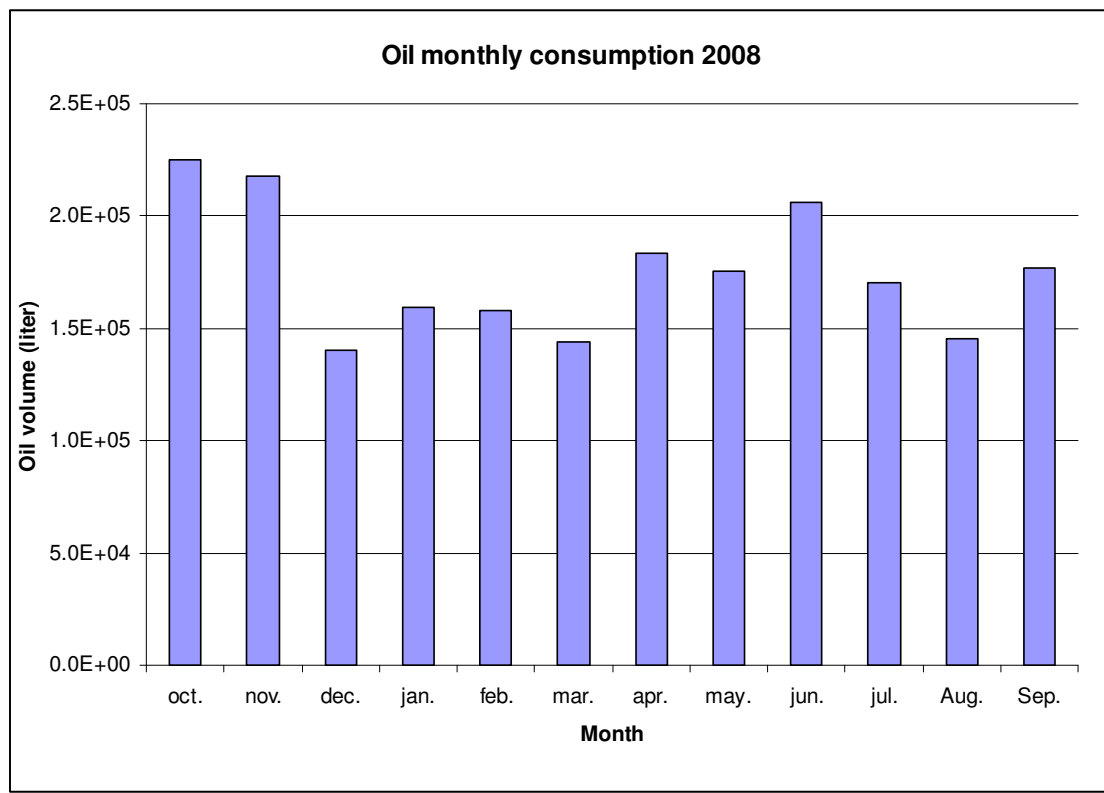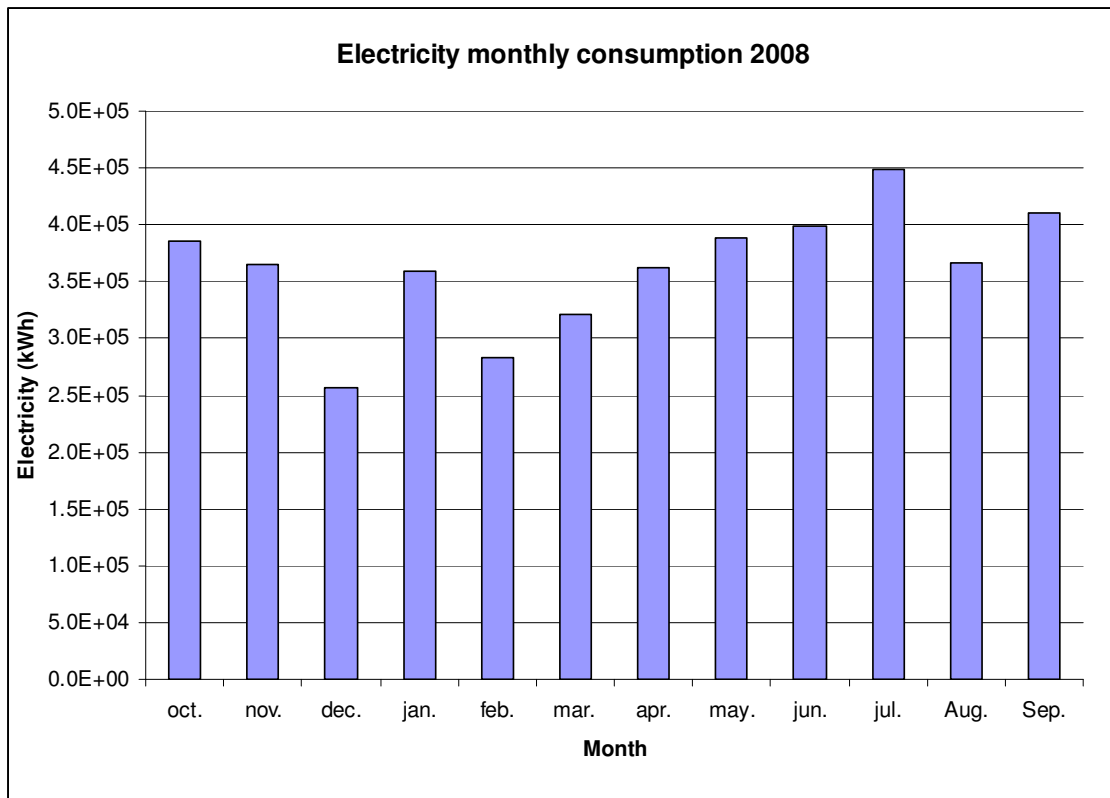
APPENDIX 2: <u>WASTE COMPOSITION</u>

Nowadays, the waste that Royal Greenland throws to the sea consists in shells and heads of shrimps with water. The matter that is interesting for producing biogas is only the shrimps waste. So, it is necessary to know the proportion of the water contained in the waste, to take it out and to calculate the amount of biogas that can be produced only with the shrimps waste.

For this, three samples of waste were collected during the production period, in the last point of the process, before going to the sea. The samples were weighed at the beginning and once the water was released.

The results are as follows in this table:

Measures:				
Weight (g)	Sample 1	Sample 2	Sample 3	Total
Bottle	120,7	127,4	122,2	370,3
Bottle with waste (shelling+water)	982,5	988	893,3	2863,8
Bottle with shelling	159	178,8	207,7	545,5
Amount of waste	861,8	860,6	771,1	2493,5
Amount of water	823,5	809,2	685,6	2318,3
Amount of shelling	38,3	51,4	85,5	175,2
Percentage shelling (Wt.)	4,444187	5,972577	11,08806	**7,026268298**
Percentage water (Wt.)	95,55581	94,02742	88,91194	**92,9737317**

APPENDIX 3: <u>BIOGAS COMPOSITION CALCULATION</u>

$$C_aH_bO_cN_dS_e + \left(a - \frac{b}{4} - \frac{c}{2} + \frac{3d}{4} + \frac{e}{2}\right) \cdot H_2O \Rightarrow$$

$$\left(\frac{a}{2} - \frac{b}{8} + \frac{c}{4} + \frac{3d}{b} + \frac{e}{4}\right) \cdot CO_2 + \left(\frac{a}{2} + \frac{b}{8} - \frac{c}{4} - \frac{3d}{8} - \frac{e}{4}\right) \cdot CH_4 + c \cdot NH_3 + d \cdot H_2S$$
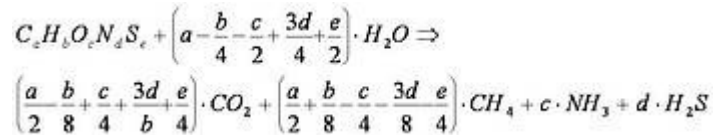
Substrate	Classification	a	b	c	d	e	Moles per mol of substrate					
							Substrate	H_2O	CO_2	CH_4	NH_3	H_2S
$C_5H_7NO_2$	Protein without S	5	7	2	1	0	1	3	2,55357143	2,5	2	0
$HO_2CCH(NH_2)CH_2SH$	Protein with S	3	7	2	1	1	1	1,5	1,80357143	1,25	2	1
$CH_3(CH_2)_{10}COOH$	Fat	12	24	2	0	0	1	5	3,5	8,5	2	0
40% protein(without S) + 5%fat		2,6	4	0,9	0,4	0	1	1,45	1,325	1,425	0,9	0
40% protein(with S) + 5%fat		1,8	4	0,9	0,4	0,4	1	0,85	1,025	0,925	0,9	0,4

Substrate	Classification	Percentage inflow		Percentage outflow			
		Substrate	H_2O	CO_2	CH_4	NH_3	H_2S
$C_5H_7NO_2$	Protein without S	25,0	75,0	36,2	35,4	28,4	0,0
$HO_2CCH(NH_2)CH_2SH$	Protein with S	40,0	60,0	29,8	20,6	33,0	16,5
$CH_3(CH_2)_{10}COOH$	Fat	16,7	83,3	25,0	60,7	14,3	0,0
40% protein(without S) + 5%fat		40,8	59,2	36,3	39,0	24,7	0,0
40% protein(with S) + 5%fat		54,1	45,9	31,5	28,5	27,7	12,3

APPENDIX 4: <u>EXPERIMENTAL MIXTURE</u>

Amount of each product introduced in each bottle

	Bottle	Inoculums	Substrate	water	active volume	total	Headspace
	nr.	gr	gr.	gr.	gr	ml	mL
blank	13	70	0	30,1	100,1	321	220,9
blank	14	69,9	0	30	99,9	321	221,1
blank	15	69,9	0	30,1	100	321	221
control 1g/L	10	70,1	0,13	29,9	100,13	321	220,87
control 1g/L	11	69,9	0,15	29,8	99,85	321	221,15
control 1g/L	12	69,9	0,1	30	100	321	221
5 g VS/L	1	69,22	4,05	26,4	99,67	321	221,33
5 g VS/L	2	69,97	4	26	99,97	321	221,03
5 g VS/L	3	70,08	4,07	26,1	100,25	321	220,75
10 g VS/L	4	70,03	7,8	22,4	100,23	321	220,77
10 g VS/L	5	70,08	7,72	22,5	100,3	321	220,7
10 g VS/L	6	69,97	7,77	22,4	100,14	321	220,86
20 g VS/L	7	70	15,47	14,8	100,27	321	220,73
20 g VS/L	8	70,25	15,53	14,5	100,28	321	220,72
20 g VS/L	9	69,9	15,55	14,7	100,15	321	220,85
35 g VS/L	16	70,01	27,13	2,9	100,04	321	220,96
35 g VS/L	17	70	27,12	2,8	99,92	321	221,08
35 g VS/L	18	70,02	27,25	2,8	100,07	321	220,93

APPENDIX 5: <u>METHANE MEASURED</u>

- Percentaje of methane produced by each sample over the experimental time.

		time	time	time	time	time	time	time	time	time	time	time
	measurement	30/04/2009	04/05/2009	06/05/2009	07/05/2009	13/05/2009	15/05/2009	18/05/2009	20/05/2009	22/05/2009	29/05/2009	12/06/2009
		Days	Days	Days	Days	Days	Days	Days	Days	Days	Days	Days
	Bottle	1,24	5,00	7,02	8,13	14,10	16,10	19,15	21,19	23,19	30,13	44,47
	nr.	CH4%	CH4%	CH4%	CH4%	CH4%	CH4%	CH4%	CH4%	CH4%	CH4%	CH4%
blank	13	0,71	2,14	2,78	2,75	4,75	6,13	6,34	6,73	7,28	7,69	11,03
blank	14	0,87	2,29	2,94	3,72	4,71	6,04	7,35	7,73	7,22	8,51	12,76
blank	15	0,78	2,33	2,57	3,35	4,78	5,97	6,52	6,67	8,05	7,88	11,96
control 1g/L	10	0,86	7,74	7,38	10,10	14,20	14,24	15,22	15,67	15,50	18,90	20,66
control 1g/L	11	0,93	5,81	8,87	10,36	12,00	16,78	16,64	15,08	17,35	18,63	24,01
control 1g/L	12	1,00	6,37	9,21	8,63	11,05	14,33	14,75	13,87	14,81	15,19	20,93
5 g VS/L	1	2,16	7,85	8,70	10,95	16,07	18,00	18,68	19,93	22,05	24,79	41,34
5 g VS/L	2	2,10	7,08	7,89	11,20	15,56	19,75	19,99	20,96	21,89	25,30	36,89
5 g VS/L	3	1,98	7,12	8,40	10,29	13,31	17,30	20,21	20,28	22,54	26,73	40,71
10 g VS/L	4	2,98	11,39	12,24	16,04	23,04	29,21	36,91	38,34	43,68	57,14	112,41
10 g VS/L	5	3,42	9,31	13,64	15,94	22,27	28,32	33,10	39,19	42,88	55,06	105,77
10 g VS/L	6	2,91	8,93	12,67	15,10	22,44	29,25	33,46	37,81	44,57	54,26	101,80
20 g VS/L	7	3,30	11,74	16,02	19,84	30,12	37,76	46,63	49,89	55,66	73,73	118,77
20 g VS/L	8	3,57	14,33	17,96	22,00	39,69	40,92	48,92	61,45	64,96	82,55	118,62
20 g VS/L	9	4,20	14,59	17,29	21,95	31,62	40,97	53,90	55,66	62,94	82,18	122,71
35 g VS/L	16	5,94	19,35	25,32	27,24	35,79	37,91	41,76	43,40	46,38	49,26	55,85
35 g VS/L	17	5,54	19,96	26,39	30,68	36,15	47,24	50,28	63,02	55,00	54,81	61,60
35 g VS/L	18	5,95	22,92	27,18	33,33	37,88	39,60	41,61	41,08	44,76	50,83	62,75

- Volume of methane produced by each sample over the experimental time

	Bottle nr.	time 30/04/2009 Days 1,24 CH4 mL	time 04/05/2009 Days 5,00 CH4 mL	time 06/05/2009 Days 7,02 CH4 mL	time 07/05/2009 Days 8,13 CH4 mL	time 13/05/2009 Days 14,10 CH4 mL	time 15/05/2009 Days 16,10 CH4 mL	time 18/05/2009 Days 19,15 CH4 mL	time 20/05/2009 Days 21,19 CH4 mL	time 22/05/2009 Days 23,19 CH4 mL	time 29/05/2009 Days 30,13 CH4 mL	time 12/06/2009 Days 44,47 CH4 mL
blank	13	1,57	4,73	6,15	6,08	10,50	13,55	14,00	14,87	16,08	16,99	24,37
blank	14	1,92	5,06	6,50	8,22	10,41	13,35	16,24	17,08	15,95	18,82	28,21
blank	15	1,73	5,15	5,68	7,40	10,57	13,19	14,41	14,74	17,78	17,42	26,43
control 1g/L	10	1,91	17,10	16,32	22,31	31,38	31,47	33,63	34,64	34,25	41,77	45,66
control 1g/L	11	2,06	12,86	19,62	22,93	26,56	37,13	36,83	33,38	38,40	41,22	53,13
control 1g/L	12	2,21	14,09	20,37	19,08	24,44	31,68	32,62	30,67	32,75	33,59	46,28
5 g VS/L	1	4,77	17,38	19,26	24,23	35,58	39,84	41,34	44,10	48,80	54,86	91,50
5 g VS/L	2	4,64	15,65	17,43	24,75	34,40	43,66	44,19	46,32	48,37	55,91	81,54
5 g VS/L	3	4,37	15,73	18,55	22,71	29,39	38,20	44,61	44,76	49,75	59,00	89,86
10g VS/L	4	6,58	25,15	27,03	35,41	50,87	64,48	81,49	84,64	96,44	126,14	248,16
10g VS/L	5	7,54	20,56	30,10	35,17	49,16	62,51	73,06	86,49	94,63	121,53	233,44
10g VS/L	6	6,44	19,72	27,99	33,35	49,55	64,61	73,91	83,50	98,44	119,84	224,83
20 g VS/L	7	7,29	25,91	35,36	43,79	66,49	83,35	102,92	110,12	122,85	162,75	262,16
20 g VS/L	8	7,88	31,62	39,65	48,55	87,61	90,33	107,98	135,64	143,38	182,21	261,82
20 g VS/L	9	9,27	32,21	38,17	48,47	69,84	90,47	119,04	122,94	138,99	181,50	271,01
35 g VS/L	16	13,13	42,75	55,94	60,19	79,08	83,78	92,27	95,89	102,49	108,85	123,41
35 g VS/L	17	12,25	44,12	58,35	67,84	79,92	104,44	111,15	139,32	121,59	121,17	136,18
35 g VS/L	18	13,15	50,64	60,05	73,64	83,69	87,49	91,92	90,77	98,90	112,29	138,63

- Average values and standard desviation

a) Test solutions' content:

Start time	29/04/	2009	12:30:00			
	total	Inocolum	Substrate	water	active vl	Headspace
	ml	gr	gr.	gr.	gr	mL
blank average	321	69,93	0,00	30,07	100,00	221,00
blank SD	321	0,08	0,00	0,19	0,10	0,05
control 1g/L average	321	69,97	0,13	29,90	99,87	221,13
control 1g/L SD	321	0,17	19,87	0,33	0,15	0,07
5 g VS/L average	321	69,76	4,04	26,17	99,96	221,04
5 g VS/L SD	321	0,67	0,89	0,80	0,29	0,13
10g VS/L average	321	70,03	7,76	22,43	100,22	220,78
10g VS/L SD	321	0,08	0,52	0,26	0,08	0,04
20g VS/L average	321	70,05	15,52	14,67	100,23	220,77
20g VS/L SD	321	0,26	0,27	1,04	0,07	0,03
35g VS/L average	321	70,01	27,17	2,83	100,01	220,99
35g VS/L SD	321	0,01	0,27	2,04	0,08	0,04

b) Volume of methane produced (mL).

	30/04/2009	04/05/2009	06/05/2009	07/05/2009	13/05/2009	15/05/2009	18/05/2009	20/05/2009	22/05/2009	29/05/2009	12/06/2009
	Days	Days	Days	Days	Days	Days	Days	Days	Days	Days	Days
Days	1,24	5,00	7,02	8,13	14,10	16,10	19,15	21,19	23,19	30,13	44,47
	CH4 mL	CH4 mL	CH4 mL	CH4 mL	CH4 mL	CH4 mL	CH4 mL	CH4 mL	CH4 mL	CH4 mL	CH4 mL
blank average	1,74	4,98	6,11	7,24	10,50	13,36	14,88	15,57	16,61	17,74	26,34
blank SD	10,08	4,46	6,73	14,92	0,74	1,34	8,02	8,45	6,14	5,41	7,29
control 1g/L average	2,06	14,68	18,77	21,44	27,46	33,43	34,36	32,89	35,13	38,86	48,36
control 1g/L SD	7,48	14,83	11,48	9,63	12,96	9,60	6,39	6,16	8,32	11,77	8,57
5 g VS/L average	4,59	16,25	18,41	23,90	33,12	40,57	43,38	45,06	48,97	56,59	87,63
5 g VS/L SD	4,53	6,03	5,00	4,43	9,92	6,90	4,11	2,53	1,44	3,80	6,10
10g VS/L average	6,85	21,81	28,37	34,65	49,86	63,87	76,15	84,88	96,50	122,50	235,48
10g VS/L SD	8,75	13,40	5,53	3,25	1,80	1,84	6,10	1,78	1,98	2,66	5,01
20g VS/L average	8,15	29,91	37,73	46,94	74,65	88,05	109,98	122,90	135,07	175,49	265,00
20g VS/L SD	12,50	11,63	5,78	5,80	15,20	4,63	7,50	10,38	8,00	6,29	1,97
35g VS/L average	12,84	45,84	58,11	67,22	80,90	91,90	98,45	108,66	107,66	114,11	132,74
35g VS/L SD	4,01	9,19	3,55	10,04	3,03	11,98	11,18	24,55	11,33	5,57	6,16

Graph 1: Volume of methane produced (mL) vs. time
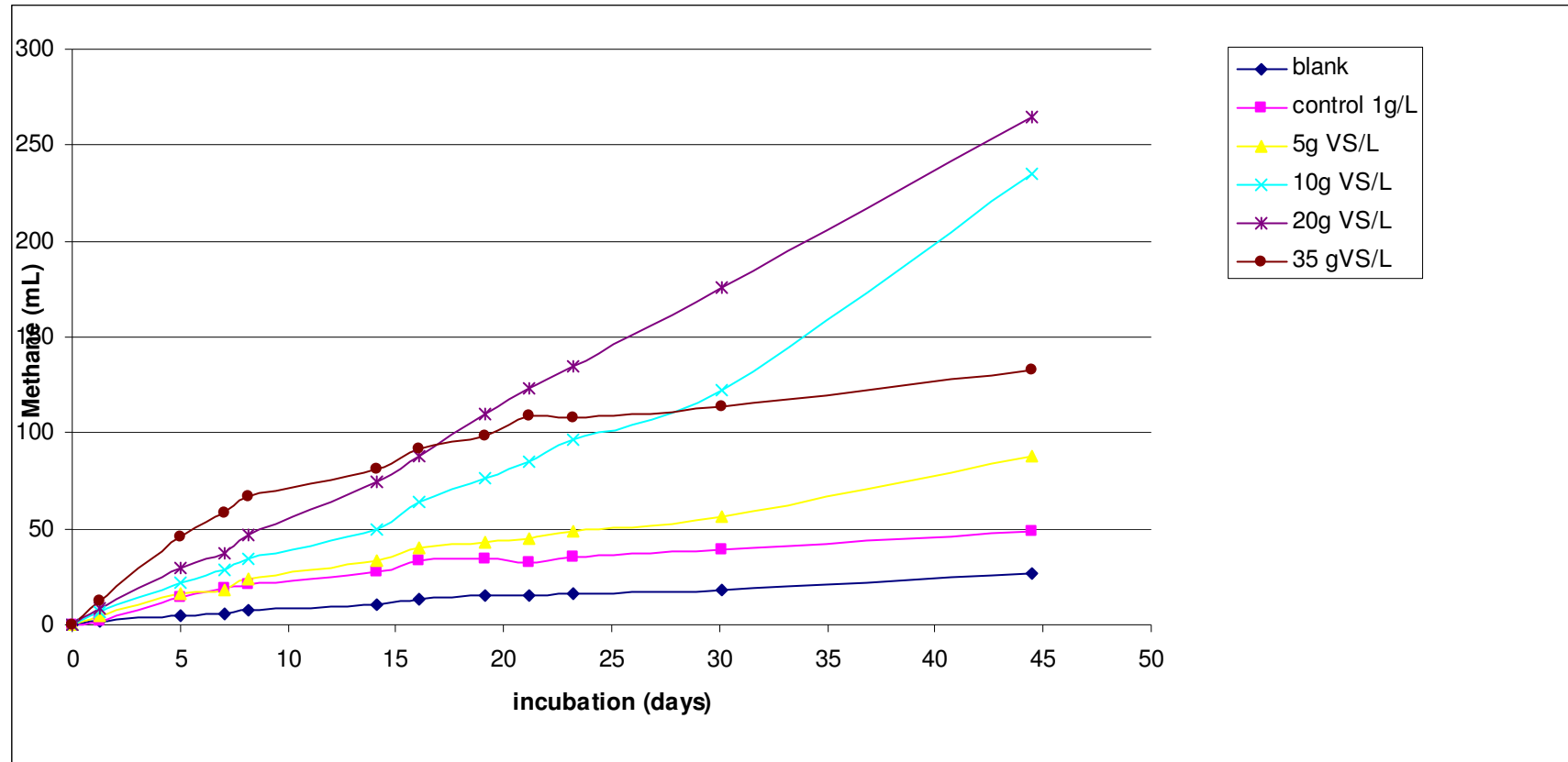
- Volume of CH4 produced per 1gVS.

	time	time	time	time	time	time	time	time	time	time	time
	30/04/2009	04/05/2009	06/05/2009	07/05/2009	13/05/2009	15/05/2009	18/05/2009	20/05/2009	22/05/2009	29/05/2009	12/06/2009
	Days	Days	Days	Days	Days	Days	Days	Days	Days	Days	Days
	1,24	5,00	7,02	8,13	14,10	16,10	19,15	21,19	23,19	30,13	44.47
	CH4 mL/g VS	CH4 mL/g VS	CH4 mL/g VS	CH4 mL/g VS	CH4 mL/g VS	CH4 mL/g VS	CH4 mL/g VS	CH4 mL/g VS	CH4 mL/g VS	CH4 mL	CH4 mL
control	2,44	74,63	97,37	109,28	130,51	154,36	149,82	133,29	142,52	166,71	173,84
5 g VS/L	5,47	21,63	23,60	31,97	43,42	52,20	54,68	56,59	62,10	74,54	117,61
10g VS/L	5,10	16,80	22,23	27,37	39,31	50,43	61,18	69,21	79,78	104,61	208,83
20g VS/L	3,20	12,46	15,79	19,84	32,05	37,31	47,51	53,62	59,19	78,81	119,23
35g VS/L	3,17	11,66	14,84	17,12	20,09	22,41	23,85	26,56	25,98	27,50	30,36

APPENDIX 6: <u>ROYAL GREENLAND SISIMUT PLANT DISTRIBUTION</u>
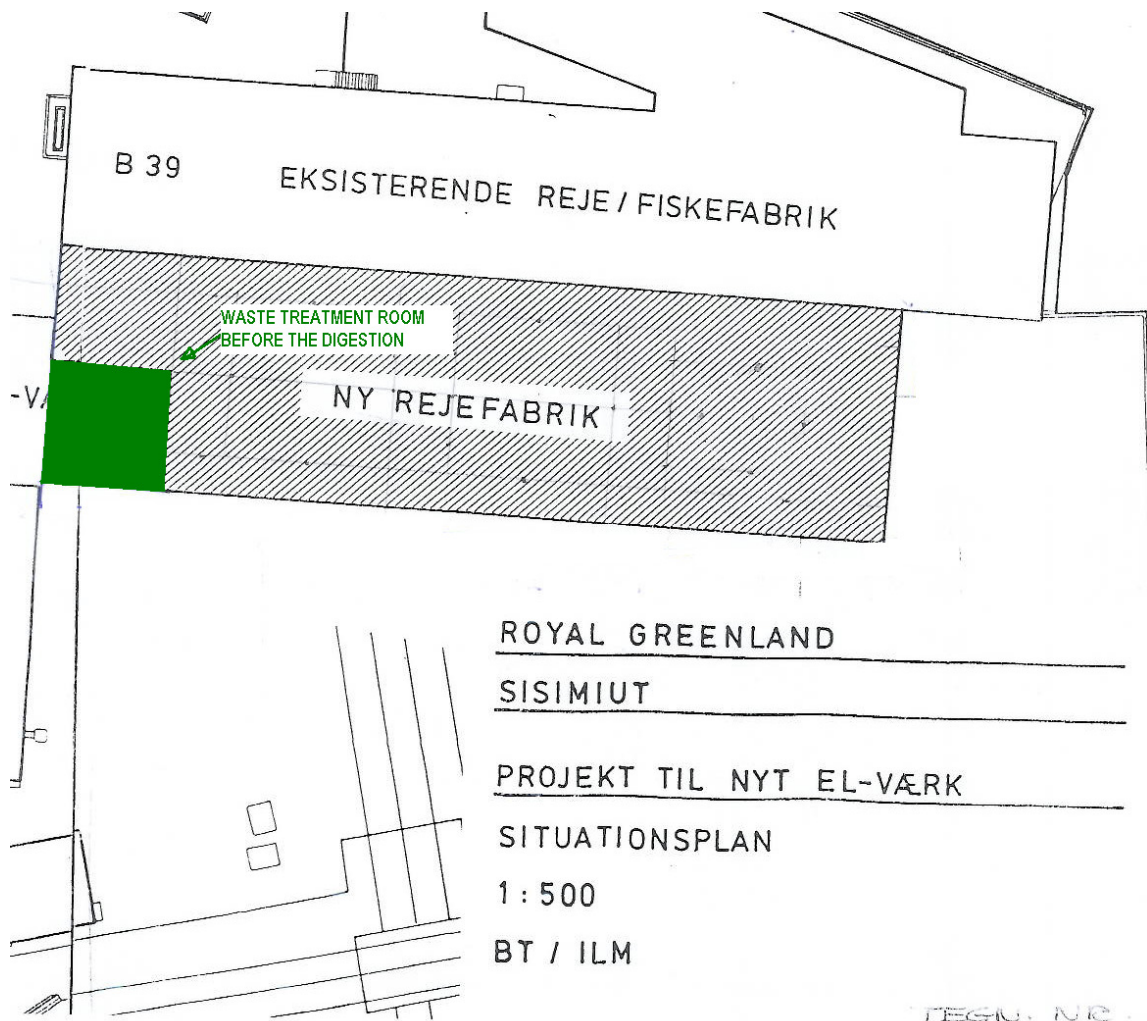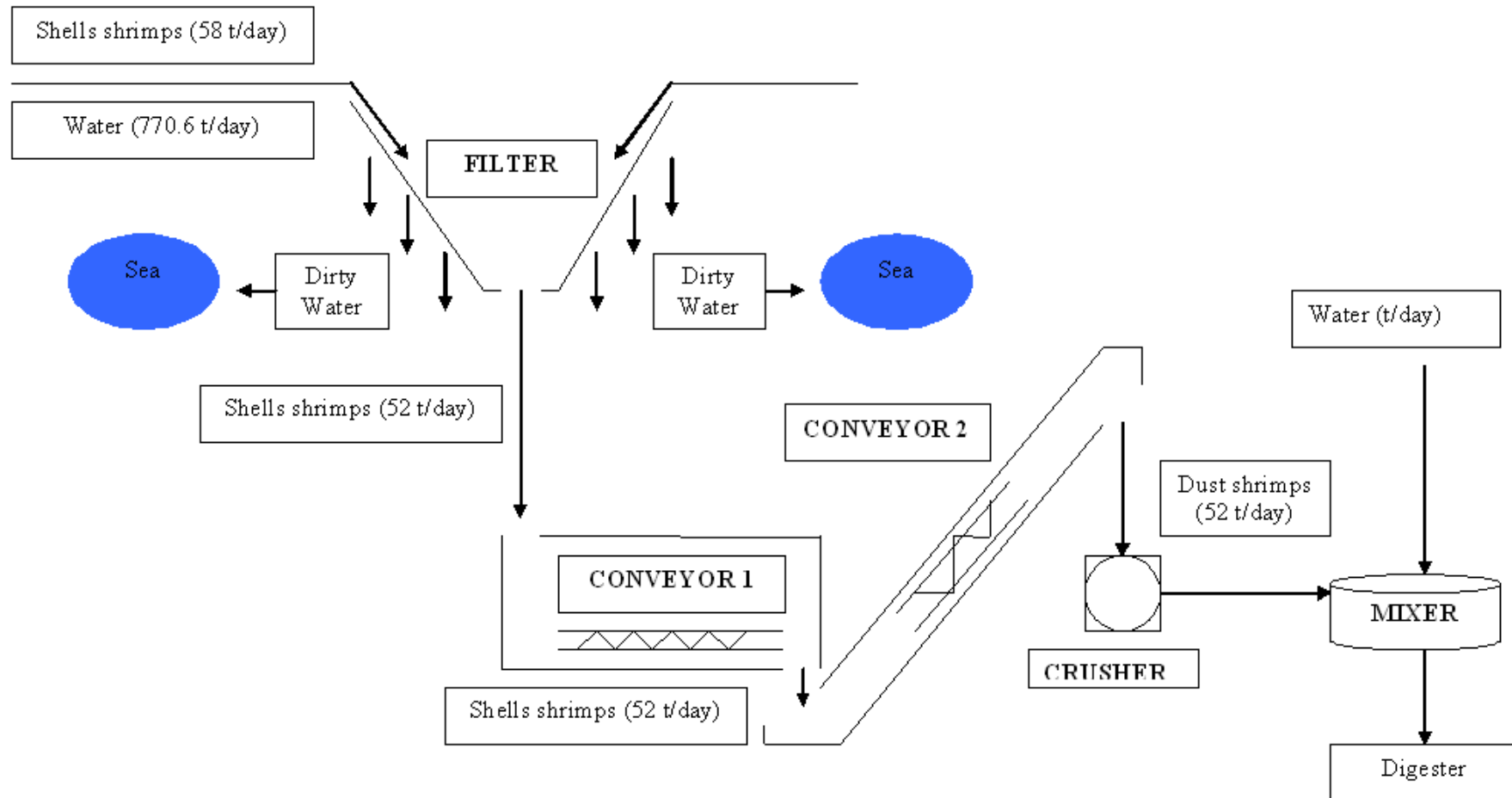
APPENDIX 7: <u>WATER HEATING PROCESS</u>
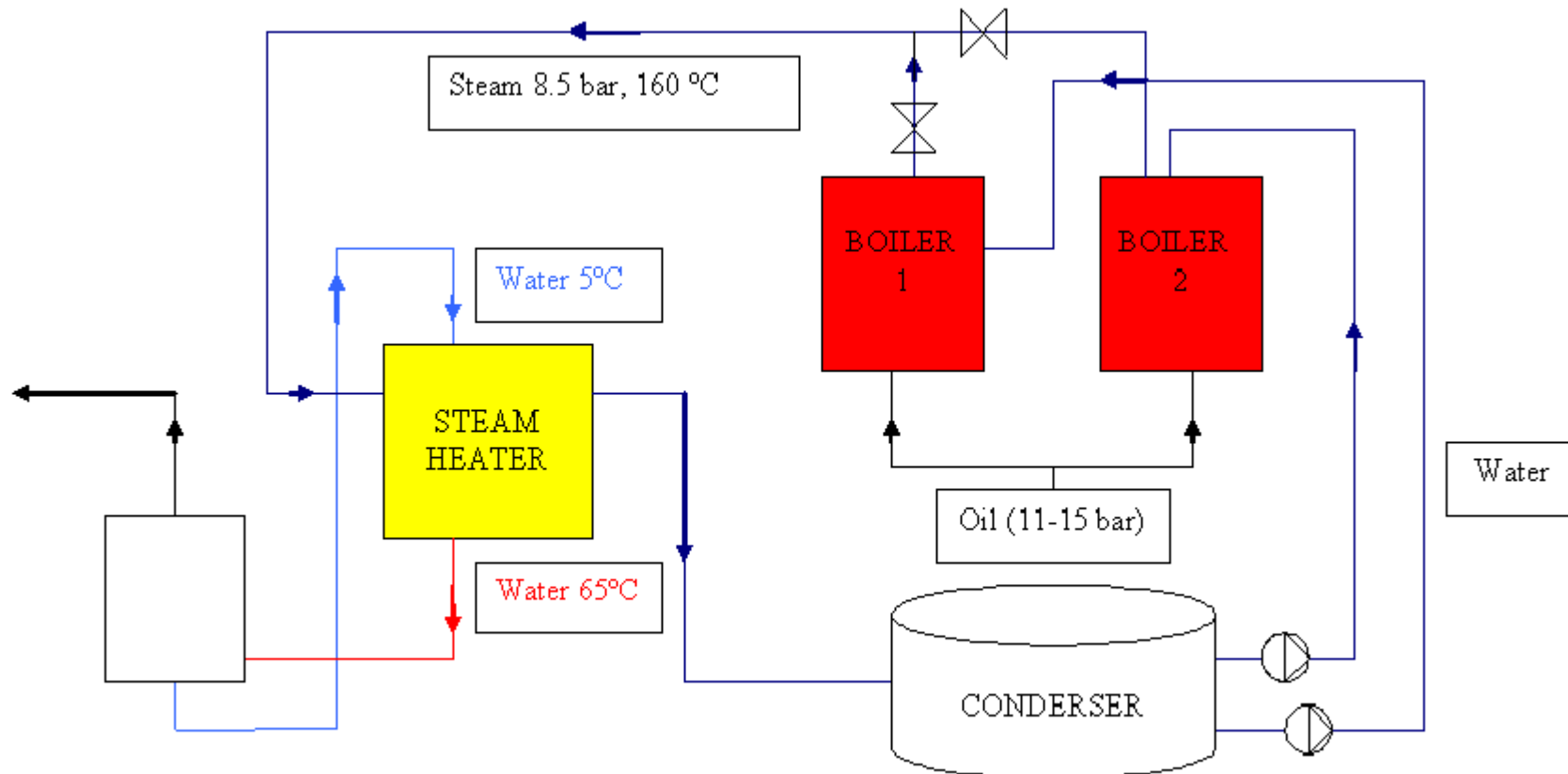
APPENDIX 8: <u>BIOGAS PLANT DESIGN - Waste treatment before the digester</u>

APPENDIX 9: <u>SCALING THE BIOGAS PLANT</u>

April 1008

Raw material	2118	Tn		
Final meat	646	Tn		
Waste (shells)	1472	Tn	56,61538	Tn/day

Filter efficiency	0,9			
Waste collected	50,95	Tn/day	2,830769	Tn/hour (18h)
vs%	13		2,123077	Tn/hour (24h)

SLURRY	**5-10%VS**			
%VS	9			
water added	22,65	Tn/day	0,94359	Tn/h
Total slurry	**73,6**	**Tn/day**	3,066667	**Tn/h**

DIGESTOR   Vd=SdxRT

Sd (slurry)	73,6	m3/day	3,066667	m3/h (24h)
RT	20	day	[mesophilic bacteria]	
Vd	**1472**	**m3**		
Vd + safety	1800			
H=xD	1			
D	13,19			
H	13,19			

GASHOLDER

Potential biogas	31,5	m3 BG/Tn slurry
Gas produced	2318,4	m3/day
	96,6	m3/h (24h)
Gas produced in 6 h	579,6	m3
Gas holder volum	828	m3
H=xD	1,00	
D	10,18	m3
H	10,18	m3