SAVONIA

Implementation and Process of Biogas Plant in Food Industry

Kamil Wysocki

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SAVONIA UNIVERSITY OF APPLIED SCIENCES THESIS Abstract

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Author(s) Kamil Wysocki			
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Supervisor(s) Ritva Käyhkö, Ari Mikkonen			
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Abstract

This thesis focuses on the production of biogas obtained from the food industry. The main idea of the work was to present anaerobic digestion process for food industry and having co-operation with the factory of frozen French fries, Farm Frites Poland SA, where the existing Wastewater Treatment Plant was developed by implementation of biogas plant.

Thesis introduces the proper management of food wastes and losses, and their utilization. This installation and technology brings a lot of benefits such as: recovery of electricity and heat by the CHP units, lower operating costs and, of course, reducing greenhouse gases emissions.

In chapter 2 the main concepts of the thesis and their explanation are presented. The next section contains information about biogas; what it is, its potential as well as its advantages and disadvantages. Chapter 4 presents different branches of the food industry where the anaerobic stage may be successfully implemented and their legal framework. In chapter 5 the focus is on the production of biogas during the anaerobic process; its feedstock, process biology and technology and also possibilities of use. The last chapter is a presentation of a real, implemented biogas plant in Farm Frites Poland SA, which has improved the process of wastewater treatment and allowed recovery of electricity and heat for the need of factory. Presented are laboratory analysis and comparison of post-production wastewater with finally purified effluent.

Keywords

biogas, anaerobic digestion, food industry, wastewater treatment, cogeneration

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Appendix 1 The block diagram of technological flow of WWTP

LIST OF ABBREVIATIONS

AD	Anaerobic Digestion
CHP	Combined Heat and Power
COD	Chemical Oxygen Demand
DAF	Dissolved Air Flotation
DM	Dry Matter
FFP	Farm Frites Poland SA
ODM	Organic Dry Matter
pH	Scale of acidity or alkalinity of water soluble substances
SBR	Sequencing Batch Reactor
TSS	Total suspended solids
VFA	Volatile fatty acids
WWTP	Wastewater Treatment Plant

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FOREWORD

This thesis is final work for my Bachelor's Degree completed at Savonia University of Applied Sciences. It confirms the ability to use the skills obtained while engineering education in the programme of Industrial Management.

I would like to thank to my supervisors, Ritva Käyhkö and Ari Mikkonen, and all those involved in achieving the final project. Without their advice and help, achieving the goal would have been impossible.

My great thankfulness I addressed to Farm Frites Poland S.A. for possibility of co-operation and complementing my thesis with real application, and following persons from department of Wastewater Treatment Plant, for their support and shared knowledge which was priceless experience, which I really appreciate:

Jarosław Milewczyk, Head of WWTP
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Wiesław Bońkowski, Mechanic
Monika Kubiak, Lab technician

1 INTRODUCTION

Every day we rely on energy to provide us with electricity, hot water, and fuel for our cars. Most of this energy comes from fossil fuels, such as coal, oil, and natural gas. These are non-renewable (conventional) energy sources, which means that if we use them all up, we can never get more during our lifetime. Fossil fuels also contribute greatly to global climate change by releasing carbon dioxide into the air when they are burned.

Because fossil fuels can run out and are bad for the environment, it is important that we start switching to other energy sources, like renewable (alternative) energy sources. These are energy sources that are constantly being replenished, such as sunlight, wind, and water. This means that we can use them as much as we want, and we do not have to worry about them running out. Additionally, renewable energy sources are usually much more environmentally friendly than fossil fuels. Overall, they release very few chemicals, like carbon dioxide, that can harm the environment.

Topic of my thesis was discovered from my personal interest in renewable energies but also, it was influenced by my working background. As a teenager, I started my experience on Wastewater Treatment Plant in potato processing factory, Farm Frites Poland SA. Summer and weekend jobs there, got me closer to the modern technology, where I have found my personal interest. After graduation from technical high school I became employed there as an Operator of Waste Water Treatment Plant (WWTP). With my decision to study abroad, I left the department in a time where biogas plant was implemented but not fully operated.

With my thesis I wish to get closer overview in production of biogas from food industry, its wastes and losses. To support theoretical background, the practical use and importance of this renewable source is considered with real application of biogas plant placed in, above mentioned, Farm Frites Poland SA. The result of my work will show the waste management, efficiency of the process, its benefits and different possibilities of utilization.

2 BASIC CONCEPTS

2.1 Implementation

Implementation inherently represents a change in a company's existing technological process, architecture. In other words is the carrying out, execution, or practice of a plan, a method, or any design, idea, model, standard or policy for doing something.

2.2 Food industry

Food industry can cover all aspects of food production and later all sales and distribution channel. Major importance, according to thesis, is directed to digestible organic wastes from food industries and its accompanying preparation and processing.

2.3 Industrial biogas plant

It is a plant where biogas is produced from food wastes collected during their production, processing or distribution and use by consumers. The main purpose of industrial biogas plant is to effectively use wastes and losses through cogeneration.

2.4 Cogeneration

Cogeneration, it is simply energy saving and recovery. It is the production of heat and electricity in the most efficient manner, in one technological process so-called combination. Higher degree of fuel utilization, limited emissions of greenhouse gases are terms most recognized with this technology.

2.5 Wastewater treatment

It is a process of conversion of wastewater into clear effluent, which can be turned back to water cycle with minimum impact on the environment. WWTP's are commonly used in processing industries for treating the post-production sewage. Implementation of anaerobic digestion system into wastewater treatment is and definitely will be, a great opportunity for biogas recovery and all benefits associated with this.

3 BIOGAS

3.1 What is it?

Biogas, a combustible gas, is a product of the microbial decomposition of organic matter (such as: wastewater, waste from agro-food industry, biomass) in a moist environment that excludes air. This process is also named anaerobic digestion (AD). In nature, this biological decay takes place on the bottom of lakes, in swamps, or also in ruminants' stomachs.

The energy content of biogas from AD is chemically committed in methane. The composition and properties of biogas vary to some degree depending on feedstock types, digestion systems, temperature etc. Table 1 shows some average biogas composition values, available in the most of the literature.

Table 1 Chemical mixture content of biogas

Compound	Chemical symbol	Content (%)
Methane	CH_4	50-75
Carbon dioxide	CO_2	25-45
Water vapour	H_2O	2-7
Oxygen	O_2	< 2
Nitrogen	N_2	< 2
Ammonia	NH_3	< 1
Hydrogen	H_2	< 1
Hydrogen sulphide	H_2S	< 1

Biogas is increasingly being recognized as the most "effective" renewable energy substrate, resistant to the impact of financial crisis, well stimulating the development of the food industries and significantly affects the climate protection. Energy from biomass has the advantage over the other that its production is in a wide range characterized by CO_2 neutral, and that it can be produced under strict control and according to demand.

3.2 Biogas potential

"Biogas plays an important role in creating a sustainable society and reducing dependence on oil. By producing biogas, waste is converted to energy reducing the refuse mountain and securing energy supplies without impact on the environment. Sewage slurry, waste food, manure, abattoir refuse and by-products from forestry can be converted to biogas by various techniques, such as decomposition or gasification. After processing, this climate-friendly gas can be used in vehicles and for the production of electricity or heat within industry. It also creates an eco-friendly and usable by-product - bio manure - used in farming. […]. A fact sheet from the World Bioenergy Association estimates the global substrate potential for biogas production to 10,000 TWh. There are no exact figures for total biogas production in the world, but the same report estimates production at between 300 and 400 TWh, so just a fraction of the potential." (Rasmussen & Mathiasson, 2015) The greatest increases in production of biogas are expected in India, China, United Kingdom, Italy, Poland, France, Czech Republic and also in USA.

3.3 Pros and cons

Presented as green energy source, biogas production and biogas itself as a product, has great potential and plenty of advantages. One might even say that it is devoid of disadvantages. But nothing is perfect, so attention is on both, pros and cons, and this shows which of them "speaks" more strongly.

Table 2 Pros and cons of biogas

Advantages	Disadvantages
• It is renewable and clean • Reduced greenhouse gas emissions • Reduced migration of global warming • Lowered dependency on fossil fuels • Reduction of wastes • Creation of work placements • Used in different and efficient way • Operated on many various feed-stocks • Reduced odours	• Expensive investments in technology • Continuous flow of feedstock • Constant control and surveillance for right digestion process • Complicate legal framework • Risk of explosion (flammable methane)

Advantages	Disadvantages
• Allowed more economical water management • Reduced pollution of environment e.g. groundwater, rivers • Used as fertiliser	

From side of environment and society biogas is very valuable source and it is worth of attention. Even negative aspects can be turned into positive. When considering investments and risks of explosion, the right construction, handling and performance of the biogas plant, it can decrease expenses and starts to be, not immediately, economically profitable.

3.4 Food industry and biogas

Every year, approximately 4.4 billion tonnes of food are produced globally. About 1.3 billion tons of food from above number is never consumed at all, it is waste or loss. Food loss and waste can appear at each stage of the food supply chain. Although, those two terms are pretty close, in wider point of view they have individual meaning. “Loss” relates to food that is not edible yet and is typically present during production, storage, processing and distribution. “Waste”, on the other hand, is the food which is of good quality for human consumption but is not consumed because it is thrown away. According to Dalberg’s analysis, about 320 million metric tons of food is lost or waste, which can be seen on the figure below.

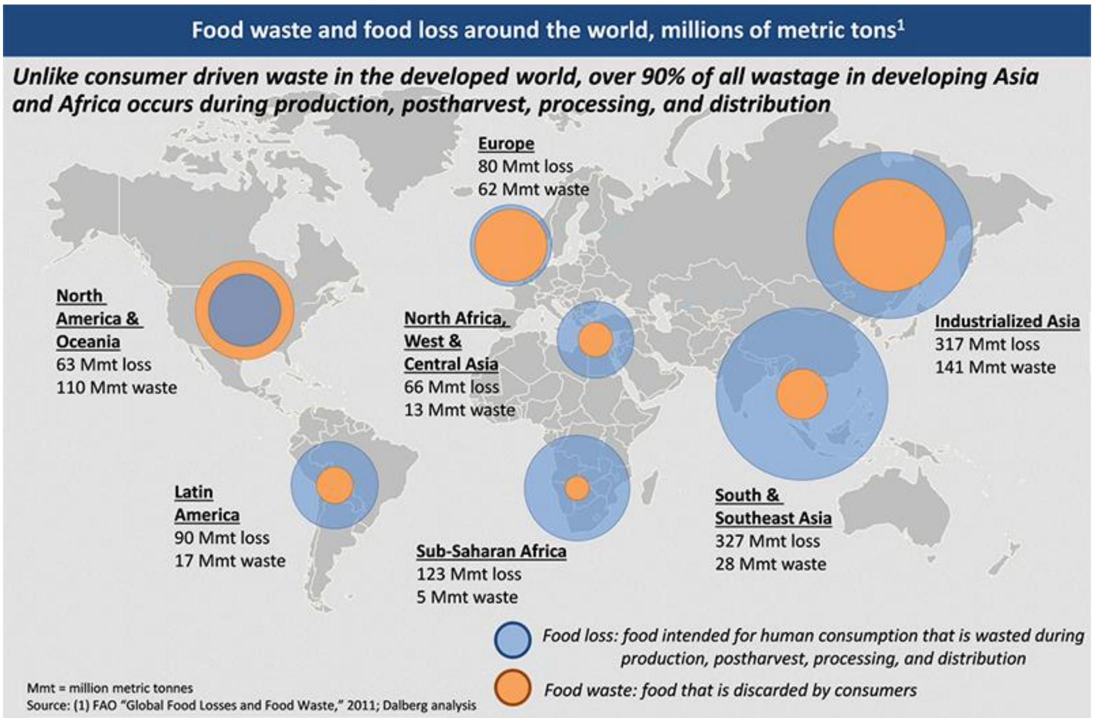

Figure 1 Food waste and food loss around the world (Tzemach Lemmon, 2014)

"*Unconsumed food also has effects beyond food security, ranging from the economic - one year's unconsumed food is worth roughly $750 billion - to the environmental - unconsumed food is responsible for 3.3 billion tons in CO2 emissions per year."* (Tzemach Lemmon, 2014) The next figure shows the carbon dioxide emissions (in kilograms) produced by one kilogram (1 kg) of different kind of food products. It contains all issues produced on the farm, in the factory, in the shop and home. Meat, cheese and eggs have the biggest impact, while milk, vegetables or nuts have much lower footprint on the environment.

Figure 2 Greenhouse gas emissions by product (Venkat & Hamerschlag, 2011)

All over the world actions are taken to go through this existing problem. Saving, preserving, or recycling of the food preceding the right solutions, where one of them is anaerobic digestion. The digestion of waste could complete a cycle of raw materials based on food production or food waste management. Waste disposals are used for the production of biogas and the biogas can substitute fossil fuels for the generation of electricity and heat. The following figure greatly shows this cycle.

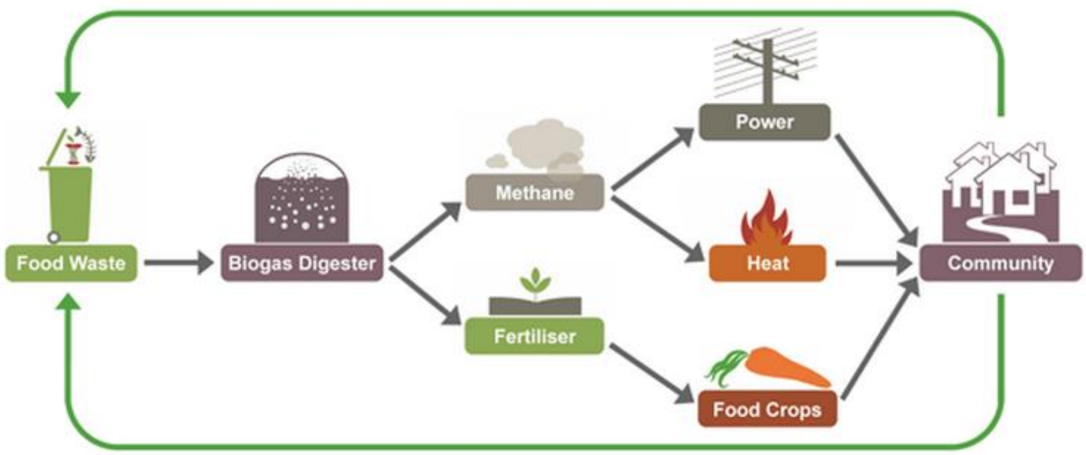

Figure 3 Food waste cycle (Camilleri, 2015)

4 IMPLEMENTATION

4.1 Overview of different industries

Under the term “food industry” the first thought which is coming is just simply “food”. When thinking and analysing this more deeply, it can be realized how extensive this concept is and how many industrial sectors could be associated. As mentioned above, wide food business generates terrifying amount of losses and wastes, however it can be controlled and skilfully managed. Table below is highlighting the most common substrates, suitable for biological treatment. Used waste code refers to the entry in the European Waste Catalogue (EWC) established by European Commission.

Table 3 Wastes suitable for digestion (Environmental Protection Agency, 2002)

Waste code	Waste description	Waste details
02 00 00	Waste from agriculture, horticulture, aquaculture, forestry, hunting and fishing, food preparation and processing	wastes from agriculture, horticulture, aquaculture, forestry, hunting and fishing
		wastes from the preparation and processing of meat, fish and other foods of animal origin
		wastes from fruit, vegetables, cereals, edible oils, cocoa, coffee, tea and tobacco preparation and processing; conserve production; yeast and yeast extract production, molasses preparation and fermentation
		wastes from sugar processing
		wastes from the dairy products industry
		wastes from the baking and confectionery industry
		wastes from the production of alcoholic and non-alcoholic beverages (except coffee, tea and cocoa)

4.2 Legal framework

The decision to build a plant for biogas, besides technological, logistical and financial aspects must also be preceded by a thorough analysis of the feasibility of such investment in the selected location and form, in context of formal and legal requirements. Due to the special nature of this type of objects, mainly for the sake of its raw material, it needs to be examined whether the investment phase and operating the project. Well written business plan can facilitate the rightness of the decision to build, as well as its profitability. Main parts which must be contained are:

1. Feasibility studies
   This stage contains data collection of the investment such as: market for products, supply chain of raw materials, infrastructure and recruitment of qualified staff. Cost-benefits analysis is a final result.

2. Planning
   As in every project, planning is the most time-consuming and major phase. Plenty of permissions from the authorities should be obtained. Those can be grouped in following way:
   - Urban regulations (e.g. location, space management)
   - Building regulations (infrastructure e.g. access roads)
   - Environmental protection regulations (e.g. connection to water supply and sewerage system)
   - Energetics regulations (e.g. connection to the grid)

   The application for required authorization should contain (Deublein & Steinhauser, 2008):
   - Purpose of the plant and short description of the process
   - Location of the plant
   - General layout plans
   - Detailed description of the processes and operation of the plant
   - Description of all technical equipment including costs
   - All raw materials and products
   - Measures for the protection of the environment (emissions, noise, vibrations, heat recovery, soil protection, water protection)
   - Measures for safety-related risk analyses, explosion protection, operation manuals

- Measures for the shutdown of the plant (plan for re-cultivation of the places)

3. Financing

   Biogas plants can be funded in many ways e.g. with own resources, bank loan, private investors and public promotions (grants). "*The governments of the European Union, states, regional counties, cities, districts, municipalities, and power supply companies promote regenerative power production. The promotion consists in loans at a low interest rate, partial remission of debts, special depreciation rates, and guaranteed prices for the power above the normal tariff."* (Deublein & Steinhauser, 2008)

4. Building process

   Potential contractors, considered during planning stage, ensuring that the construction of a plant is carried out in accordance with canons of industry and necessarily taking into account all the conditions set out in this project.

5. Operating phase

   After complete technological installation, commissioning phase takes place. This is not an easy task, because normal gas production starts approximately after 2-3 months of operation of the plant. It is associated with the delivery of substrates for biogas production, proper start-up of individual system components, as well as "fine-tuning" of equipment working on the plant. Visible effects are not felt immediately, sometimes several months are needed to get benefits, especially all cost savings related to the production of electricity or heat. The main tool for monitoring the normal work of a plant is to provide daily reports from maintenance and/or operational matters. Indicators included in such reports might be e.g.:

   - special occurrences, above all operational disturbances
   - all maintenance work
   - operating outages of components, performance controls
   - emission measurements
   - laboratory expertise for biogas content
   - value measurements for bioreactor (e.g. pH, COD, temperature)
   - disposal of residues

5 OPERATION OF BIOGAS PLANT

5.1 Feedstocks

"In general, all types of biomass can be used as substrates as long as they contain carbohydrates, proteins, fats, cellulose, and hemicellulose as main components. It is important that the following points are taken into consideration when selecting the biomass:

- *The content of organic substance should be appropriate for the selected fermentation process.*
- *The nutritional value of the organic substance, hence the potential for gas formation, should be as high as possible.*
- *The substrate should be free of pathogens and other organisms which would need to be made innocuous prior to the fermentation process.*
- *The content of harmful substances and trash should be low to allow the fermentation process to take place smoothly.*
- *The composition of the biogas should be appropriate for further application.*
- *The composition of the fermentation residue should be such that it can be used, e.g., as fertilizer."* (Deublein & Steinhauser, 2008)

Biogas efficiency for different kind of feedstock is shown in Table 4. Data is collected from many sources and it can vary. Generally, methane (CH_4) content in the food wastes is the average of about 800 m^3 / Mg of ODM.

Table 4 Characteristics of selected substrates for AD; its dry matter (DM) and organic dry matter (ODM) content

Substrate	**DM** [%]	**ODM** [% DM]	**Methane production from 1Mg of ODM** [m^3 / Mg ODM]
Brewers spent grain	20-25	70-80	580-750
Fresh fruit or vegetable pulp	13	90	650-750
Effluent from the processing of vegetables and fruits	3.7	70-75	1500-2000
Process water	1.6	65-90	3000-4500
Expeller pressing of vegetables	22-26	95	250-350
Molasses	80-90	85-90	360-490
Fruit pomace	25-45	90-95	590-660

Substrate	DM [%]	ODM [% DM]	Methane production from 1Mg of ODM [m^3 / Mg ODM]
Apple pomace	25-45	85-90	660-680
Grapes pomace	40-50	80-90	640-690
Glycerine	84.0	91.5	1196.0
Wastes from production of oil	78.8	97.0	600.0
Wastes from production of cheese	79.3	94.0	610.2
Bakery wastes	87.7	97.1	403.4
Whey	5.4	86	383.3

5.2 Anaerobic digestion

5.2.1 Process biology

5.2.1.1 Stages of AD

Main principle of anaerobic digestion can be divided into four steps where each involves different groups of microorganisms. Their graphic interpretation is shown in Figure 4.

- Phase 1 – hydrolysis.
  During this phase the long chain organic compounds (e.g. proteins, fats, and carbohydrates) are split into more simple organic compounds (e.g. amino acids, fatty acids, sugars) through bacterial action.

- Phase 2 – acidogenesis (also acidification).
  The products of hydrolysis are subsequently metabolized in the acidogenesis phase by acidogenic (fermentative) bacteria into methanogenic substrates. Sugars, amino acids and fatty acids are broken down into acetate, CO_2 (carbon dioxide), H_2 (hydrogen) and also VFA (volatile fatty acids) and alcohols.

- Phase 3 – acetogenesis (acetic acid formation).
  Products, which cannot be converted in previous phase, are converted into methanogenic substrates here. The VFA and alcohols are degraded from acetogenic bacteria into acetic acid, hydrogen and carbon dioxide which are the source compounds for biogas production.

- Phase 4 – methanogenesis (methane formation).
  The products from the previous phases are converted into methane and carbon dioxide by methanogenic microorganisms. The end product is a combus-

tible gas called biogas. This last phase is the slowest biochemical reaction in the process. It is influenced by feedstock composition, feeding rate, pH value and temperature.

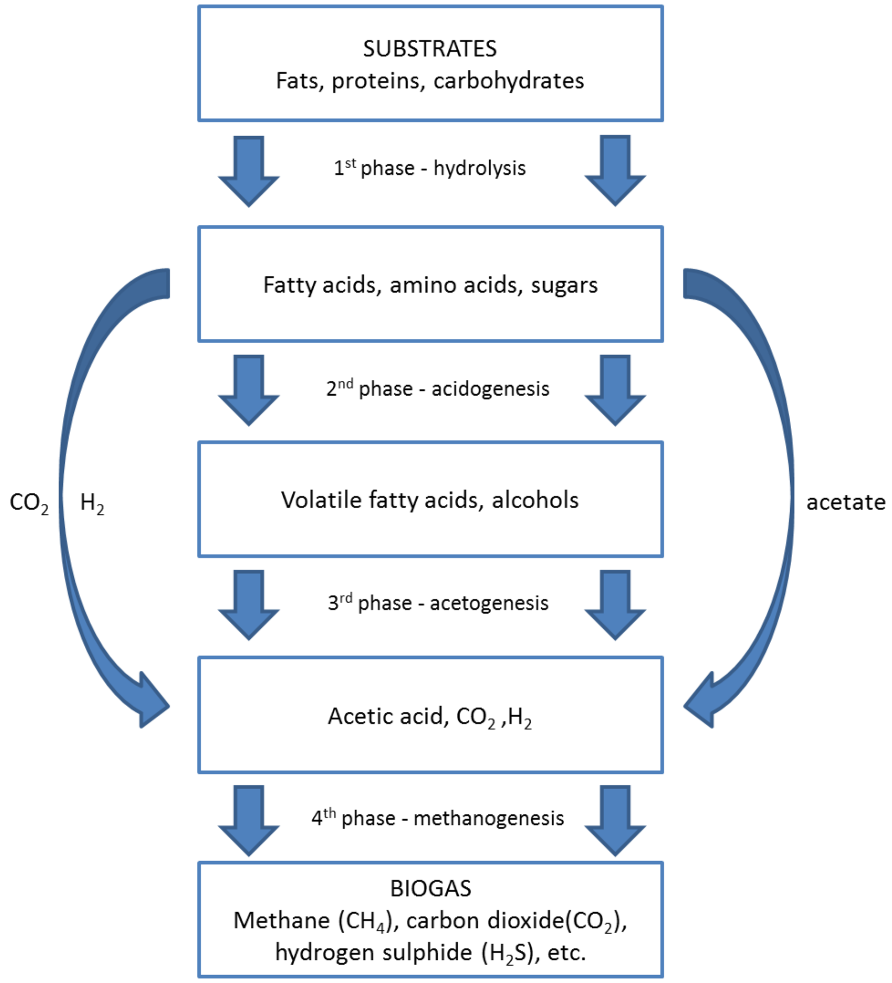

Figure 4 Diagram of anaerobic digestion process

5.2.1.2 Temperature

In natural environments anaerobic digestion occurrs in a wide range of temperatures, starting from 4 °C (e.g. lakes) to 60 °C. However, for the industrial processes, the temperature range is about 20-55 °C (del Real Olvera & Lopez-Lopez, 2012). It is generally known that higher temperature can produce higher rate of methane and there is a direct relation between the process temperature and hydraulic retention time (HRT; average time interval when the substrate is kept inside the digester tank) (Al Seadi, et al., 2008). AD process can be divided into three temperature ranges, which are showed in Table 5.

Table 5 Temperature ranges and typical retention time (Al Seadi, et al., 2008)

Thermal stage	Process temperatures	Minimum retention time
Psychrophilic	< 20 °C	70-80 days
Mesophilic	30-42 °C	30-40 days
Thermophilic	43-55 °C	15-20 days

5.2.1.3 pH value

The bacteria involved in the different stages of the process have different pH value, ensuring their optimum growth. The optimum pH of hydrolysing and acid-forming bacteria is 4.5 to 6.3. However, they are not rely absolutely on those values and can survive even at a slightly higher pH value. But then their activity might be much less. Differently it looks for bacteria producing acetic acid and methane. The pH must have exact figures of between 6.8 and 7.5. If the fermentation takes place in one fermenter, the pH value should be set at this range. Regardless of whether the process is single or in two stages, the pH is set automatically predominantly by the presence of basic or acidic of waste products produced during AD.

5.2.1.4 Stirring of biomass

Mixing the biomass is necessary to:

- ensure the process homogeneously in the entire volume
- maintain homogeneous consistency
- preventing the formation of scum

Also, mixing the biomass increases the access of bacteria to the particles of organic matter, and thus accelerates the fermentation process.

5.2.1.5 Inhibitors

There are various reasons for the disruptions of gas production in relation to the process. On the one hand, they may be related to technical problems of installation. On the other hand, it can happen due to inhibitors. These are substances which in small quantities are toxic to bacteria and interfere with process of decomposition. They can be divided into those that get into the fermenter by the addition of substrate, and those which are present as intermediate products of the various stages of decomposition. The list of inhibitors is introduced in Table 6.

Table 6 Inhibitors and their concentration

<table>
<tr><th>Inhibitor</th><th colspan="2">Damaging concentration</th></tr>
<tr><td>Sodium</td><td colspan="2">Between 6 and 30 g/l (in adopted cultures even to 60 g/l)</td></tr>
<tr><td>Potassium</td><td colspan="2">from 3 g/l</td></tr>
<tr><td>Calcium</td><td colspan="2">from 2,8 g/l $CaCl_2$ (calcium chloride)</td></tr>
<tr><td>Magnesium</td><td colspan="2">from 2,4 g/l $MgCl_2$ (magnesium chloride)</td></tr>
<tr><td>Ammonium</td><td colspan="2">2,7 – 10 g/l</td></tr>
<tr><td>Ammonia</td><td colspan="2">from 0,15 g/l</td></tr>
<tr><td>Sulphur</td><td colspan="2">from 50 mg/l H_2S (hydrogen sulphide)
from 100 mg/l S^{2-} (sulfide)
from 160 mg/l Na_2S (sodium sulfide)

(in adopted cultures to 600 mg/l Na_2S and 1000 mg/l H_2S)</td></tr>
<tr><td>Heavy metals
(with sulfides they can be neutralized)</td><td><u>As free ions:</u>
from 100 m/l Ni (nickel)
from 40 mg/l Cu (copper)
from 130 mg/l Cr (chromi-um)
from 340 mg/l Pb (lead)
from 400 mg/l Zn (zinc)</td><td><u>In carbonate forms:</u>
from 160 mg/l Zn (zinc)
from 170 mg/l Cu (copper)
from 180 mg/l Cd (cadmium)
from 530 mg/l Cr^{3+} (chromium III ion)
from 1750 mg/l Fe (iron)</td></tr>
<tr><td>Volatile fatty acids</td><td colspan="2">from 50 mg/l</td></tr>
</table>

5.2.2 Process technology

The technique for the production of biogas plant has a very broad spectrum. The possibility of combining components and aggregates is almost endless. For each specific application it is necessary that qualified personnel conducts a case-specific assessment of the suitability of aggregates and system and the matching performance. Typical variants of production method are shown in Table 7.

Table 7 Process technology for producing biogas

Criteria	Characteristics
Dry matter content	Dry fermentation Wet fermentation
Method of feeding	Continuous Batch process or discontinuous

Criteria	Characteristics
Number of process phases	Single-phase Two-phase

5.2.2.1 Dry matter content

The consistency of the substrate depends on the content of dry matter. The division between wet and dry fermentation can be made here. There is no exact definition of the boundary of those two, it is in practice accepted that for wet fermentation the DM content in the fermenter is 12%, and on this water content, it is possible to pump the material. If the DM content increases above 12%, the material usually loses its ability to pumping and is then referred as a dry fermentation. In industrial biogas plants it is most common to apply wet fermentation process.

5.2.2.2 Method of feeding into reactor

Feeding method can be closely related to DM content. For dry fermentation batch process is most important, while for wet fermentation, continuous process. In the discontinuous filling the whole process takes place in one sealed container and meanwhile any portion of fresh substrate is not added or taken out. After a set time, the fermenter is emptied and loaded with fresh substrate. *"Most installations work according to the continuous process, whereby the substrate is fed into the digester either constantly or at short intervals; biogas and also the digestate are removed on an ongoing basis"* (Agency of Renewable Resources, 2013).

5.2.2.3 Number of process phases

In biogas plants there mostly occurs one- or two-phase installation. In one-phase systems there is no dimensional separation of the different stages of the fermentation process, i.e. the whole process takes place in one tank, resulting in lower investment costs. In other hand, in two-phase installation different stages of the process are held in different tanks. In this way, more beneficial conditions are created for various microorganisms from different stages of anaerobic digestion. Two-phase system generates higher costs but gives more control over ongoing process.

5.2.2.4 Components of anaerobic plant

Although several possibilities exist for biogas plants, the technical operation of each has to work according to the same method. The main purpose is to produce biogas. Plenty of components are included, starting from phase of choice of substrates, its relevant treatment and further to energetic utilization of the gas. List of main equipment can be read from Table 8.

Table 8 Main components of AD plant

Component	Characteristics
Mixers, clarifiers, centrifuges	Main equipment of pre-treatment. Major purpose is to removing of unsuitable matter and prepares the substrate for fermentation process.
Digester	Heart of the plant. Different types of digesters can be applied but all of them should: • Be gas and dust-proof • Have the possibility to achieve desired process temperature by providing heat (heating system) • To prevent heat loss and variation of temperatures (heat insulation) • To provide the opportunity to perfect movement of the substrate; to not allow: the temperature drops, formation of scum and bottom deposits, a decrease in the concentration of nutrients in the substrate and wrong degassing of substrate • To have equipment or capability of removing sediments • To have equipment to discharge of obtained biogas and have measurement technology which control and regulate the process • To have ability to collect the laboratory samples
Stirrer, circulation in digester	This device generates the required homogeneity of the substrate.
Gas storage	Main purpose of it is to adjust imbalance

Component	Characteristics
	between gas production and its consumption. This must be gas-proof, secure from pressure and impermeable to UV radiation, like also for weather and temperature conditions.
Flare	Plays role of security system for gas storage. In case of overloading the tank, gas will combusts.
Residues tank	Residues can be stored in closed tank, after emptying is great to use as fertilizer
Cogeneration unit	Most common is installation of CHP (Combined Heat and Power), where heat and electricity can be used for purposes of a plant or can be sold further e.g. to community.
Gas cleansing	• Desulphurization station – it can be performed by biological, chemical and physical methods. First, biological can take place in and out of digester with adding of oxygen and special bacteria. Chemical can exist inside and outside of reactor by adding there chemical compounds which react with sulphur. Physical desulphurization takes place with filters after gas production. • Biogas drying station – warm and humid output from digester should be dehumidified and cooled in order to prevent corrosions. • Compression station – in case where biogas is used for vehicles, then requires compression to 22 bars. • Removing CO_2 - removing CO_2 is a method for the reduction of ammonia. It is executed through gas washing, pressure wash-

Component	Characteristics
	ing or adsorption washing.
Pipelines	A gas- / dustproof pipelines for ensuring proper process flow on different stages
Control and measuring equipment	For control and surveillance of the process, setting optimal parameters for biogas production according to efficiency and demand

5.3 Utilization of produced biogas

Fermentation gas which is formed from the food industry is widely used. The easiest way to use biogas is just burn it directly in boilers or burners. Direct combustion is good for heat production either on site, or transported by pipeline to the end customers (Al Seadi, ym., 2008). This method does not need any gas cleansing compared to others mentioned below.

As a result of gas combustion in gas engines, you can get even approx. 90% of energy, including 36% of electricity and 54% of heat; of course, these values may be less depending on the size of the application. Thermal energy can meet the demand for heating digesters, and if there is an excess, it can be utilized for heating other rooms of a plant. Electricity is used as drive energy for pumps, scrapers, stirrers, ventilation, lighting etc. Preferred is the installation of diesel-gas generators, so that in times of shortage of gas, the liquid fuel can be used. There is also the possibility for use of gas as a chemical raw material. The main component, methane, can be used to produce ethylene, propylene, acetylene, which is the basis of production e.g. plastics, solvents, synthetic rubber, pharmaceuticals.

In summary, typical examples of energetic use of biogas includes electricity production mainly in spark ignition engines, thermal energy in gas boilers and production of both, energy and heat in one associated units (cogeneration). Other technical possibilities include the supply of gas to the gas grid, as well as use it as fuel for vehicles. The working principle of industrial biogas plant is seen in Figure 5.

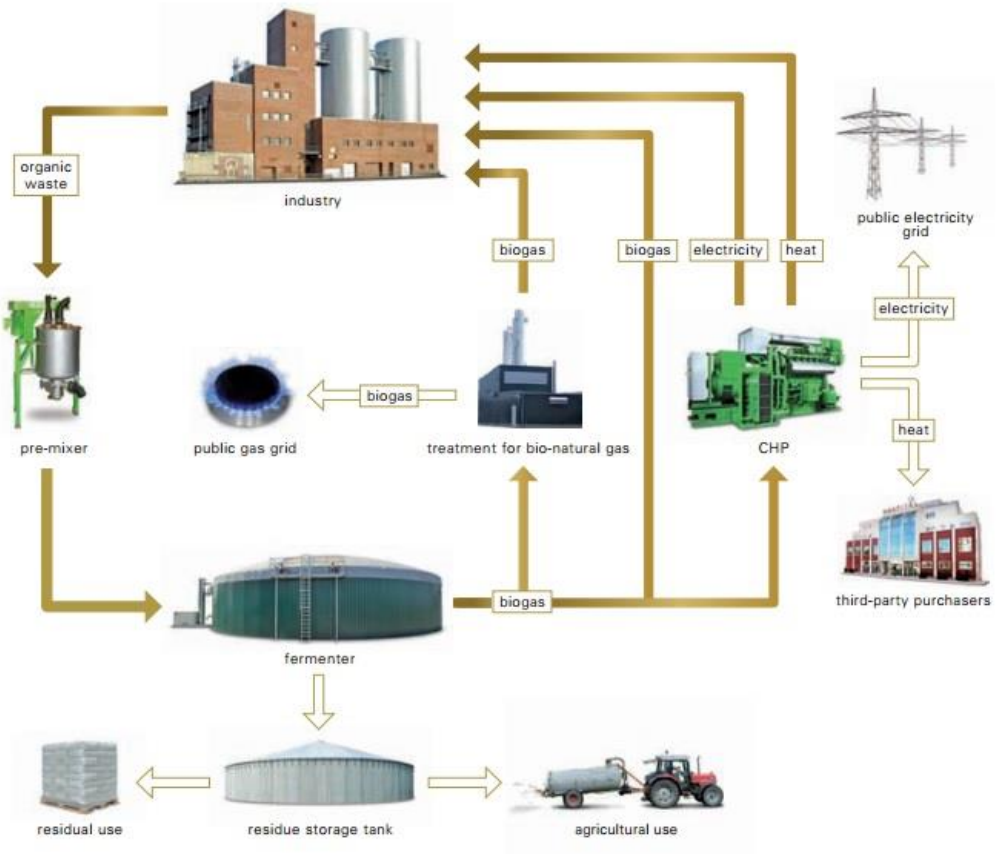

Figure 5 Operation of industrial biogas plant (EnviTec Biogas AG, 2011)

6 STUDY CASE – FARM FRITES POLAND SA

6.1 Company's profile

Farm Frites Poland SA (FFP) is one of the leading producers of frozen French fries in Central and Eastern Europe (Figure 6).

Figure 6 Picture of FFP factory

It was established in 1993 as a joint venture of two Dutch potato processing producers: Farm Frites and Aviko. A factory was built and a line of French fries initiated in the Autumn of 1994, within twelve months of the start of construction.

The decision to locate the factory in Lebork was influenced by favourable climate and appropriate soil conditions classified as "First Zone for Healthy Potatoes". An added bonus was Lebork authorities' positive approach to the venture which they recognized as a development opportunity for the town.

Initially, FFP employed 80 workers, including a few specialists from Holland who were responsible for implementing the international production standards and for training their Polish successors. The annual potato processing amounted to 40.000 tons.
In July 2004, a new line for potato pancakes was introduced and in July 2011, a new line for potato flakes. Currently, three modern production lines enable the factory to process around 60 different types of product, which find their way to the tables of individual consumers and restaurants in numerous European countries and beyond.

At present, there are 211 people working at Farm Frites Poland SA, and the amount of potatoes used for production annually exceeds 200.000 tons (Farm Frites Poland SA).

6.2 Wastewater Treatment Plant

Object of interest is the Wastewater Treatment Plant of Farm Frites Poland SA. At the turn of the years 2011/2012 developments were initiated. Modern anaerobic plant was commissioned. Together with the existing mechanical – chemical - biological plant it improved wastewater treatment process. This investment has managed in improving the quality of post-production effluents and in significant reduction in amount of dewatered sludge and reducing parameters such as chemical oxygen demand (COD), volatile fatty acids (VFA), nitrogen and total suspended solids (TSS). Additionally, the fermentation process in an anaerobic installation generates biogas, which contains a considerable amount of methane. The purified methane is cogenerated.

6.2.1 Data of post-production wastewater

First of all, wastewater from potato processing is coming to WWTP and its flow is measured. Table 9 shows in one column the amount of post-production effluent, which comes to the plant and in other column, purified effluent, which goes to municipal sewage system by pipelines. Data is collected in periods and is starting from 1.1.2015; period is approximately 28 days.

Table 9 Amount of post-production and purified effluent

Period	**To factory's WWTP** (m^3)	**To municipal sewage system** (m^3)
1	33243	37886
2	39597	48521
3	40394	45792
4	37563	43295
5	41787	48423
6	37868	43107
7	26717	40352
8	26696	30196
9	34542	39437
10	34074	39855
11	35109	40425
12	38811	46330
13	38113	48244

Besidesss measurements of flow, laboratory is providing analysis of content of sewage. In cooperation with them, analysis from the past year, 2015, is considered. Huge amount of data of laboratory reports was divided into periods; in this case period is a quarter of a year. Results from each period were calculated and taken as an average value. Table below introduces main parameters and contents of effluent from production.

- **Period 1:** 1.1.2015 - 31.3.2015
- **Period 2:** 1.4.2015 - 30.6.2015
- **Period 3:** 1.7.2015 - 30.9.2015
- **Period 4:** 1.10.2015 - 31.12.2015

Table 10 Content of post-production effluent

Factor	Description	1	2	3	4	Unit
T	Temperature	31,24	31,62	30,81	28,69	°C
pH		5,05	5,02	5,37	6,35	
COD		9470,94	8752,59	6930,42	7179,74	mg/l
TSS		6659,40	5930,73	5424,12	5189,57	mg/l
TN	Total nitrogen	503,94	501,09	421,54	416,59	mg/l
NO_3	Nitrate	10,21	10,90	5,89	5,42	mg/l
NH_4	Ammonia nitrogen	88,02	76,69	101,97	105,57	mg/l
TP	Total phosphorus	100,54	86,00	92,31	78,56	mg/l
PO_4	Orthophosphate	179,20	160,87	162,89	163,63	mg/l
SO_4	Sulphate	299,29	274,37	311,21	386,99	mg/l
Cl	Chloride	319,38	349,04	553,46	268,35	mg/l
Ca^{2+}	Calcium ion	88,11	62,48	62,67	60,78	mg/l
VFA		2589,00	2082,67	1731,60	2839,00	mg/l

6.2.2 Characteristics of process flow

6.2.2.1 Pre-treatment

Before anaerobic digestion can operate in the right way several steps need to be taken. Preparing wastewater is the first stage of whole process. When post-production sewage comes to WWTP, it goes to pumping unit 1 (P1), where it is pumped into rotary sieve (Figure 7). This machine separates bigger particles of potatoes from sewage.

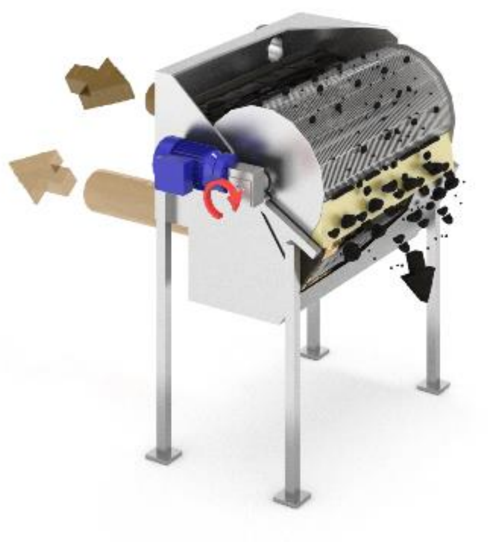

Figure 7 Rotary sieve

Trapped matters are transported by screw conveyors into container for dehydrated sediments. At the same time wastewater is continuing flow and goes to next phase, lamella clarifier (Figure 8). It is a modern efficient device (tank) for separating solids from liquids.

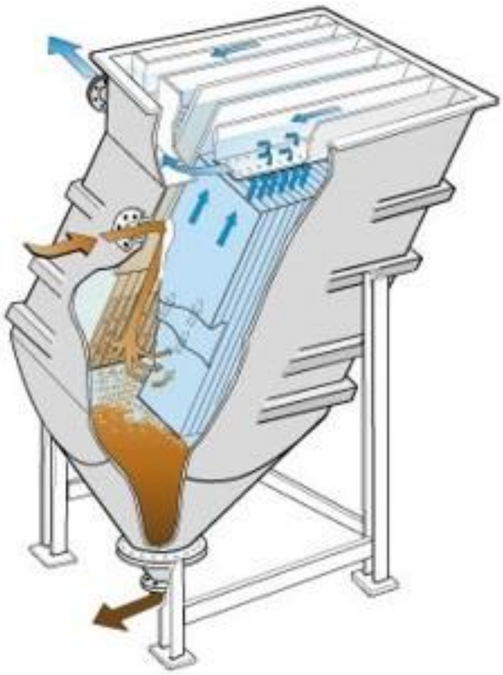

Figure 8 Lamella clarifier

Lamella clarifier is filled with lamella plates which guarantee high projected area of sedimentation. Sedimentation process is stimulated by gravitation force. Clear effluent goes out in upper part of lamella clarifier and solids settle on the bottom. Situations differ every time, wastewater content depending on season and potatoes used for production, so that's why lamella clarifier may not be enough. Next phase of pre-treatment is circular clarifier (Figure 9).

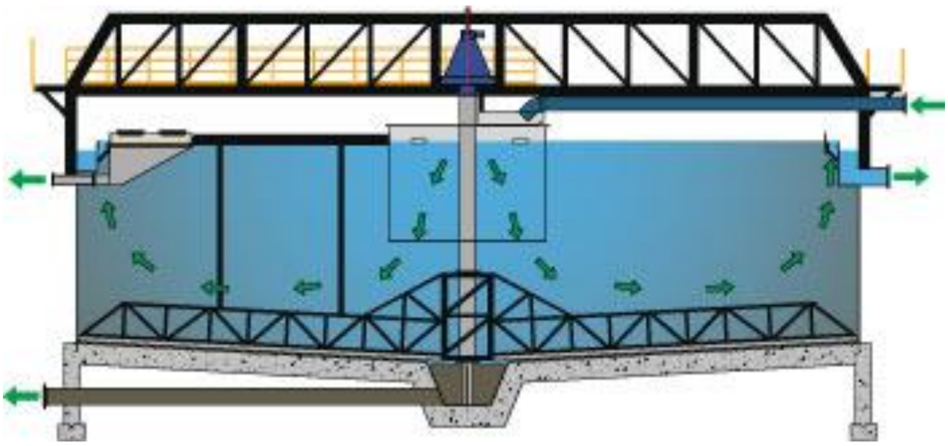

Figure 9 Circular clarifier

The wastewater from lamella comes to circular clarifier by pipelines and it is filled from the top. Small reservoir is applied to prevent disturbances in process of sedimentation. Sewage is slowly flowing out from reservoir and solids are falling down and by rotating scrapers accumulate in the hole on the bottom. At the same time clear effluent goes to pumping unit 2 (P2). The sediments from the bottom of the tanks are simultaneously and continuously discharged. Otherwise, it will interrupt the whole process. For this purpose the centrifuge decanter is used (Figure 10). Solids from both clarifiers are pumped into machine. With high speed centrifugation, solids are dried and separated from liquids. Dry matter is transported by screw conveyors into containers, when liquids are returned into pumping unit 1 (P1).

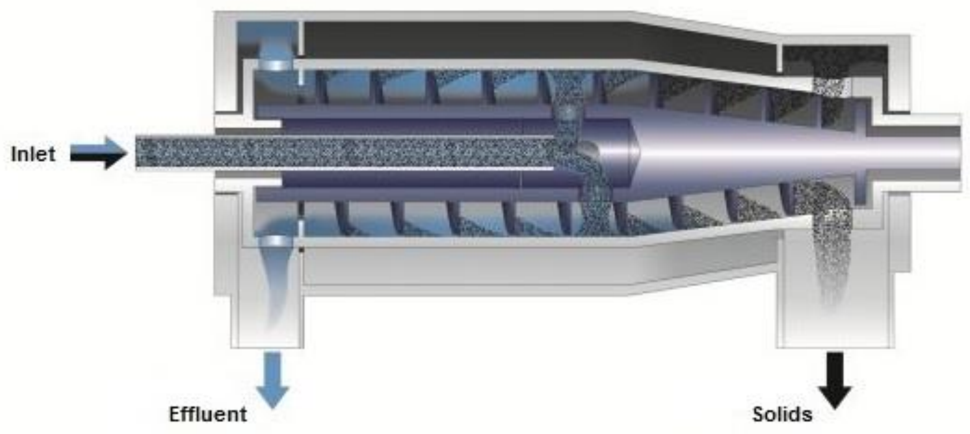

Figure 10 Centrifuge decanter

After solids are discharged, clear effluent comes to last pre-treatment phase: Dissolved Air Flotation (Figure 11). The principle of DAF is to clarify wastewater from total suspended solids, oils etc. The effluent from P2 is pumped by pipeline to DAF, where pressured air is applied. In the main flotation tank the air floats the solids to the surface, from where they are removed by skimmers to an other tank. Outflow of purified effluent is supported by sloped plate. End of plate is positioned deeply to prevent and provide clear flow without solids. Clean sewage is pumped to anaerobic stage but is also used in recirculation.

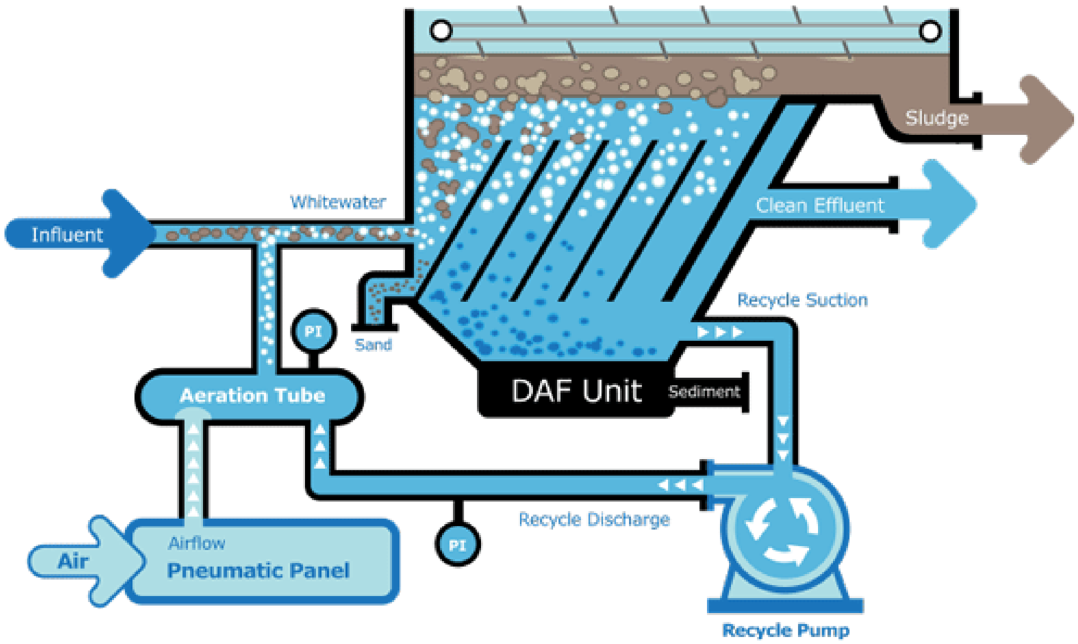

Figure 11 Dissolved Air Flotation (DAF)

6.2.2.2 Anaerobic digestion

Expansion of the existing facility in 2011 was to implement anaerobic phase which included:

- Acidification tank - capacity of 700 m^3
- High efficiency anaerobic reactor (R2S) with internal circulation - capacity of 1 100 m^3
- Biogas storage
- Flare
- Desulphurisation column
- Biogas dryer
- Cogeneration system - a generator with a capacity of 1.2 MWh
- Steam boiler
- Automation - systems for visualization and control

After all pre-treatment sewage is ready to be implemented to the anaerobic stage. This application is two-phase with continuous feeding and taking place in mesophilic thermal stage.

From DAF effluent goes to acidification tank where effluent is stirred, and carbohydrates and VFA are reduced. In independent acidification tank it is easier to optimally control the process and prevent methanogenesis phase from influence of inhibitors. That well-prepared sewage is pumped into conditioning tank in order to dilute the COD load and to achieve its maximum removal. Afterwards effluent goes to the anaerobic tank. It is high efficiency reactor, type R2S, with internal circulation. Figure 12 shows the structure of the tank with its included elements:

1. Feed
2. Outlet
3. Inlet distribution system
4. Lower separator
5. Upper separator
6. Riser
7. Downer
8. Heavy Sludge Discharge
9. Scum Sludge Discharge
10. Degassing tank
11. Biogas pipe

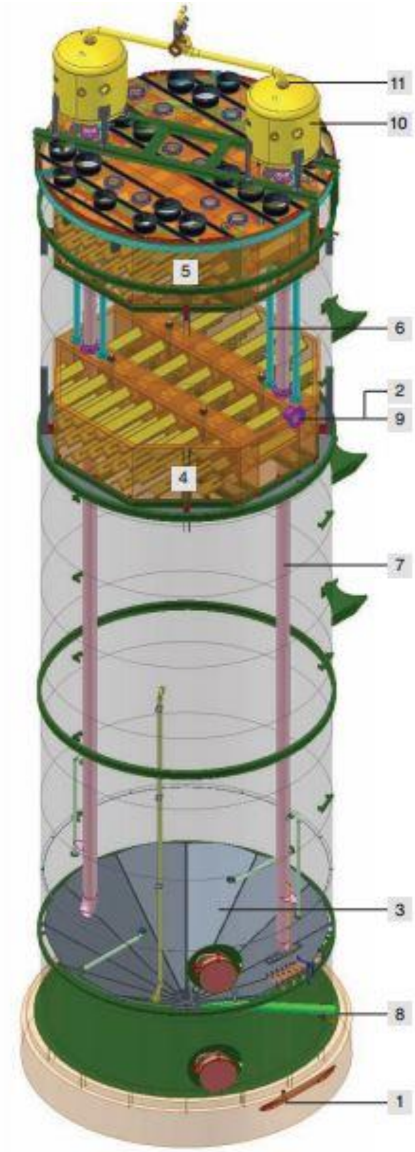

Figure 12 Anaerobic reactor - R2S

"The effluent is fed via an inlet (1) into the bottom of the reactor (3) and mixed intensively with the anaerobic biomass. The feed-in area is specially designed so that heavy sludge (i.e. calcified biomass) can be periodically discharged without interrupting the operation. Two three-phase separating systems (4, 5) allow for effective separation of effluent, biomass and biogas. The major portion of the obtained biogas is removed in the lower separator. Biogas, water and biomass from the lower reactor area are directed over a riser (6) into a degassing tank (10) on the reactor head. Water and biomass are then returned back into the lower reactor area over a downer (7). The internal recirculation is supplemented with an additional external recirculation. The outlet system for the effluent is constructed in a way that sedimentation can, for the most part, be avoided" (Aquabio Ltd). From degassing tank, the biogas by pipeline goes to the cleansing stage. Contained in the biogas, water vapour and hydrogen sulphide forms compounds which are corrosive. It is destructive for pipes and machines and it is important to remove those impurities. Firstly, biogas goes to desulphurization column. It is biological station, consists of a high tank, and its main principle is to oxidize sulphur microorganisms. The column provides reduction of H_2S from 6000-7000 ppm (parts per million) to only few ppm (Milewczyk, 2014). In decomposition of H_2S simple compounds of sulphur and water vapour are produced. According to this, after desulphurization, biogas needs to be dried in installation with compressor. When the process of cleansing is done, biogas is stored. Storage is performed in spherical tank. Tanks of this type are most often made from polyester and coated with PVC material in form of two or three membranes. In case of biogas excess, storage is connected with a safety flare where can be burned out.

Figure 13 Shown from the left: anaerobic reactor, acidification tank, desulphurization column and storage tank (FFP SA).

Before last, cogeneration phase, laboratory makes analysis of performance of anaerobic installation. Figure 14 shows methane content in biogas produced during process. Higher content of methane provides maximum effectiveness and maximum quality of biogas. Numbers are calculated as an average from each quarter of a year 2015.

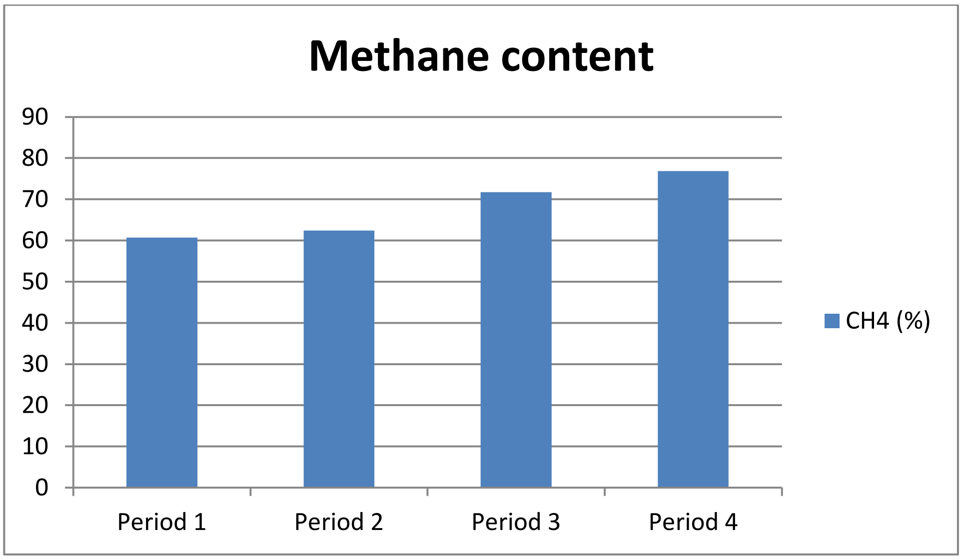

Figure 14 Methane content of produced biogas

During consultation with WWTP staff, the time where the anaerobic reactor works in most efficient way is when VFA are below 400 mg/l and COD value is low. Next figures, 15 and 16 show the reduction of the VFA and COD in each treatment period; the red values show average COD values of incoming sludge and the blue values after anaerobic digestion.

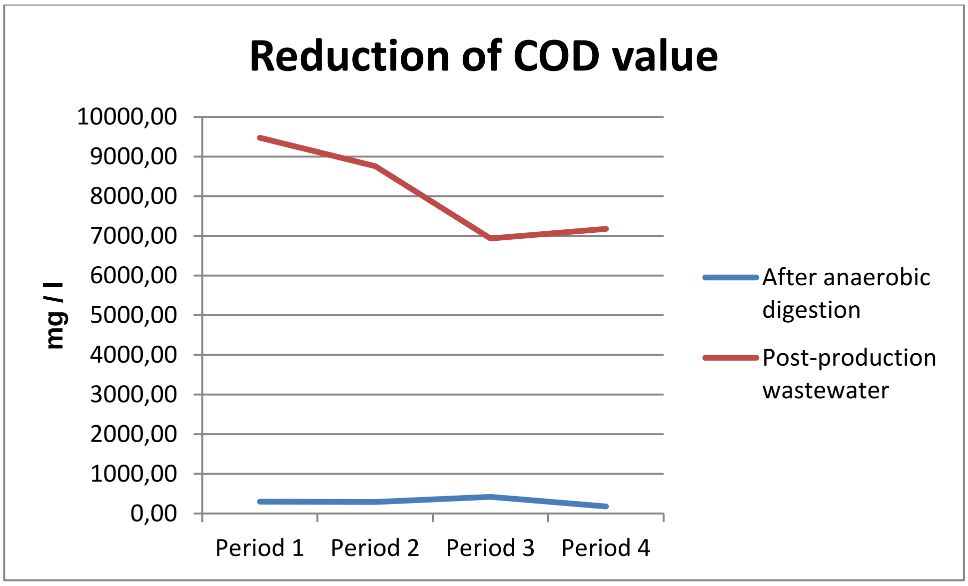

Figure 15 Reduction of chemical oxygen demand in each treatment period

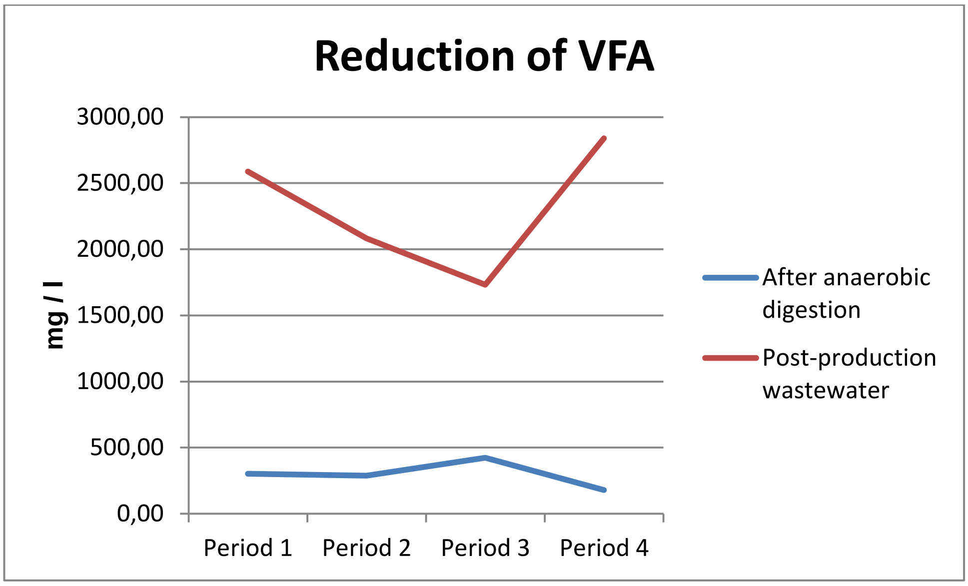

Figure 16 Reduction of volatile fatty acids in each treatment period

As shown, efficiency of reactor is very high. Period 3 is always the most interrupted according to break in production which stop a few weeks. It was time for maintenance work and little raises in parameters are caused by stopping and, afterwards, running the anaerobic stage.

Stored biogas is utilized in cogeneration unit. Generator with a capacity of 1.2 MWh produces heat energy and electricity for the use of the Wastewater Treatment Plant and factory. Additionally, applied waste heat to water (boiler) generates steam for supporting factory's production process at pressure of 4 bar. Figure below shows main principle of CHP.

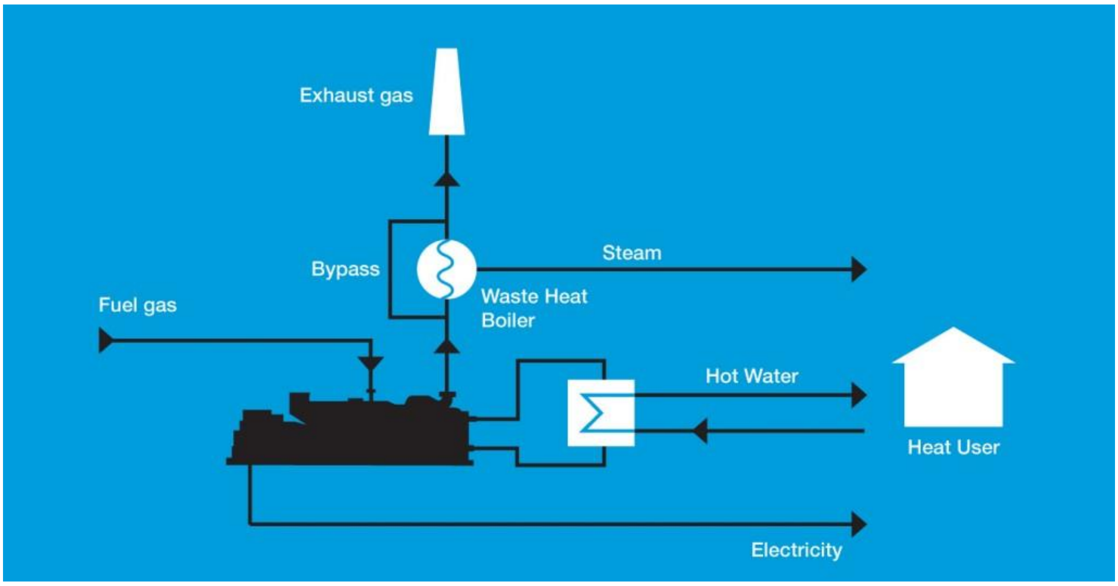

Figure 17 Main principle of CHP (Clarke Energy)

6.2.2.3 Aerobic treatment

Aerobic stage was main phase of wastewater treatment before anaerobic installation was implemented. Involved in this step are:

- SBR 1 and SBR 2 (Sequencing Batch Reactors) with a volume of 3600 m^3 each
- Excess sludge tank with a volume of 700 m^3
- Buffer tank with a volume of 200 m^3
- DAF
- Belt press

The output from anaerobic digester is discharged and by pipelines goes to SBR. Those are filled alternately and process (or cycle – one cycle takes around 6 hours) of treatment inside them can be divided into stages:

1. Filling with sewage
2. Aeration, air blowers transfer the air into bubble diffusers implemented to the floor of the tank. Organic matter is reduced and by biological oxidation, ammonia is converted to nitrite (nitrification). During aeration process of denitrification can be applied. Air blowers stop and stirrers inside the tank slowly mix the sewage for reduction of nitrates into nitrogen. It may take several minutes and aeration is starting again.
3. Sedimentation, it is idle process where suspended solids are falling to the bottom by gravitational force.
4. Decantation, clarified effluent from upper part of reactor is drained to the buffer tank and from there by pipeline transported to pumping unit 3 (P3), and then to the municipal sewage system. At the same time sedimented solids are discharged into excess sludge tank.

Figure 18 Aerobic stage - SBR's

Collected suspended solids from excess sludge tank are pumped to mixing chamber where are mixed with polyelectrolytes for better flocculation. Then prepared sludge goes to DAF unit. Suspended solids are removed and pumped to the belt press. Purified effluent flows to pumping unit 3 and then to the municipal sewage system. Last phase is dewatering the sludge by press belt. Effluent from pressing goes to pumping unit 2, and dried sludge is transported by screw conveyors to container and exported to the landfill.

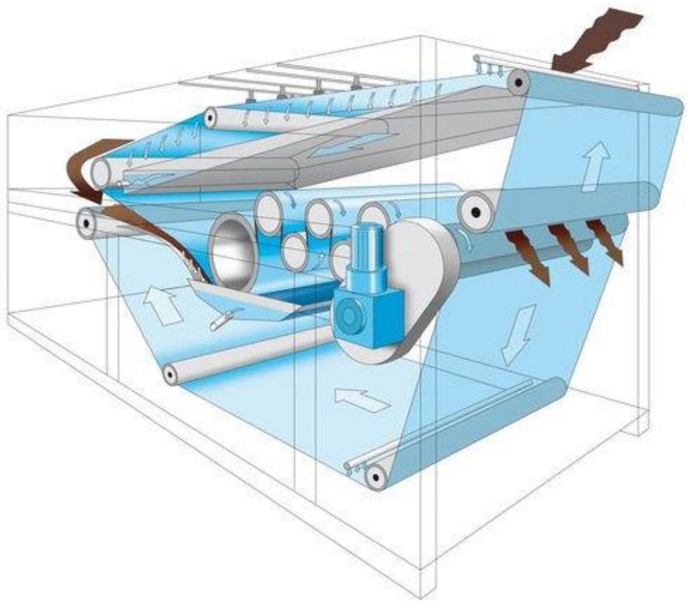

Figure 19 Belt press (Direct Industry)

6.2.3 Characteristic of chemicals supporting process

Chemical supporting on WWTP comprises treating of wastewater with selected chemical reactants, which because of their characteristics can be divided into:

1. Coagulants and flocculants, those are:
   a. polyelectrolytes in powdery and emulsion form – used for reduction of COD, ortophosphate (PO_4), H_2S. They accelerate formation of floc, increase floc density and accelerate by this sedimentation process, facilitating dewatering process. Mosty applied for clarifiers, centrifuge decanter and DAF.
   b. PIX - recommended for the removal of phosphorus from wastewater, bond of hydrogen sulphide and conditioning of sludge.
2. Reagents for pH adjustment, here most common is NaOH (sodium hydroxide). Main used are flakes or granular form and also as solution. Can be applied on each of pre-treatment phases.

6.3 Results

Cogeneration of green energy reduces demand for municipal energy ie. electricity and heat. At this moment the production of biogas secures 17-20% energy of whole factory need and successively raise. The forecast for current year is to reach level of 25-27%.

Based on WWTP reports, implemented anaerobic installation has ability to achieve the following degree of reduction for individual parameters in time when object works properly:

- COD in anaerobic stage – average above 92%
- COD for whole WWTP – 99,46%
- TSS for whole WWTP – 99,70%
- Total nitrogen for whole WWTP – 93,71%

Table 11 describes parameters and their content of purified effluent. Showed parameters are parameters contracted with Municipal Wastewater Treatment Plant and regularly controlled by them. Average values are taken from last quarter of the year 2015 (Period 4).

Table 11 Compared parameters of post-production wastewater and clear effluent

Controlled parameters	Descritpion	Post-production	Purified effluent	Contracted norm	Unit
COD		7179,74	75,28	900	mg/l
TN	Total nitrogen	416,59	36,5	50	mg/l
NH4	Ammonia nitrogen	105,57	12,09	20	mg/l
Cl	Chloride	268,35	192,78	900	mg/l
Temp	Temperature	28,69	23,69	< 35	°C
pH		6,35	7,94	6,5 - 9,5	

6.4 Conclusions

Before anaerobic stage was implemented the WWTP operated only for purification of post-production wastewater. Investment in the biogas plant has ensured for factory more modern facilities, which allow decreasing in operating costs and energy expenses.

This environmentally friendly plant provides a reduction of loads of wastewater and exceedance of parameters (resulting from an agreement between the factory and the Municipal Wastewater Treatment Plant) are uncommon and do not carry financial penalties. The less amount of excess sludge provides less use in machines from aerobic stage and also less costs in transportation and utilization of dewatered sediments.

Farm Frites Poland SA and its Wastewater Treatment Plant are great examples of a factory that provides great waste and wastewater management by optimizing the processes and technology. Their desire to ensure a satisfactory level of self-sufficiency may be worthy of imitation. This attitude shows the cost-effectiveness and environmental protection, which is very desirable in the food industry.

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Appendix 1 Block diagram of technological flow of WWTP