Research planning – assignment 3

The Biogas Optimization Project

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There is a lot of research going on in Sweden and around the world on ways to improve and optimize the biogas process and the different plants already in operation.

The production of biogas has many advantages against other biomass based processes for production of energy or fuel. Biogas can be produced from any type of biomass whether it is a pure substrate or if it is a mix of materials like source-sorted municipal organic solid waste. The biogas process can handle substrate with different water content, from wet materials like Sewage sludge to dry material as straw. There are not many conversation processes that can handle this type of variation in the substrate.

The BioGasOpt-project is a three year project with the aim to collect date and information about the biogas process, with the Växtkraft biogas plant in Västerås as a case study, to use as a basis for improving the process. Different types of technologies are tested and evaluated for its use at a biogas plant and the effect that it has on the gas yield, capacity and economy of the plant.
Background

There is a large potential for production of biogas from different kinds of organic residues as well as from different crops, farm land residues or graze. These residues are available today and is in many cases seen as a problem instead of what they really are, a resource. In Sweden alone the potential for biogas production is about 17 TWh per year, an amount of biogas that could cover 20% of the fuel demand of all private cars in Sweden [1]. However, the technology for biogas production is still developing and not yet optimized and thus not fully cost-effective. To be fully commercially competitive with other types of fuels, efficiency improvements of the process is needed.

The Växtkraft biogas plant was put into operation in 2005 for treating and producing gas from source-sorted municipal organic solid waste from the nearby cities, fat removal sludge from restaurants and lay crop silage from local farmers. As the demand for biogas increases in the Mälardalen region the plant needs to increase the gas production to meet that demand. This can be done in two ways. The first thing that can be done is to maximize the output from the present digester by increasing the capacity of the plant to get more substrate in to the process and increasing the speed of fermentation. The second option is to construct a new digester and pretreatment step as well as taking in new substrates.

There is clearly a gap of information about how an optimization of Växtkraft and other biogas plants could be performed. The biogas industry as well as the academic institutions is all focused on finding solutions to step by step increase the productivity of the process.

Partners and funding

The project is conducted in cooperation between Mälardalen University and the companies Svensk Växtkraft AB, which is the local biogas plant in Västerås, and Mercatus Engineering AB which is a company working with membrane filtration and water treatment. The Knowledge Foundation is funding this project for a three year period.

The BioGasOpt-project

The Biogasopt-projects goal is to improve the biogas process by focusing on some key issues in the process, namely pretreatment of the incoming substrate, mixing inside the digester and membrane filtration of the process water. The Process can be split up into three different parts which can be improved and optimized independently of each other but still leads to an overall efficiency increase of the process. A simple illustration of these process steps can be seen in figure 1.
Figure 1. A simplified illustration of the biogas plants different steps

Pretreatment – The pretreatment can be made up of many steps depending on the substrate. Pretreatment includes steps to remove pollutants like plastic, metal and sand from the incoming substrate as well as producing a mixture that can be fed to the digester with pumps. Pretreatment can also include different technologies to break up the structure of the material to increase the yield and/or speed of fermentation of the substrate. In this project we have studied the effect of electroporation (EP) on lay crop silage to enhance the gas output of the substrate, this could give more value to the substrate in the existing biogas plant. Other pretreatments will also be tested during the project.

Digestion – The digester is the heart of the process and by controlling the environmental conditions for the microorganisms inside their activity can be increased, which in turn leads to a higher biogas output from the plant. The operator has a number of tools to control the environmental conditions at his disposal including the temperature, mixing, retention time of the substrate as well as the type and amount of substrate fed to the digester. Mixing inside the digester is very important because it is the only way to reach each part of the digester with these control measures. In this project we have started to build up knowledge about the mixing inside a digester by modeling the flows.

Sludge treatment – Taking care of the sludge can be done in many ways depending on the plant and the substrate. The sludge can be used as a fertilizer if it complies with the laws and regulations or disposed of by covering a landfill area or in some other way. The sludge is often dewatered to decrease the need of transporting too much water or in the case of Växtkraft to reuse the water in the process. In this project we have studied the use of an ultra filtration (UF) membrane as an application in the biogas process to decrease the solid material in the process water and by doing so solve a capacity problem with too much recirculating material.

Methods
The goal of the project was to find ways to optimize the production of biogas. This work has been done in three separate steps as presented in the project section.

Membrane filtration
The first step was to clean the process water at the Växtkraft biogas plant to improve the capacity of the pretreatment. The process water is produced from the digestate, the liquid inside the digester, by running it through a centrifuge. The slurry that is produced in the
pretreatment and used as feed for the digester is produced from the process water and the incoming substrate. The problem is that the dry solid content in the process water is steadily increasing which has the effect that we can add less and less new substrate to the process while still producing a pumpable slurry. This can be solved by using an ultra filtration membrane to remove the unwanted particles in the water. A filtration unit built by Mercatus was used to evaluate the technologies potential for cleaning the process water and calculations were made looking at the economy and energy balance on this kind of installation.

The experimental set up consists of a 70 dm3 inlet tank for filtration of process water. The temperature of the process water being filtered is heated with a 6 kW oil heater. During operation of the UF the process water is pumped through a circulation loop that pushed the liquid through the membrane unit. The water becomes more concentrated with organic material in each pass as the liquid escapes through the membrane, producing a permeate. The permeate can then be recirculated back to the inlet tank or withdrawn to an outlet tank for analysis. The permeate withdrawn to the outlet tank flows through a cooler to avoid steam formation and thus loss of water from the system. The experimental set up includes thermometers and pressure meters for monitoring and control of the process. The energy consumption of the pump can be read from an electricity meter. It is also possible to measure the permeate flow with a built in flow meter which can measure flows up to 230 l/h. At the end of every batch experiment the inlet tank holds the concentrated liquid and the outlet tank holds the permeate liquid. The membrane element used in the experiment is produced by Atech Innovations Gmbh and is of the type 37/3.8 – 1200, meaning that it has 37 channels each with an internal diameter of 3.8 mm and a length of 1200 mm. This membrane has an area of 0.53 m2 and a cut-off of 50 nm and like most membrane filters it is set up, for crossflow filtration with the feed flowing parallel to the membrane to avoid clogging.

**Mixing**

The second step of the project was to analyze the mixing inside a digester. The digester is basically a black box and there is usually not a lot of sensors to control the environment for the microorganisms, so there are possibility for improvements by understanding the effect of mixing and stirring inside the digester. Even though mixing is said to be an important factor for the biogas production there is not a lot of work being done in this area. By building up a computational fluid dynamic (CFD) model of a digester the mixing has been studied and evaluated. Important factors when looking at the mixing is the velocity and turbulence fields in the digester. The data that has been compiled and will in the next step be used for improving the mixing and connecting it to the activity of the microorganisms and effect on the biogas production.

A geometry was created to resemble the biogas plant Växtkraft to see the effects that changes in the biogas recirculation system would have on the mixing of the digester. The geometry of the digester is assumed to be axisymmetric with a height of 19.5 m and a radius of 8.5 m. The gas injection is also simplified to allow a high quality mesh. As part of the liquid recirculation system a liquid outlet is placed on the bottom next to the centerline axis and the liquid is then reintroduced with an inlet trough the digester side wall close to the bottom. The Volume-Of-Fluid model is used in this study. It is valid for two or more immiscible fluids (or phases) that are separated by fluid/fluid interfaces. The method is based on a single set of momentum equations and turbulence while tracking the volume fraction of each phase in the mixture.
Electroporation

There are possibilities to improve the production rate and yield of biogas from the biogas process by using different pretreatment methods on the substrate. So in the third step of this project we have been looking at the Electroporation technology, producing pores in the cells by exposing the substrate to electrical fields. During the treatment the cells are damaged and releases nutrients that can lead to an increase in the gas production rate. The lab scale equipment used was constructed by KEA-TEC GmbH in Germany and can be used with a maximum field strength of 40 kV/cm and 10 Hz.

The experiment was made using different reaction containers and different settings of the EP equipment. During the experiment, the reaction container, electric current, the distance between the electrodes and the number of pulses were changed to find the setting with the best effect in terms of biogas production from the treated material. The result of the pre-treatment was evaluated by setting up a biochemical methane potential (BMP) experiment. During this experiment, each sample from the EP treatment and the untreated control samples were digested batch-wise in separate bottles of 100 ml at 30°C without any mixing. By measuring the pressure increase in the bottle during the digestion, the amount of biogas and the rate at which it is produced can be calculated.

Current research issues and hot topics

Publications of articles in the biogas field have increased almost exponentially under the last years and there are many popular subjects.

One of the hottest topics in biogas research today is the use of different types of pretreatment to improve the biogas yield. There is a wide range of different technologies researched around the world including thermal [2], ultrasonic [3], chemical [4] and mechanical treatments [5]. They all show potential to decrease the fermentation time of the different substrates on the expense of added chemicals or energy. There is also a trend to combine different pretreatments to increase the yield even further.

There is a lot of research on different type of waste, agricultural residues and other types of substrates that potentially could be used to produce biogas and also how to use them in an optimal way. Depending on the area where the research is done there are different types of potential substrates that are studied. Co-digestion of two or more substrates together is also a possible way to improve the gas yield from the process as well as it is useful if there is a limited supply on one single substrate. Waste is of course especially interesting in Sweden since we cannot deposit organic waste on landfills anymore according to the regulations and there is an increasing demand for methane as a vehicle fuel.

Two stage fermentation is also a popular research area. By dividing the fermentation process into two steps we can further optimize the environment for the microorganisms and speed up the process. [6]

Questions around the sustainability of the biogas process are widely discussed in the scientific community.
Central literature
Literature that has been important for my work is listed below:


O. Wallberg, A.-S. Jönsson, R. Wimmerstedt, Ultrafiltration of kraft black liquor with a ceramic membrane (2003). This article is about the separation of lignin with an ultrafiltration membrane at different temperatures under 100°C and studying the effect of different control parameters on the results. [7]

O. Wallberg, A.-S. Jönsson, Separation of lignin in kraft cooking liquor from a continuous digester by ultrafiltration at temperatures above 100°C (2006). This article is about the separation of lignin with an ultrafiltration membrane at different temperatures over 100°C and studying the effect of different control parameters on the results. [8]

Karim, K., Varma, R., Vesvikar, M., and Al-Dahhan, M.: Flow pattern visualization of a simulated digester (2004). This article is about understanding and visualizing the mixing inside a digester using computer automated radioactive particle tracking (CARPT) and computed tomography (CT). [9]

Karim, K., Thoma, G. J., and Al-Dahhan, M. H.: Gas-lift digester configuration effects on mixing effectiveness (2007). This article is about the mixing inside a digester and identifying the poorly mixed zone. [10]

Carlsson M, Lagerkvist A, Rapport SGC 190 - Elektroporation för forcerad metanutvinning från förnyelsebara resurser (2008). In this article they are studying the effects of electroporation on suger beets, food waste and sludge from a waste water treatment plant. They are using the same setup as in my own research. [11]

Uldal M, Andreas L, Lagerkvist A, Rapport SGC 205 – Optimerad gasproduktion med elektroporation (2009). In this article they are studying the effects of electroporation on food waste using different setting of the equipment. They are using the same setup as in my own research. [12]
Conferences and Journals

Conferences

It is hard to pick out the most important conferences for research in biogas technology because it is spread between many different areas like water treatment, waste treatment, environmental technologies and conferences around green and renewable energy. Some good examples are listed below.

World Congress on Anaerobic Digestion

The aim of the conference is to focus on the advances, frontiers and applications of anaerobic digestion for a more sustainable planet. The theme of the conference is “Anaerobic Digestion: Water and Energy for the World”. Relevant issues are addressed to promote experience exchange and international cooperation.

International symposium on energy from biomass and waste

The aim of the Symposium is to explore the advances made in the application of technologies for energy recovery from biomass and waste. Technologies in this area are currently undergoing rapid development. The goal of the symposium is to encourage discussion in these fields.

International conference on applied energy

The aim of the conference is explore the advances made in the application and technologies for energy production.

Journals

Journal publications are valued higher then conference papers in the energy field and some of the journals in this field can be seen below.

BIORESOURCE TECHNOLOGY

Bioresource Technology publishes articles on the fundamentals, applications and management of bioresource technology. The journal includes topics as Biofuels, Bioprocesses and bioproducts, Biomass and feedstocks utilization, Environmental protection and Thermochemical conversion of biomass.

WATER SCIENCE AND TECHNOLOGY

Water Science and Technology is an international journal publishing original research papers on water pollutants, quality and treatments. It also includes biological processes like biogas production which has always been strongly related to water treatment.

WATER RESEARCH

Water Research publishes refereed, original research papers on all aspects of the science and technology of water quality and its management worldwide.
BIOMASS & BIOENERGY

Biomass and Bioenergy is an international journal publishing original research papers and short communications, review articles and case studies on biological resources, chemical and biological processes, and biomass products for new renewable sources of energy, food and materials.

ENERGY CONVERSION AND MANAGEMENT

Energy Conversion and Management has a wide focus in the energy field and its scope also includes biomass conversion.

Research groups

Technical University of Denmark

At the Technical University of Denmark the biogas process has been studied for many years at the department of Environment and resources and the department of biotechnology among others. They have performed a lot of studies looking at different configurations of the biogas process, co-digestion and different ways to control the process.

Lund University

Lund University has strong research around the system perspective of biogas production looking from the life cycle perspective. They are also doing some experimental work including pre-treatment experiments.

Swedish university of agricultural science

SLU has a lot of research about the microorganisms in the biogas process as well as a focus on the agricultural systems with different types of crops for biogas and fertilization effects from the residues from the process.

Wageningen University in the Netherlands

The Wageningen University is focusing on the digesters operation looking at different ways to optimize it. Sulphate reduction has been one focus of their work.

Ghent University in Belgium

Ghent University has a wide range of research in the biogas field spanning the entire field.

A lot of interesting research related to the biogas field is made in Sweden and the Nordic countries but there are also other groups that cannot be found through the same channels. Reserch done in Germany for example may only be available in German.
The BioGasOpt-project

Hypothesis

Here are my three main hypotheses around my current work.

“There is a potential to increase the production of biogas from silage by pretreating it before digestion”

“The lack of mixing inside a digester leads to dead zones with lower production of biogas”

“The capacity of a biogas plant can be increased by improving the water treatment of the recirculated process water”

Research questions

Membrane filtration
  • Can an ultra filtration membrane be used to clean the process water?
  • What effect does the temperature have on the filtration process?
  • Can the separation of dry solids lead to a capacity increase?
  • Is it economically feasible to install this kind of water treatment at a biogas plant?
  • What is the biogas potential from the different liquids both going in and out of membrane filter?

Mixing inside a digester
  • What does the mixing pattern inside a digester with gas lift mixing look like?
  • Do we have any unmixed zones in the digester?
  • How does the mixing effect the retention time of the material?
  • How can the mixing be improved?
  • What effect does the mixing have on the production of biogas?

Pretreatment
  • What types of pretreatment can be used to increase the gas production from lay crop silage?
  • What effect does electroporation have on the gas yield from lay crop?
  • Is it economically feasible to use this type of technology at a biogas plant?
  • What effect does mechanical treatment have on the gas yield from lay crop?

Future questions to be answered
  • What does the mass balance of the Växtkraft biogas plant look like?
Expected results

Some answers to these questions have already been discovered during my previous work. The membrane filtration unit can be used to clean the process water and a higher temperature leads to a much shorter filtration process. A temperature around 100-110°C works well but when the temperature is increased to 120°C more dry solids slips through the membrane. Decreasing the dry solids in the liquid from 4 % to 1.6 % according to the experimental results means that we can introduce 30 % more biowaste to the process. This type of installation is expensive and the result of the economic calculations is inconclusive. The results from the BMP experiments of the process water, concentrate and permeate are being analyzed and are expected to show how much biogas we are losing if we separate the organic solids from the process water to be used as a fertilizer. The setup can be seen in figure 2.

Figure 2. The membrane filtration unit at the Växtkraft biogas plant.

The first simulation of the mixing inside the digester has already been completed and it is showing the velocity and turbulence inside the digester. The velocity contours and the bubbles movement has been simulated and can be seen in figure 3. In the data from the simulation the low flow areas of the digester can be seen. In future work more simulations will be made to determine how the mixing can be improved and experiments will be performed to see the effect that different intensities of mixing has on the microorganisms and the biogas production.
Figure 3. The velocity contours of one section of the digester (left). The up flow is generated in the center of the digester by the rising bubbles (right). The up flow is in the center of the digester and by rotating these pictures 360° with the axis on the right side of the picture an entire view of the cylindrical tank can be seen.

The data from the electroporation experiments show an increased gas production of over 100 % during 36 days of fermentation. The experiments are done in lab scale and up scaling the experiment might be difficult. Mechanical treatment has been tested on the lay crop silage as well and the result will show how effective this kind of treatment really is.

Figure 4. The electroporation equipment used during the experiments.
Research activities

Ongoing work

Bio methane potential experiments around mechanical treatment of the lay crop silage have been started. Measurements and samples of the produced gas are taken at a regular basis.

New experiments will soon be started by a thesis worker with the aim to discover the effect of mixing on the biogas yield.

Preparations are being made to film inside the digester to get visual information on the mixing on the surface.

Future work

To understand the process as a whole and how to improve it, a material and energy balance will be made to find where the bottle necks are and where energy could be saved.

The operator has a number of different indicators on how well the process is going including volatile fatty acids, dry solids, ph, ammonium levels and alkalinity. But there is also a lot of automated data stored from the process that can be used to further enhance the operation of the plant. The data will be analyzed to see how they can be used for the process control.

Articles and publications

The membrane filtration article is being revised.
I am writing on my licentiate thesis.

Future publications

Journal article around the mixing inside the digester and the electroporation experiments.

Time plan and milestones

Here are the fixed dates of the project at this time. No further detailed planning has been made after the licentiate because this is one of the major milestones of my work.

Time plan 2010

May – Filming inside the digester and revision of the membrane filtration article

June – Completion of the Bio Methane potential experiments of the mechanically treated lay crop silage. Writing articles from the Bio methane potential experiments.

August – Simulating the digester in a 3D model and writing an article from the results. Write about the results from the thesis worker.
September – Write on the licentiate thesis. Keep working with the simulation results.

October and November – Work on the licentiate thesis and the preparations for the defense. Work on the mass balance of the Växtkraft biogas plant.

December – Licentiate defense

Milestones

December 2010 - **Licentiate defense** – After the licentiate defense the research will be evaluated and the work will be focused on one part of the process.

April 2013 - **Dissertation**

References


