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EFFICIENCY OF ULTRASONIC TREATMENT FOR SECONDARY SLUDGE DISINTEGRATION IN BERGISCH GLADBACH, GERMANY

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Abstract

Anaerobic digestion is one of the most common processes used for sludge stabilization. A known alternative to improve this practice and increase biogas production is the use of ultrasonic disintegration of the sludge as a pretreatment to the anaerobic process. The wastewater and sludge treatment plant in Bergish Gladbach, Germany, decided to test this technology in a pilot scale plant in order to study its real effects over their sludge, considering its implementation on the big scale.

The pilot plant consisted of two reactors of 60 liters each with 30 days of solids retention time. The effects of the ultrasound were tested using a laboratory reactor operated with a frequency of 20 kHz and two different energy inputs that defined the phases of the project, low energy at about 300 W and high energy at about 550 W. One liter of raw secondary sludge was treated daily under these conditions for two minutes to later be fed to reactor 1 while reactor 2 remained as control. Parameters such as gas production, temperature, dry and volatile solids, organic acids, lime reserve and pH were continuously measured in order to control the performance of the digestion process in both systems. Additional physical characteristics were tested in the treated and non-treated sludge, such as dewaterability, viscosity as well as microscope analysis.

After the end of the three phases of the project there was no clear evidence of the effects of the ultrasonic treatment over the digestion process of reactor 1. Gas production for this system was slightly higher than the one of the control reactor just at the end of the project, not being entirely clear if is an effect of the applied ultrasound. On the other hand, physical characteristics of the sludge were affected by the ultrasonic disintegration, somewhat improving dewaterabiliy and viscosity. Energy – cost calculations were carried out in order to analyze the benefits of the implementation of the system in the big scale treatment plant.

Key words: Anaerobic digestion; ultrasonic disintegration; secondary sludge; biogas.

EFFICIENCY OF ULTRASONIC TREATMENT FOR SECONDARY SLUDGE DISINTEGRATION IN BERGISCH GLADBACH, GERMANY.

Resumen

La digestión anaerobia es uno de los procesos más comunes usados para la estabilización de lodos. Una conocida alternativa para mejorar esta práctica e incrementar la producción de biogás es el uso de desintegración con ultrasonido del lodo como pretratamiento del proceso anaeróbico. La planta de tratamiento de aguas residuales de Bergisch Gladbach, en Alemania, decidió probar esta tecnología en una planta piloto para estudiar los efectos reales sobre sus lodos, considerando su implementación en la gran escala.

La planta piloto consistió en dos reactores de 60 litros de capacidad cada uno, con un tiempo de retención de sólidos de 30 días. Los efectos del ultrasonido fueron probados usando un reactor de escala laboratorio operado con una frecuencia de 20 kHz y dos diferentes niveles de energía, los cuales definieron las fases del proyecto, baja energía y alta energía, alrededor de 300W y 500W respectivamente. Diariamente se trató un litro de lodo secundario durante dos minutos bajo estas condiciones, para luego ser alimentado al reactor 1, mientras que el reactor 2 permaneció como control. Parámetros como la producción de gas, la temperatura, sólidos totales y volátiles, ácidos orgánicos, reservas alcalinas y pH fueron medidos continuamente para controlar el desempeño de la digestión anaerobia en ambos sistemas. Adicionalmente, características físicas fueron estudiadas en el lodo tratado y en el no tratado con el ultrasonido, tales como la deshidratabilidad, la viscosidad así como un análisis bajo el microscopio.

Al finalizar el proyecto, no hubo evidencias claras de los efectos del tratamiento con el ultrasonido sobre el proceso de digestión del reactor 1. La producción de gas para este sistema fue ligeramente superior que la del reactor de control solo al final del proyecto, lo cual no establece claramente si es un efecto del ultrasonido aplicado. Por otro lado, las características físicas del lodo sufrieron ciertos cambios como efecto de la desintegración con el ultrasonido, mejorando en cierta forma la deshidratabilidad y la viscosidad. Se realizaron cálculos de energía – costos que permiten analizar los beneficios de la implementación del sistema en la gran escala en la planta de tratamiento.

Palabras claves: Digestión anaerobia, desintegración con ultrasonido, lodo secundario; biogás.

Chapter 1. Introduction

Sewage sludge is an unavoidable product resulting from all wastewater treatment facilities and it should be treated prior reuse or disposal. The treatment and handling of this substance accounts for a big part of the total operation costs of wastewater treatment, because of this reducing its volume and facilitate its handling are always top priorities. This product contains different substances removed from wastewater, and the alternatives for its treatment are varied. However, the most widely used stabilization treatment for sludge is *anaerobic digestion*, which is the decomposition of organic matter in the absence of oxygen and could lead to mass reduction and important yields of biogas, useful for the production of electricity and heat.

The downside of the anaerobic digestion is that the degradation rates are slow, requiring long retention times of the sludge in big digesters reactors. However, exist certain techniques that could help improve the stabilization of the sludge, therefore increasing the biogas yield, shortening retention times in the reactors, improving dewaterability and other properties of the sludge that are key for a successful treatment. Especially the dewatering capacity of the sludge is a highly important characteristic that influences the final volume reduction and therefore the costs of transport and disposal (Bruus et. al., 1992 in Feng et al. 2009)

Among the different techniques known for improving the stabilization of the sludge, the pretreatment is one of them. In this case, sludge is pretreated in order to ease the breakup of flocs and molecules resulting in better efficiencies during digestion. From the different alternatives available for the pretreatment, this project evaluates the use of sonication as a technique for the disintegration of the sludge. The ultrasonic pretreatment has proven to be efficient at increasing biogas yield, improving dewaterability, reducing retention times in anaerobic reactors, among other benefits (Show, Tay, & Hung, 2010), moreover, like other physical treatments, ultrasonic disintegration of the sludge is non-hazardous to the environment (Bien and Wolny, 1997 in Chu et al. 2001)

For this reason, the municipal wastewater and sludge treatment plant in Bergisch Gladbach, Germany, tested this technology in order to evaluate its implementation in the sludge treatment facilities. Through the comparison of pretreated sludge with ultrasound system and non-pretreated sludge, it was possible to evaluate the real effects of this technology over the anaerobic digestion process and analyze the feasibility of its implementation on the large scale.

To achieve this, the project pursued the following objective:

Analyze the efficiency of an ultrasonic system for the disintegration of secondary sludge in a municipal treatment plant in Bergisch Gladbach, Germany.

The main objective was supported by the following specific objectives:

- Compare the biogas yield in the digestion of secondary sludge treated with and without ultrasonic system.
- Compare the total amount of solids in final sludge treated with and without ultrasonic system.
- Analyze the dewaterability of the secondary sludge treated with an ultrasonic system.
- Carry out an energy - cost analysis on the implementation of an ultrasonic system in the treatment of secondary sludge.

Chapter 2. Wastewater

Wastewater is received into treatment facilities carrying a vast amount of constituents to be removed from the influent. Wastewater treatment is basically carried out in three phases, primary treatment, also known as mechanical treatment, secondary or biological treatment and tertiary or advanced treatment. The latest is not viable in all situations and only applicable under specific quality requirements.

2.1 Wastewater quantity and quality

Wastewater quantity considering only sanitary sewage is known as dry weather flow and it can be estimated from the sewage contributed per day times the population; being the sanitary sewage about 80% of the water supply quantity (National Programme on Technology Enhanced Learning, 2014).

According to the World Health Organization in Sturm (2013a), the minimum daily water demand per capita in urban areas is of 50 l/d, which implies about 40 l/d of wastewater per capita in urban areas.

Concerning the characteristics and constituents of the wastewater, these depend mainly on its origin, whether it is municipal or industrial wastewater, and in the last case, depending on the type of industrial activity that generated it. Nevertheless, being the case of the project municipal wastewater, here will be mentioned the main and most common substances that can be found in this type of inflow.

2.1.1. Total solids.

Wastewater contains about 0,05% of total solids from which 50% are dissolved such as calcium, sodium and soluble organic compounds and the other 50% corresponds to insoluble substances that can either settle or remain in suspension (Valdez & Vázquez Gonzalez, 2003).

2.1.2. Biodegradable organics.

Measured as biological oxygen demand (BOD) and chemical oxygen demand (COD). The BOD refers directly to the amount of dissolved oxygen in milligrams per liter (mg/L) consumed by the microorganisms, mainly bacteria, to oxidize the substrate into inorganic compounds and more bacterial cells (Gerardi, 2002). The degradation of these organics can create “dead zones” with anoxic conditions in aquatic ecosystems affecting plants, fish and other organisms (The World Bank, 2014).

2.1.3. Pathogens.

Microorganisms present in the wastewater that can cause diseases to the people in contact with them.

2.1.4. Nutrients.

Phosphorus and nitrogen can lead to the growth of unwanted algae, causing eutrophication when discharged in aquatic ecosystems. Moreover, these nutrients can also affect groundwater reserves when discharged on land (Sturm, 2013b).

2.2. Wastewater Treatment

2.2.1. Mechanical treatment

The mechanical treatment, also called primary treatment is aimed to reduce gross, suspended and floatable solid particles from the inflow. The mains steps are screening, coagulation – flocculation and sedimentation, sometimes chemical substances are added to improve the speed and performance of the operations.

Screening. This is actually considered a pretreatment, and it can go from coarse screening to fine screening, depending on the size of the solids removed. This operation reduces the solids that could damage pipes or equipment downstream in the treatment plant. The screening could be done through a set of parallel bars, wires or a mesh.

Sand and grit removal. The purpose is to remove grit in the form of sand, gravel, cinder or other heavy inorganic matter with high settling capacity to prevent damage and clogging in the equipment downstream. This can be done in grit chambers or through centrifugal separation (Metcalf & Eddy, 2003).

Sedimentation. Through this operation particles with density higher than water density are removed from the influent. Suspended solids and chemical flocs are examples of the materials removed.

Clarifiers or sedimentation tanks could remove particles through plain sedimentation or after the coagulation – flocculation stage. The sedimentation process is considered to be efficient when it is possible to remove from 50 to 70 percent of the suspended solids and up to 40% of the biological oxygen demand (Metcalf & Eddy, 2003). From primary sedimentation is obtained the primary sludge that later on will be treated.

2.2.2. Biological Treatment

After the mechanical treatment, the effluent still contains about 50% of the suspended particles as well as virtually all dissolved particles, organics and inorganics, which should be significantly reduced. For this reason, during secondary treatment biological or physicochemical processes are used, being the most common the first alternative (Valdez & Vázquez Gonzalez, 2003).

Biological treatment process depend on microorganisms to consume the organic compounds in the wastewater and to transform them into biological cells called biomass. These are carefully controlled to simulate in a short time in specially engineered reactors, the processes that would normally develop in the nature, in fresh water ecosystems (Valdez & Vázquez Gonzalez, 2003).

As stated by Tchobanogous et al. (2003), while the primary treatment more specifically primary sedimentation is highly efficient at removing setteable solids, the biological process are “essencial for removing soluble, colloidal and suspended organic

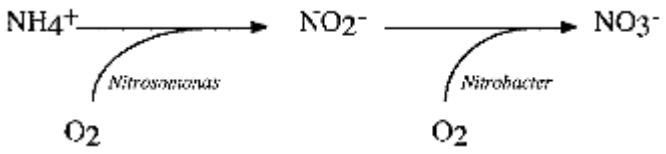
substances, for biological nitrification and denitrification and for biological phosphorous removal"

Activated Sludge.

This is one of the most common biological treatment alternatives. The process is constituted by a reactor where suspended microorganisms are held and a sedimentation tank for the separation of the biomass from the water and a recirculation system. Activated sludge processes can include nitrification, biological nitrogen removal and/or biological phosphorous removal, in aerobic or anaerobic reactors (Metcalf & Eddy, 2003).

The sludge produced during this process can be treated mixed with the primary sludge or separately.

The first step of this process is the *nitrification*, where NH_4^+ is oxidized by the action of nitrifying bacteria into nitrite and later on into nitrate ions, this process is shown in the following diagram (Gerardi, 2002),



The different communities of microorganisms oxidize waste into carbon dioxide (CO_2), water (H_2O), nitrite ions (NO_2^-), nitrate ions (NO_3^-), sulfate ions (SO_4^{2-}), phosphate ions (PO_4^{2-}), and more bacterial cells (Gerardi, 2002)

The biological oxidation of ammonia by the nitrifying bacteria need high availability of oxygen (> 1.0 mg/l) and the optimum pH is between 7.5 and 8.5, the process follows these reactions (Del Águila, 2011):

$$NH_4^+ + 3/2\ O_2 \longrightarrow NO_2^- + 2\ H^+ + H_2O$$
$$NO_2^- + 1/2\ O_2 \longrightarrow NO_3^-$$
$$NH_4^+ + 2\ O_2 \longrightarrow NO_3^- + 2\ H^+ + H_2O$$

The following step is the *denitrification* that takes places in anoxic conditions where only chemically bound oxygen is present (concentration <0.2 mg/l) and used by the microorganisms to transform NO_3^- into molecular nitrogen N_2 that goes into the atmosphere. The dinitrification process follows this reaction (Del Águila, 2011):

$$6\ NO_3^- + 5\ CH_3OH \longrightarrow 5\ CO_2 + 3\ N_2 + 7\ H_2O + 6\ OH^-$$

As mentioned by Gerardi (2002), “nitrification does not remove nitrogen from the wastewater, it simply transforms it from ammonium ions to nitrate ions while denitrification removes nitrogen from the wastewater by converting it to insoluble gases that escapes to the atmosphere.”

Regarding the *phosphorous removal*, for the inorganic compounds, this can be done with coagulants and precipitant chemical agents such as aluminium and iron salts, which require some mixing to generate precipitable compounds that are later easily separated with the sludge. Here are some examples of the reactions occurred in this process (Lenntech B.V, 2014).

$$Al^{3+} + H_nPO_4^{3-n} \leftrightarrow AlPO_4 + nH^+$$
$$Fe^{3+} + H_nPO_4^{3-n} \leftrightarrow FePO_4 + nH^+$$

Phosphorous can also be removed in a biological way in an activated sludge process, through its incorporation into the cells biomass which are later eliminated with the sludge via sedimentation. To achieve this, the phosphorous accumulating organisms (PAO) store and process phosphorous compounds in a combined anaerobic-aerobic process.

In the anaerobic phase the microorganisms consume and metabolize BOD, filling the stocks for carbonaceous substrate and releasing phosphate into the water. During the aerobic phase the bacteria metabolizes the organic compounds and produces CO_2

and H_2O, by doing this the bacteria is now able to accumulate phosphates and not only thrive but also multiply in the aerobic environment, having an advantage over those microorganisms that are not able to live during the anaerobic phase (Suárez & Jácome, 2007).

Chapter 3. Sewage sludge

Sludge can be simply defined as a “mixture of water and solid separated from various types of water as a result of natural or artificial processes”, while Sewage Sludge is the “sludge from urban wastewater plants” (Metcalf & Eddy, 2003)

Sludge is the largest by-product from wastewater treatment operations and its disposal is one of the most challenging environmental problems in wastewater treating processes (Garg, 2009).

As mentioned before, from most primary and secondary treatment processes sludge is produced, and it can be called primary sludge, secondary or activated sludge depending on the operation they come from (Metcalf & Eddy, 2003).

3.1. Sludge quantity and quality

The specific amounts of solids generated will vary significantly. However daily quantities for big cities could be estimated as shown in table1, while table 2 shows the typical solids concentration according to the wastewater treatment process, which allows to make a more accurate estimation of the sludge generated.

Table 1. Amount of solids generated in wastewater treatment processes. Adapted from Metcalf & Eddy, (2003)

Treatment operation or process	Average dry solids ($kg/10^3$) m^3
Primary sedimentation	150
Activates sludge	80
Chemical addition to primary tanks for phosphorus removal (800-1600 mg Lime/l)	800 + primary sedimentation solids
Suspended growth nitrification	Negligible
Suspended growth denitrification	18

Table 2. Typical solids concentration resulting from wastewater treatment processes. Adapted from Metcalf & Eddy, (2003)

Operation or process application		Typical solids concentration (% dry solids)
Primary settling tank	Primary sludge	6
	Primary sludge and waste activated sludge	4
	Primary sludge with iron salt addition for phosphorus removal	2
Secondary settling tank	Waste activated sludge with primary settling	0.8
	Waste activated sludge without primary settling	1.3
Anaerobic digester	Primary sludge	3.5
	Primary sludge and waste activated sludge	2.5

As well as the quantity, the quality of the sludge depends on its origin and the wastewater treatment process they come from and their characteristics will define their treatment and final disposal. Table 3 shows typical composition for some untreated sludge.

Table 3. Chemical composition of untreated sludge. Adapted from Metcalf & Eddy, (2003)

Item	Untreated primary sludge	Untreated activated sludge
Total dry solids (TS) %	5 – 9	0.8 – 1.2
Volatile solids Volatile solids (% of TS)	60 – 80	59 – 88
Nitrogen (N, % of TS)	1.5 – 4	2.4 – 5.0
Phosphorus (P_7O_5 % TS)	0.8 – 2.8	2.8 – 11
pH	5.0 – 8.0	6.5 – 8.0
Alcality (mg/L as $CaCO_3$)	500 – 1500	580 – 1100
Organic acids (mg/L as HAc)	200 – 2000	110 – 1700

3.2. Sludge treatment

As sludge carries a vast amount of dangerous components, responsible for the offensive character of untreated wastewater, from where they have been removed, it must be treated to remove the organic matter, pathogens and other contaminants it contains, to later on proceed to its reuse or final disposal.

Usually these solids and biosolids are the most voluminous substances removed from treated wastewater, and processing them for its reuse or final disposal is usually very complex and expensive (Metcalf & Eddy, 2003) . However, the treatment of these biosolids can be beneficial in the generation of bioenergy in the form of methane, which helps in the sustainability of the treatment process. To improve the digestion process of the sludge, this could be pretreated, in order to increase the biogas yield.

Volume reduction and decontamination for safe reuse or disposal are the main reason to treat sewage sludge. This is a bulky product, therefore its handling is usually complex and expensive. Exist many different sludge treatment options available, Figure 1 shows different treatment combinations due to they are not used all at the same time, and adequate treatment is based on the best combination according to the mentioned above.

Usually, just as wastewater, sludge must have a preliminary treatment, to enhance the efficiency of the subsequent operation, this treatment will depend mainly on the characteristics of the sludge and its final destiny, whether it is land use, incineration or disposal.

According to Metcalf & Eddy, (2003), the principal operations carried out in this stage are:

Grinding: where large flocs are sheared to prevent clogging in pipes and equipment.

Degritting: this could be done through the application of centrifugal forces in a flowing system to achieve separation of the grit particles from the organic sludge (Garg, 2009) or through sedimentation in a grit chamber, where the flow velocity is reduced to less than 0.3 m/s allowing the heavier particles to settle.

Mixing: sludge is blended to create a uniform sludge mixture for the following treatments.

Storage: storing will ensure a uniform feed rate to the treatment plant, protecting the downstream equipment and processes.

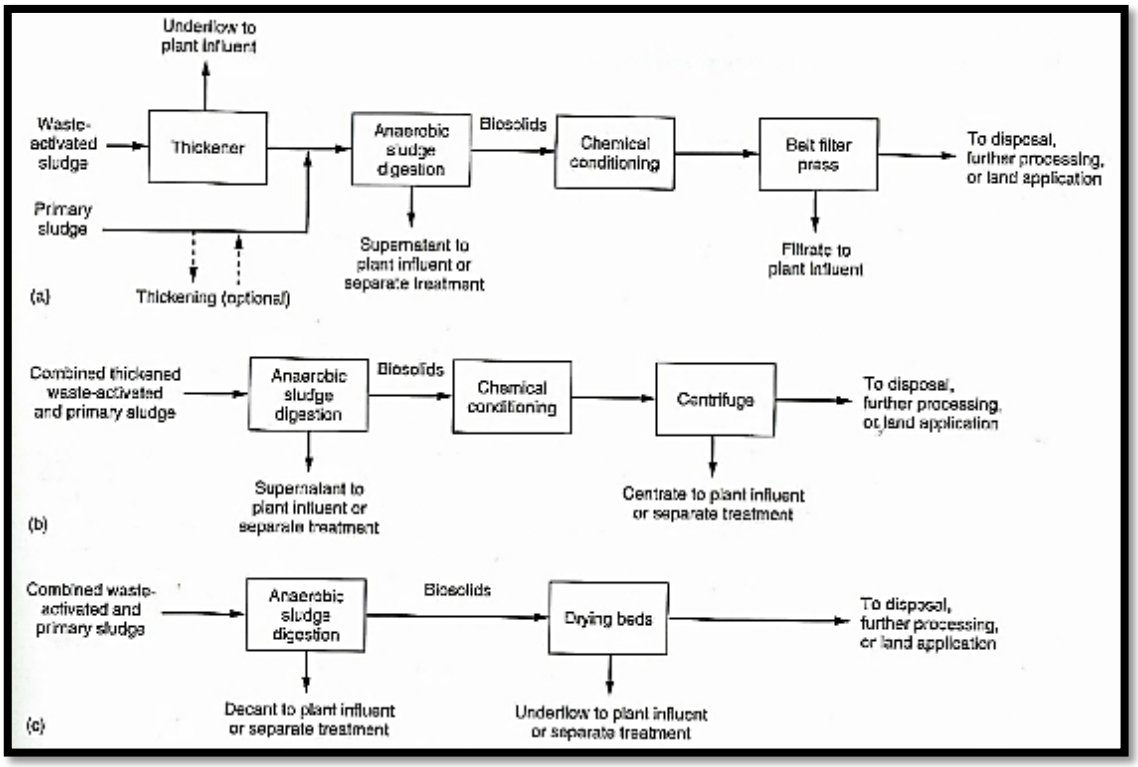


Figure 1. Different sludge treatment combinations including stabilization and dewatering operations (Metcalf & Eddy, 2003)**.**

Followed by these, there are different methods to achieve sludge concentration, stabilization, handling and disposal. These are:

3.1.1. Thickening

Procedure used to remove a fraction of the liquids in the sludge, decreasing its total volume and increasing the solids percent. This volume reduction reduces the size of tanks and equipment as well as the quantity of chemicals, heat and fuel required downstream. Usually the water retired from the sludge is returned to the wastewater treatment facilities (Metcalf & Eddy, 2003).

3.1.2. Disintegration

As mentioned before, anaerobic digestion is the most common process used for sludge stabilization and despite all the advantages that it presents, such as volume reduction and production of methane, this method represents a disadvantage related to slow organics degradation, therefore, long fermentation periods; furthermore, “only 30-50% of the total COD or volatile solids (VS) can be degraded in very long time” (Show et al. 2010, p.54).

Exist different options in order to disintegrate the sludge prior digestion to enhance its performance, some of these options are: mechanical disintegration such as ultrasonic treatment and chemical disintegration such as enzyme addition.

3.1.3. Stabilization

The main stabilization methods, according to Tchobanogous et al. (2003), are:

Alkaline Stabilization: in this process lime in form of $Ca(OH)_2$ or quicklime is added to the sludge to rich a pH of 12 or higher, disabling microbial activities, and therefore preventing odors and putrefaction (Metcalf & Eddy, 2003). The reaction of the lime with sludge water creates an exothermic reaction, which kept above 55°C improves pathogen die-off (Bauerfeld, Dockhorn, & Dichtl, 2005).

Aerobic Digestion: this process is based on a biochemical oxidative stabilization of the sludge, where the cell tissue is aerobically oxidized, destroyed and transformed into products such as CO_2, H_2O, NH_4^+, NO_2^- and NO_3^- (Shammas & Wang, 2009). This process offers some advantages like a very valuable fertilizer

obtained from the sludge, an easy operation and low capital costs. Nonetheless the operation costs are large, mainly due to the oxygen supply, the performance of the process is highly sensitive to temperature and aeration conditions, also, methane as byproduct is not recovered, which represents a big disadvantage (Metcalf & Eddy, 2003).

Composting: in this aerobic process the sludge is converted to a stable product through a biological degradation, where about 30% of the volatile solids transform into CO_2 and water. This process generates temperatures up to 70°C, thus destroying pathogens. Through this, biosolids can be directly used in agriculture, depending only on the composition of the sludge (heavy metals, toxic elements, etc.) To reduce the size of composting facilities up to 40%, sludge can be stabilized by aerobic or anaerobic digestion prior composting (Metcalf & Eddy, 2003).

Other process for sludge stabilization and the most commonly used is *anaerobic digestion*, but due to the importance that this method represents for the project, the following section is dedicated to it.

Anaerobic Digestion

It is the decomposition of organic matter in the absence of oxygen (Metcalf & Eddy, 2003). The purpose of this process is to reduce volume and the organic matter to stable and inorganic compounds. Additionally, anaerobic digestion produces methane gas, which can be burned for heat or electricity generation (Cheremisinoff, 2002). In the anaerobic digestion process are involved waste conversion and stabilization as shown in the figure below. The main products from this process are methane (CH_4), carbon dioxide (CO_2) and organic residues. The main advantages it presents are reduction in organic contents of the sludge, improved dewaterability, destruction of most pathogens, generation of useful end products, low nutrients requirements and no oxygen requirement (Gray, 2004; Taricska, Long, Chen, Hung, & Zou, 2009)

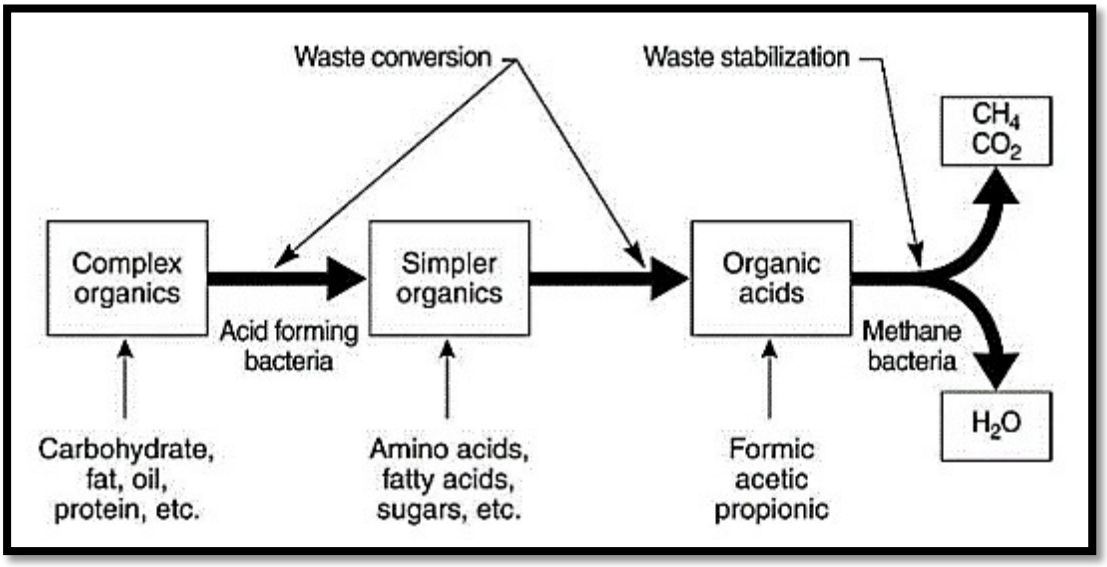


Figure 2. General anaerobic biological reactions (Taricska et al., 2009)**.**

Three basic types of chemical and biochemical reactions involved in anaerobic digestion occur almost simultaneously, these are hydrolysis, fermentation or acidogenesis and methanogenesis (Metcalf & Eddy, 2003). Firstly is the hydrolysis of the high molecular weight organic compounds (carbohydrates, fats and proteins) into simpler substances, then comes the fermentation and the conversion of these substances into organic acids, such as acetic acid (CH_3COOH) and propionic acid (CH_3CH_2COOH) by acid forming bacteria, here along with the organic acids, gases such as hydrogen sulfide and carbon dioxide are generated (Cheremisinoff, 2002; Taricska et al., 2009). Then follows the gasification of the organic acids to methane and CO_2 by the methane forming bacteria (Huan, Yiying, Mahar, Zhiyu, & Yongfeng, 2009).

Assuming that the compound $C_5H_7O_2N$ is representative for secondary sludge, the overall anaerobic digestion process can be expressed in the following reactions (van Haandel & van der Lubbe, 2007):

$$C_5H_7O_2N + 3H_2O + H^+ \rightarrow 2.5\,CO_2 + 2.5\,CH_4 + NH_4^+ \text{ or}$$
$$C_5H_7O_2N + 4H_2O \rightarrow HCO_3^- + 1.5\,CO_2 + 2.5\,CH_4 + NH_4^+$$

The bacteria involved in these reactions are strict anaerobes, therefore, in the presence of oxygen, toxicity and die off of the bacteria may occur.

The basic configuration of the reactor is the single stage conventional configuration (Figure 3). This reactor has a circular cross section, it is unmixed and it allows digestion, supernatant separation and withdrawal, and stabilization and withdrawal of concentrated sludge (Taricska et al., 2009).

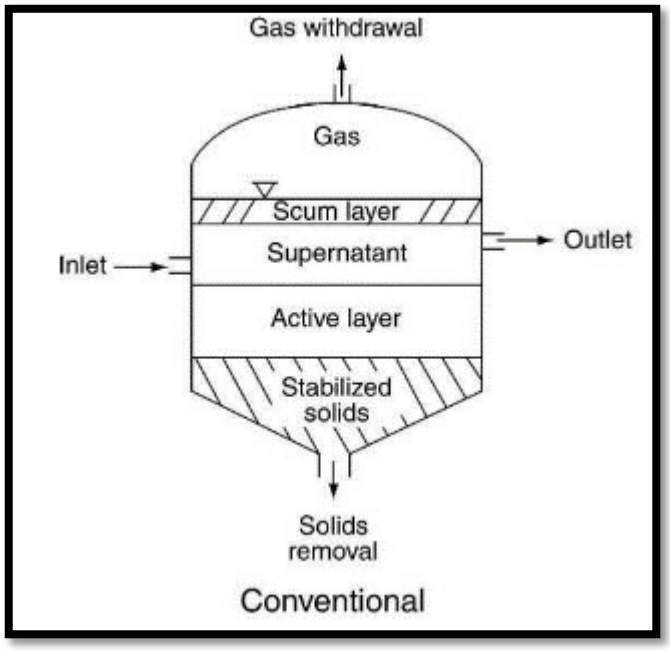


Figure 3. Digester reactor configuration (Taricska et al., 2009)**.**

The effectiveness of the digestion process can be measured by a combination of several parameters such as the destruction of the organic matter, volume and quality of gas produced, pH value, organics acids content and alkalinity concentration (Cheremisinoff, 2002)

From the anaerobic stabilization process, gases generated by bacterial activity are methane (CH_4) and carbon dioxide (CO_2), which in cases of good operation should be about 65% CH_4 and 35% CO_2 and only small traces of other gases (Cheremisinoff, 2002).

Control parameters

Exist different parameters that can be used as control of the performance of the digestion process. Some of these parameters are (Mountain Empire Community College, 2014):

Volatile solids. The content of organic or volatile matter in the digested sludge should be around 50%. When the amount is lower, it might be problems associated with temperature of the reactor, overload, mixing, or low organic content in the inflow.

Volume and gas quality. Gas production should be relatively constant in relation to the organic load fed to the reactor, and when the volume of gas produced is not corresponding, it might be a sign of toxic compounds inside the reactor. Regarding the composition of the biogas produced, this one should be around 65% methane (CH_4) and 35% carbon dioxide (CO_2).

pH. This parameter indicates the acids (H^+) concentration in the reactor, its value should be between 6.5 and 7.5 to benefit CH_4 formation.

Volatile acids and alkalinity. Acetic acid and other organic acids are formed by acid forming bacteria during the digestion process. The amount of this acids is a good indicator of the performance of the reactor. Their value should not be higher than 500 mg/L of acetic acid.

On the other hand, the buffering capacity of the sludge, which id the ability to neutralize acids, is indicated by the bicarbonate alkalinity in the form of $CaCO_3$. The value of this parameter usually varies from 2000 to 5000 mg/L.

A good indicator for the stability of the digestion process is the ration between the volatile acids in mg/L of acetic acid and the bicarbonate alkalinity in mg/L of CaCO3, this is,

$$\frac{\text{Volatile acids, HAc (mg/L)}}{\text{Bicarbonate alkalinity, } CaCO_3 \text{ (mg/L)}} \leq 0.25$$

3.1.4. Dewatering/Drying

This operation pursues the reduction of the water content in the sludge to reduce costs and handling problems in transportation, storage and final disposal. Exist different techniques for removing moisture from sludge, the selection relies on the characteristics of the sludge, its intended use, the space and budget available and the environmental conditions of the location (Metcalf & Eddy, 2003).

According to (Metcalf & Eddy, 2003) Some methods used for dewatering the sludge are:

Centrifuge: based on the density differences, the solid-bowl centrifuges can be used for dewatering of solids and biosolids.

Belt Filter Press: previous conditioning with polymer, the sludge firstly is thickened by gravity, later a low pressure is applied, then the sludge enters a high pressure section where is sheared, removing a big deal of water.

Filter press: the principle is to dewater the sludge by imposing a great pressure to force the water out.

Sludge drying beds: these follow the principle of the extended aeration activated sludge treatment process to digest and settle the solids and biosolids, and later on, use them as land conditioners or dispose them in a landfill.

Lagoons: the principle is the evaporation, therefore they are appropriate systems for climates with a high evaporation rate. Biosolids are removed mechanically, usually with solids concentrations of 25 to 30%.

Sometimes, and depending on the final goal, after dewatering the sludge, comes the final drying, to achieve a higher moisture reduction by the application of heat. Among the benefits, there is volume reduction, therefore easier transportation and handling, aside from the pathogen removal (Metcalf & Eddy, 2003). After heat drying, activated

sludge is considered a superior sludge product. It retains most of the organic solids and more nitrogen than other sludge (Cheremisinoff, 2002).

3.1.5. Disposal

After sludge has been stabilized and dried out, it still must be properly disposed; the two main alternatives are incineration and disposal in land.

The incineration involves high capital and operation costs, strict maintenance, harmful byproducts and residues; however it offers a great volume reduction, elimination of pathogens and toxic compounds, and energy recovery potential, all by the conversion of the organic matter through oxidation into carbon dioxide, water and ashes.

For a better performance of the incineration process sludge is usually dewatered and should not be stabilized as this reduces volatile material, increasing the fuel requirement. There are four basic types of incinerators used in wastewater treatment plants, the multiple hearth incinerator, the fluid bed incinerator, the electric furnace and the cyclonic furnace. Each system has a particular method of incineration and they differ from one another in cost, efficiency, and environmental impact (Metcalf & Eddy, 2003).

There are some options such as disposal in water and disposal in land. About disposing the final sludge in water, there already exist restrictions in some countries due to the environmental impact this creates. Regarding land disposal, options are burial, fill and its use as a fertilizer or soil conditioner, from these, the last alternative happens to be the least harmful for the environment, and in fact, it is a suitable solution for those soil with little natural agricultural value, saving the producer tons of money in artificial fertilizers.

Biosolids in sludge can be used for land improvement and also, land applications can be useful for biosolids treatment. The combination of the sunlight, microorganisms in the soil and desiccation can destroy pathogens and harmful organics (Metcalf & Eddy, 2003).

In Agricultural application specially, biosolids represent a great benefit for the land, nutrients improve plant growth and act as partial replacement for chemical fertilizer, organic matter not only improves soil structure and its water retention and infiltration capacity but also enhances the capacity of the soil to retain potassium, calcium and magnesium, essentials for plants and for increasing the biological diversity in soil (Metcalf & Eddy, 2003) and reducing its erosion (Cheremisinoff, 2002).

The major fertilizing elements are nitrogen, phosphorous and potassium, and the amount each requires depends on the soil, climatic conditions and crop.

Nonetheless, for its further use, especially as a soil conditioner, biosolids must meet regulations which vary from country to country, but in general limit the content of pathogens and pollutants, as well as the vector attraction factor.

Chapter 4. Wastewater treatment in Bergisch Gladbach[1].

The wastewater treatment plant of Bergisch Gladbach (Figure 4) has a treatment capacity of 200.000 equivalents, and it currently handles close to 150.000 equivalents, covering the wastewater treatment requirements from Bergisch Gladbach and Bensberg. The inflow is in average 20.000 m^3/d during dry weather being the maximum about 1200 l/s during rainy weather and its organic load (BOD_5) is close to 300 mg/L.

Figure 4. Wastewater treatment plant of the city of Bergisch Gladbach, Germany.

[1] The information in this chapter was obtained from the information booklet of the treatment plant (Klärwerk Beningsfeld, 2012), the personnel and ACRON system administration software.

4.1. Mechanical treatment.

The wastewater inflow is taken from two channels as mentioned before, the one coming from Bensberg is elevated with a screw pump and mixed with the other one before entering the screening system, where coarse materials (Ø > 6 mm) are separated and the water continues to the aerated grit removal section, to later enter the primary clarifiers, two sedimentation tanks of 1500 m^3 each, were primary sludge (settled material and floating fats) are removed and sent to the sludge treatment facilities. Figure 5 shows the different steps of the mechanical treatment in Bergisch Gladbach.

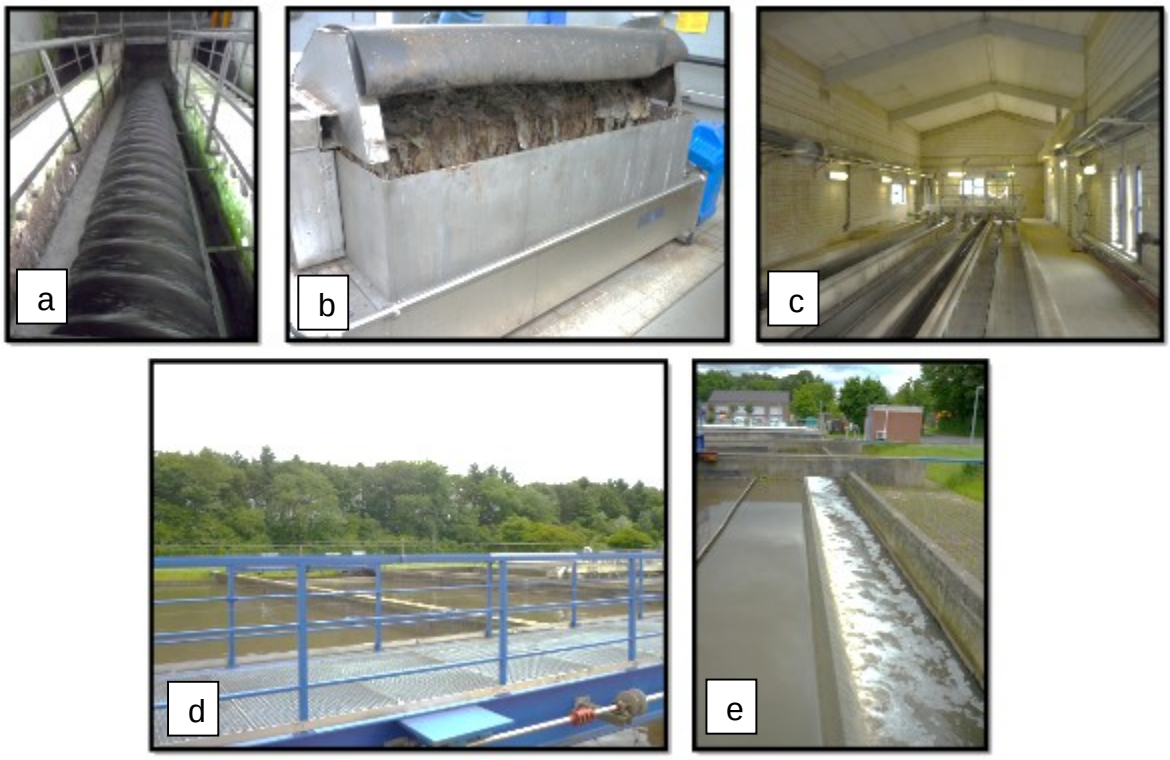


Figure 5. Mechanical treatment: a. screw pump; b. press and washing system for screened materials; c. grit chambers; d. primary clarifiers; e. overflow of primary clarifiers (by the author, 2014).

4.2. Biological treatment.

After the primary sedimentation, the water goes into the activated sludge tanks, were carbon, nitrogen and phosphate compounds are removed by the actions of microorganisms. The overall volume of the biological reactors is 20.000 m^3.

Nitrogen is removed through a process of nitrification - denitrification, and the phosphate removal in reached through biological processes and chemical precipitation with the use of aluminium and iron salts. The average retention time is 14 hours, after which the water goes to the secondary clarifiers, with a total volume of 11.100 m^3.

In the secondary sedimentation tanks secondary sludge is collected and then divided in two parts, one goes back as recirculation to the activated sludge tanks, while the other portion, an average volume of 1000 – 1500 m^3/d of excess sludge, is pumped to the sludge treatment section. Figure 6 shows the steps of the biological treatment in Bergisch Gladbach.

After the biological treatment, the water is filtered in antracit-sand filters with an approximate area of 360 m^2 to be later disposed in a canal to discharge in the Rhein river.

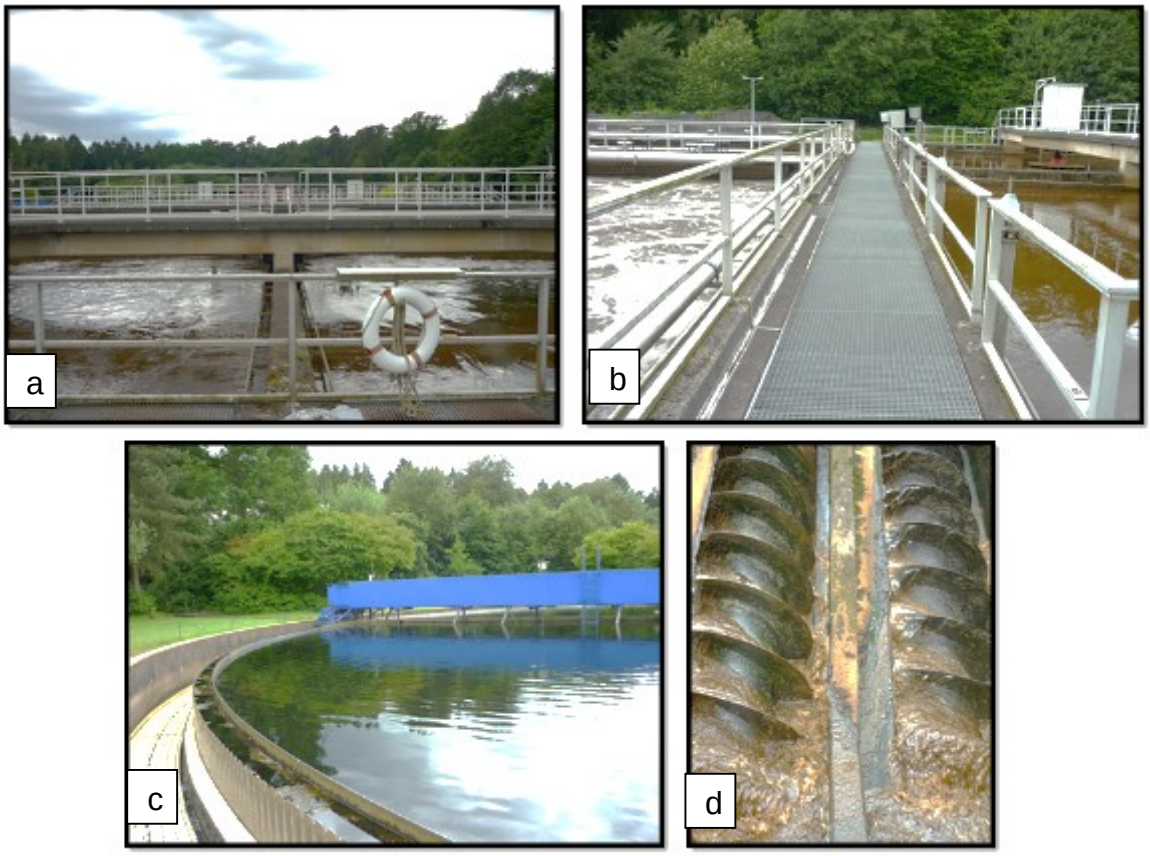


Figure 6. Biological treatment facilities: a and b. activated sludge – anoxic and aerobic tanks; c. secondary sedimentation; d. pumping (by the author, 2014).

Chapter 5. Sludge treatment in Bergisch Gladbach[2].

The primary sludge goes into pre-thickener, were it is settled until reaching a dry solids content of 4 to 5 % and it is later pumped into the reactor for anaerobic digestion at a rate of 100 – 130 m^3/d.

The excess sludge, pumped from the secondary sedimentation, is thickened in two disk thickeners for a volume reduction of up to 80%, a dry solids content in average of 3 - 4 % and an organics solids content close to 60%. Before being anaerobically digested, the secondary sludge is mixed with enzymes added for biological disintegration and improvement of the digestion process.

The stabilization process is carried out through anaerobic digestion, in two digesters of 3300 m^3 each and 30 days retention time, where both sludge types are treated separately. The digesters have an operation temperature of 38°C and a constant mixing to reach the degradation of the organic substances and the generation of biogas with a 60% methane content as a byproduct of the biological activity.

After digestion, the sludge is dewatered in two membrane filter press. The characteristics of the final sludge are 30% of dry solids content and 55% of volatile solids content. The final disposition of the sludge is incineration.

Biogas Production.

This is a product of the anaerobic digestion. Its methane content is about 60% percent, which makes it a high energy product. The biogas is dehumidified by cooling and then purified with activated carbon for the elimination of H_2S and siloxane compounds. Then it is sent to the energy plant, where two modules of 360 kW each, work on the conversion to heat and energy. The treatment plant has an energy production of almost 3 million kWh/a.

[2] The information in this chapter was obtained from the information booklet of the treatment plant (Klärwerk Beningsfeld, 2012), the personnel and ACRON system administration software.

Chapter 6. Ultrasound system

6.1. Description of the system

Ultrasound is sound energy at frequencies above 20 kHz, generated by the transformation of mechanical or electrical energy into high-frequency vibrations by a transducer (Show et al., 2010).

Through ultrasonic disintegration it is possible to break up microbial cells to release intracellular materials, and solubilize a portion if the insoluble organic matter. It works more efficiently at frequency values ranging from 20 to 40 kHz as summarized by Show et al. (2010), from Harrison STL (1991) and Atchley et al. (1988).

The application of the high acoustic energy generated by the ultrasound to a liquid, will modify the character of the dissolved substances in the liquid through the generation of a series of physical and chemical reactions resulting from “the generation and collapse of cavitation bubbles produced under the acoustic condition” (Show et al., 2010). The cavitation process generate “hot spots” with temperatures up to about 5000 K and pressure up to a several hundred atmospheres, as indicated by Tiehm et al. (2001) and Wang et al. (1999) in Show et al. (2010). Figure 7 illustrates this process.

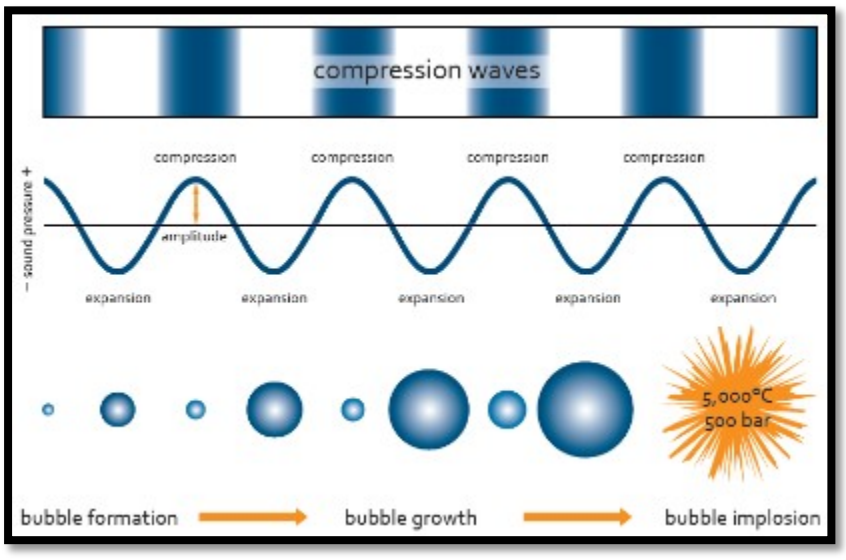


Figure 7. Cavitation bubbles produced under acoustic conditions (ULTRAWAVES GmbH, 2012b)

Sound is composed of longitudinal waves that alternate cycles of compression and rarefaction that can produce cavitation in high power ultrasound applications. The results of cavitation, which is the “formation, growth, and collapse through implosion of microbubbles” filled with gas or vapor, can be the emission of shock waves, the erosion of solid surfaces and the production of several chemical reactions within the liquid, as stated by Neppiras EA (1980) in (Show et al., 2010).

Several factors influence the effects of the cavitation, some of these factors mentioned by Show et al. (2010) are the temperature of the liquid, being more beneficial when it is higher, the viscosity and surface tension of the liquid, the ultrasound intensity or acoustic energy density and the frequency of ultrasound vibration, which as mentioned before, results better in values ranging from 20 to 40 kHz.

The typical ultrasound system counts with 5 or more oscillating units “consisting of a converter, booster and sonotrode” (ULTRAWAVES GmbH, 2012; p. 7). Figure 8 shows the diagram of the complete system and the picture of an installed equipment.

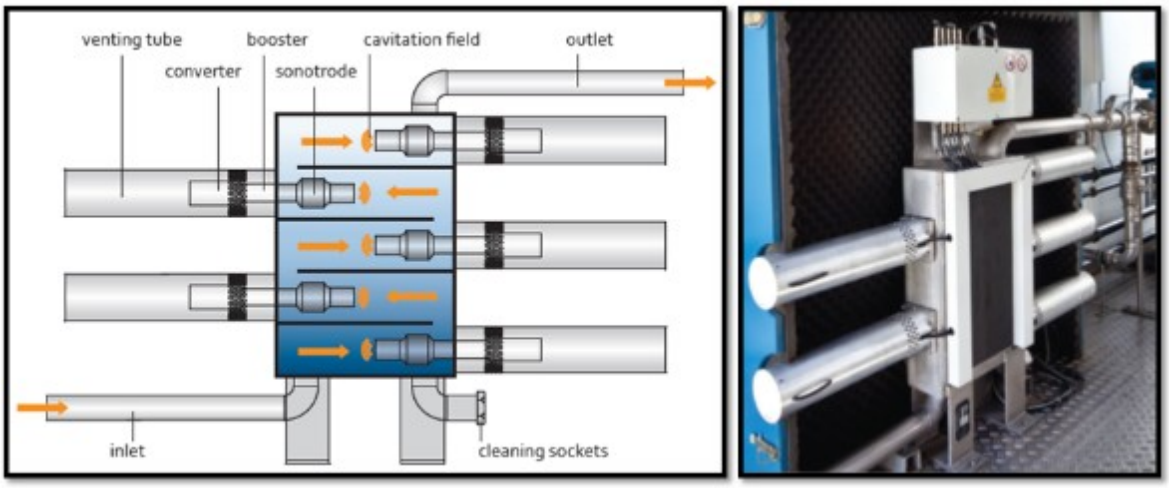


Figure 8. Diagram and picture of an ultrasound reactor (ULTRAWAVES GmbH, 2012b, 2012c).

Figure 9 shows a sonotrode with the configuration system of the reactor as well as a sonotrode working on water. As is possible to appreciate in this picture, the most active area of the sonotrode is its base.

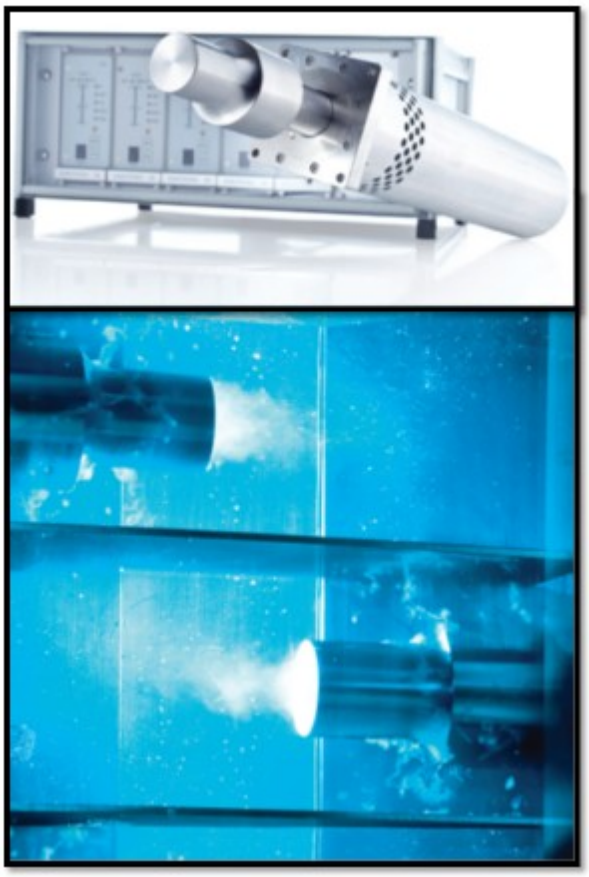


Figure 9. Sonotrode of the reactor uninstalled and in operation (ULTRAWAVES GmbH, 2012a)

6.2 Influencing parameters

When it comes to a successful application in sludge disintegration, Show et al. (2010) summarizes that the most influencing parameters are the frequency, the treatment time and the applied energy.

The frequency has proven to give better yields at low values in order to build up and strengthen the desired shear forces within the liquid, established by Tiehm et al. (2001).

The treatment time, which Chu et al. (2001) studied and concluded that in the first 20 minutes affect the floc structure and the dewaterability of the sludge; from 20 to 60 minutes, the floc size did not chance significantly, bacteria and coliform within the liquid were disinfected and the chemical oxygen demand increased; the last stage, from 60

to 120 minutes, important effects regarding the transformation of solid state compounds into soluble forms were observed only with a raise in the bulk temperature of the sludge. More importantly, concerning the methane production, a treatment time longer than 30 minutes did not lead to higher yields.

The energy level, here is concluded that "typically energy doses between 4 and 10 kWh/m^3 should be sufficient" to react a considerable reduction of floc size and an increase in the COD.

6.3 Application of ultrasonic treatment in anaerobic digestion

As mentioned in chapter 3, anaerobic digestion is defined basically by three reactions that occurs almost simultaneously, hydrolysis, acidogenesis and methanogenesis. From these reactions, Eastman JA and Fergusson JF (1918) state in Show et al. (2010) that the limiting step is given by the hydrolysis of the organic matter particles into soluble substances. If the sewage sludge is pretreated with ultrasound before the anaerobic digestion process, this last one will be enhanced due to the lyses of the cell and the release of the intracellular organics and the higher availability of sites from microbial action (Show et al., 2010).

Previous studies presented in Show et al. (2010) have found stability of the sludge in short residence times, 2.2 times higher gas production than the control reactor (Neis et al. 2000), acceleration in the anaerobic digestion (Tiehm et al. 1997), smaller floc sizes in shorter times (Jean et al. 2000), destruction of the floc structure and therefore, a higher release of on intracellular organic substances by the action of hydrolytic bacteria (Wang et al. 1999), among other beneficial effects regarding the treatment of the sludge.

6.4. Effects of the ultrasonic sludge disintegration

Structural changes. Highly porous flocs (≈100 μm) could be disintegrated into microflocs (≈13 μm), and release some extracellular polymers by the action of mechanical forces generated by ultrasonic waves, by varying the intensity, the floc size could reduce up to 35% of its size in shorter times according to the stated by Jorand F. et. al, (1995), (Show et al., 2010)

COD/SCOD Change Muller et al. (2004) indicates that the Chemical oxygen demand (COD) increases in the aqueous phase due to the release of the intracellular compounds by the breakup of microbial cell walls. On the other hand, the relation between the soluble chemical oxygen demand (SCOD) and the ultrasonic treatment time is considered linear, due to its significant increase during sonication and its acceleration effect over sludge degradation, as studied by Wu JM et al. (1992), (Show et al., 2010).

Biogas Fermentation reactors containing disintegrated sludge have presented 5 – 10% higher percentage of methane as the control fermenters according to Neis U (2000). For this, Onyeche TI et al. (2002) and Clark PB et al. (2000) assure that the hydraulic retention time (HTR) is a key factor in the production of methane, but longer HTR not necessarily indicates higher methane yield, to this, other factors are also important, such as adequate stirring and temperature.

Chapter 7. Experimental methodology

7.1. Experimental setup.

In order to reach the objectives of the research, a pilot scale plant was set up and operated. The components of the pilot plant, as showed on figure 10, are:

- a. Steel reactor for anaerobic digestion (2)
- b. Steel tanks for the storage of the biogas (2)
- c. Recirculation pumps (2)
- d. Pressure manometers (2)
- e. Peristaltic pump (1)
- f. Digital control panel (1)

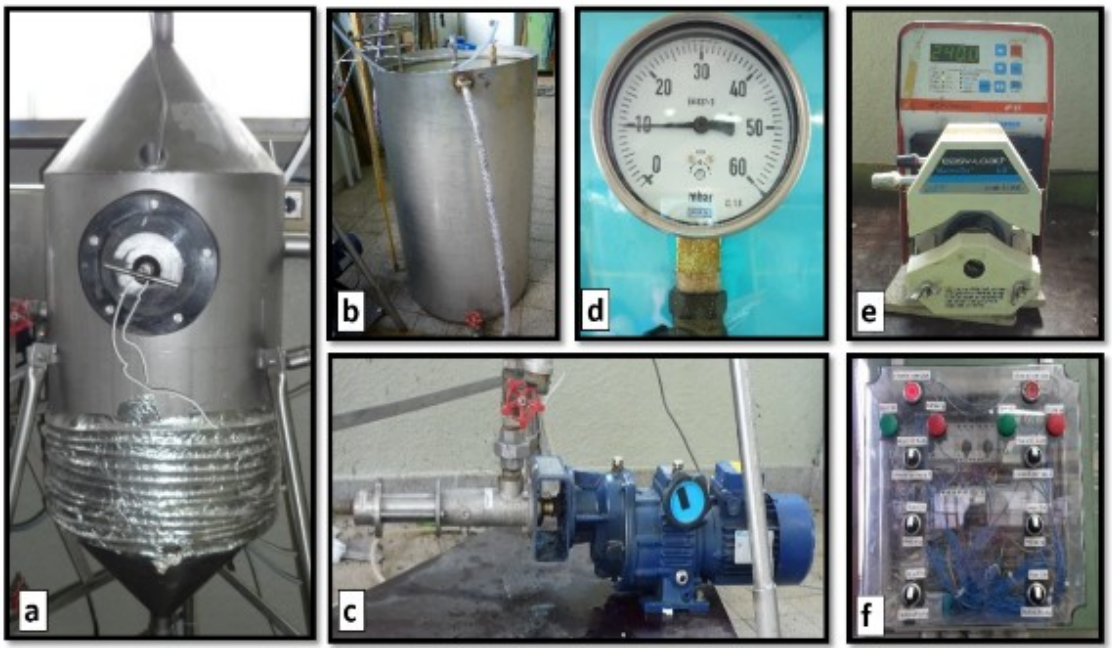


Figure 10. Elements of the experimental setup of the pilot plant (by the author, 2014).

The two reactors of 60 liters capacity each were set up with their corresponding gas tanks (figure 11), pump and manometers; the pilot plant is presented on figure 12.

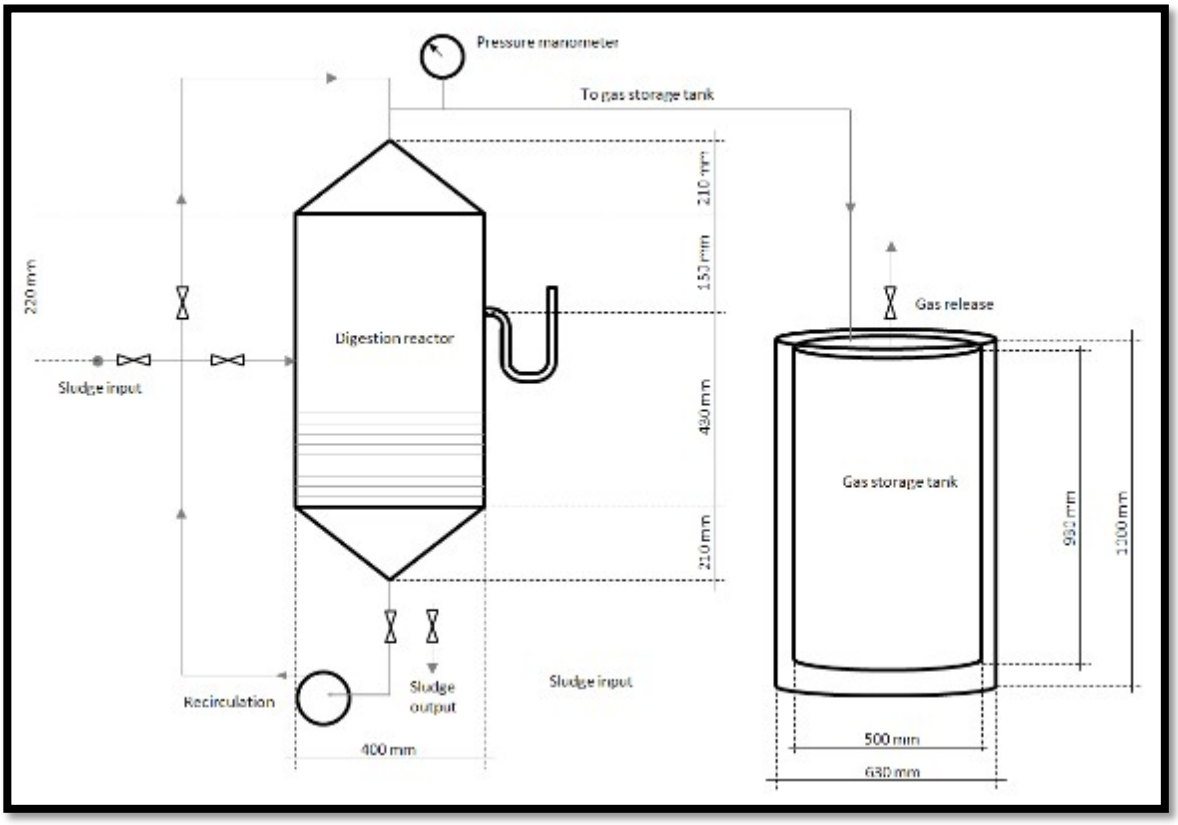


Figure 11. Anaerobic digestion reactor and gas storage tank used in the pilot plant (by the author, 2014).

Figure 12. Set up of the pilot plant (by the author, 2014).

The reactors, called R1 and R2 were initially filled up with sludge from the digester reactor for secondary sludge in the treatment plant in order to start running the pilot

plant and during the whole experiment these were operated on the mesophilic range of temperature, close to 38°C to simulate in the best possible way the behavior of the big scale reactors in the treatment plant, this is an important factor that influences microbial activity and methane formation (Metcalf & Eddy, 2003).

7.2. Phases of the project

As presented on figure 13, the project was divided in three phases; the first phase, divided in two periods (phase 1.1 and 1.2) to ease the presentation of the results was the stabilization phase. Phase 2 was the beginning of the ultrasonic treatment applied to R1, during this phase the energy input what low. Afterwards, phase 3 was characterized by the application of high energy ultrasound to R1.

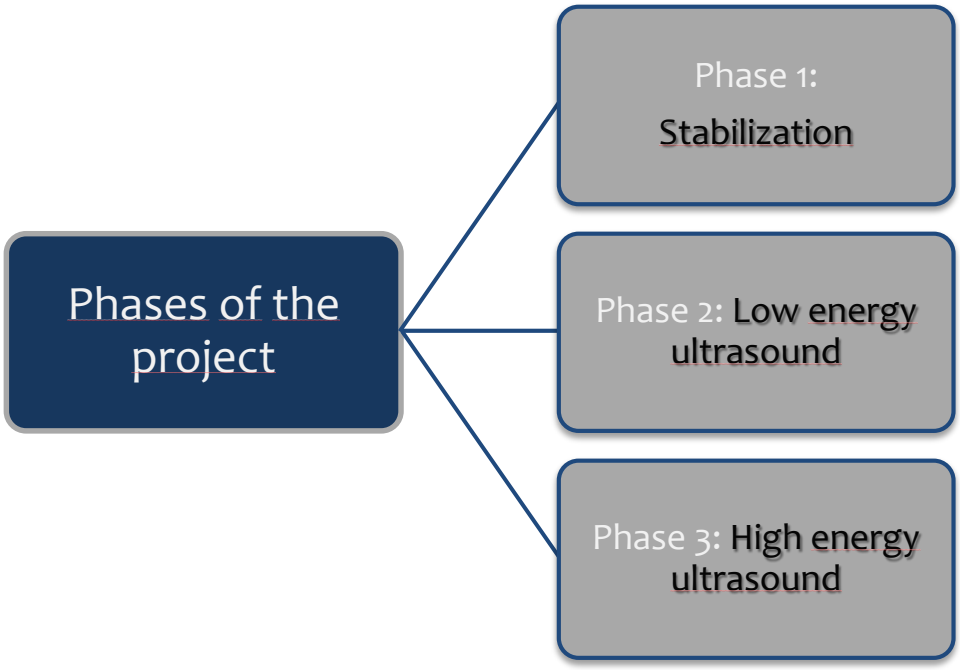


Figure 13. Experimental phases of the project (by the author, 2014).

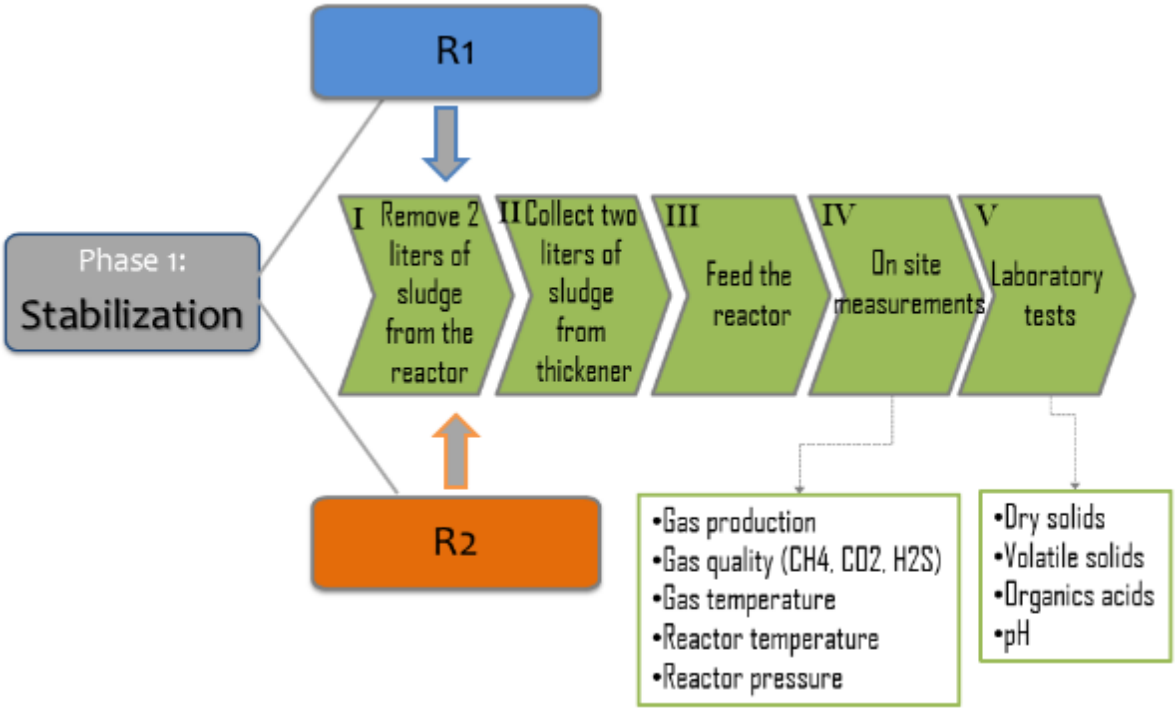


Figure 14. Steps followed during phase 1 (by the author, 2014).

During phase 1 as shown on figure 14, the steps carried out were the same for both reactors, R1 and R2, here were established the necessary tests to control the performance of the reactors. This phase lasted 62 days.

Figure 15 presents the steps for phase two; as indicated in the diagram in this phase was initiated the ultrasonic treatment for R1, being this the only variation on the operation and control of the reactors in order to establish a more accurate comparison. During this phase a low energy input was used for the sonication of the raw sludge used to feed R1.

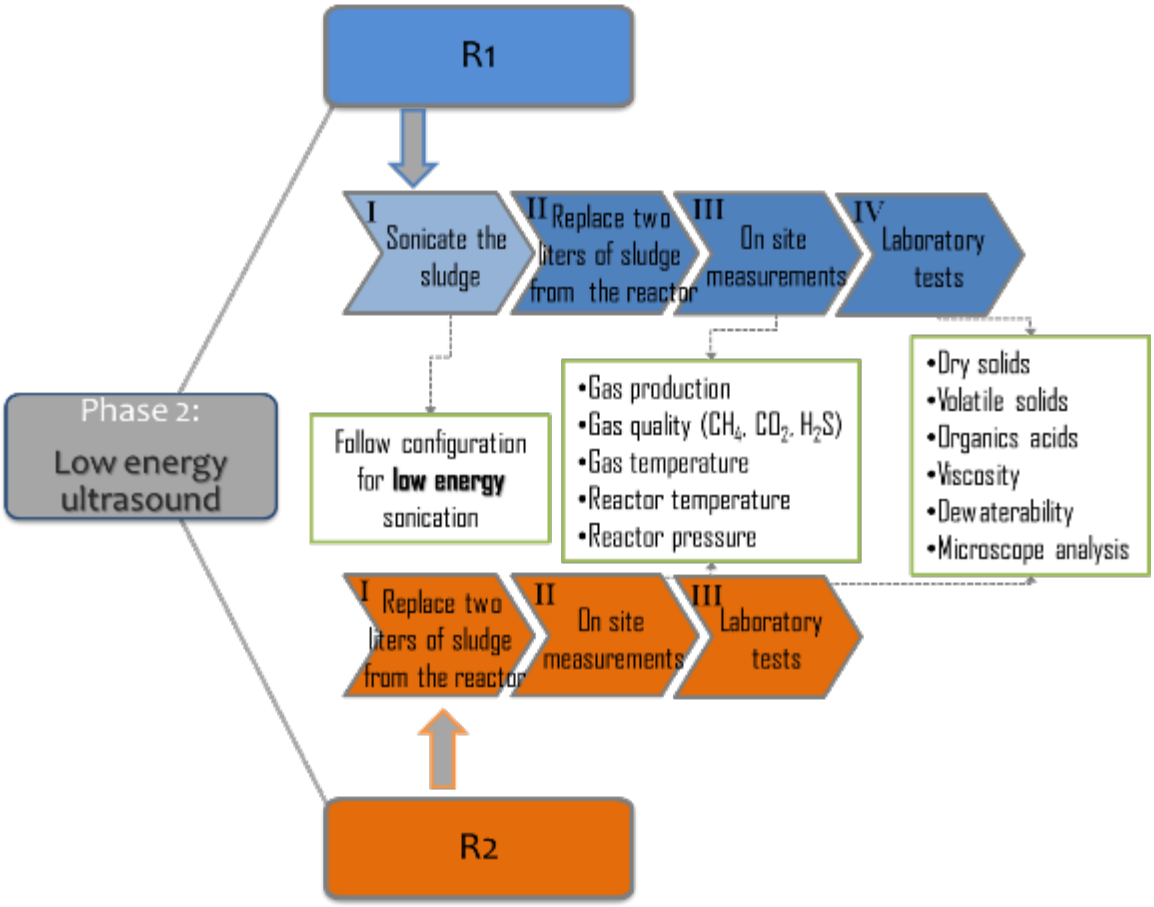


Figure 15. Steps followed during phase 2 (by the author, 2014).

Phase 3 followed the same configuration of phase two except here high ultrasonic energy was applied to R1 before the feeding of the sludge. The details related to the energy input will be presented in the results.

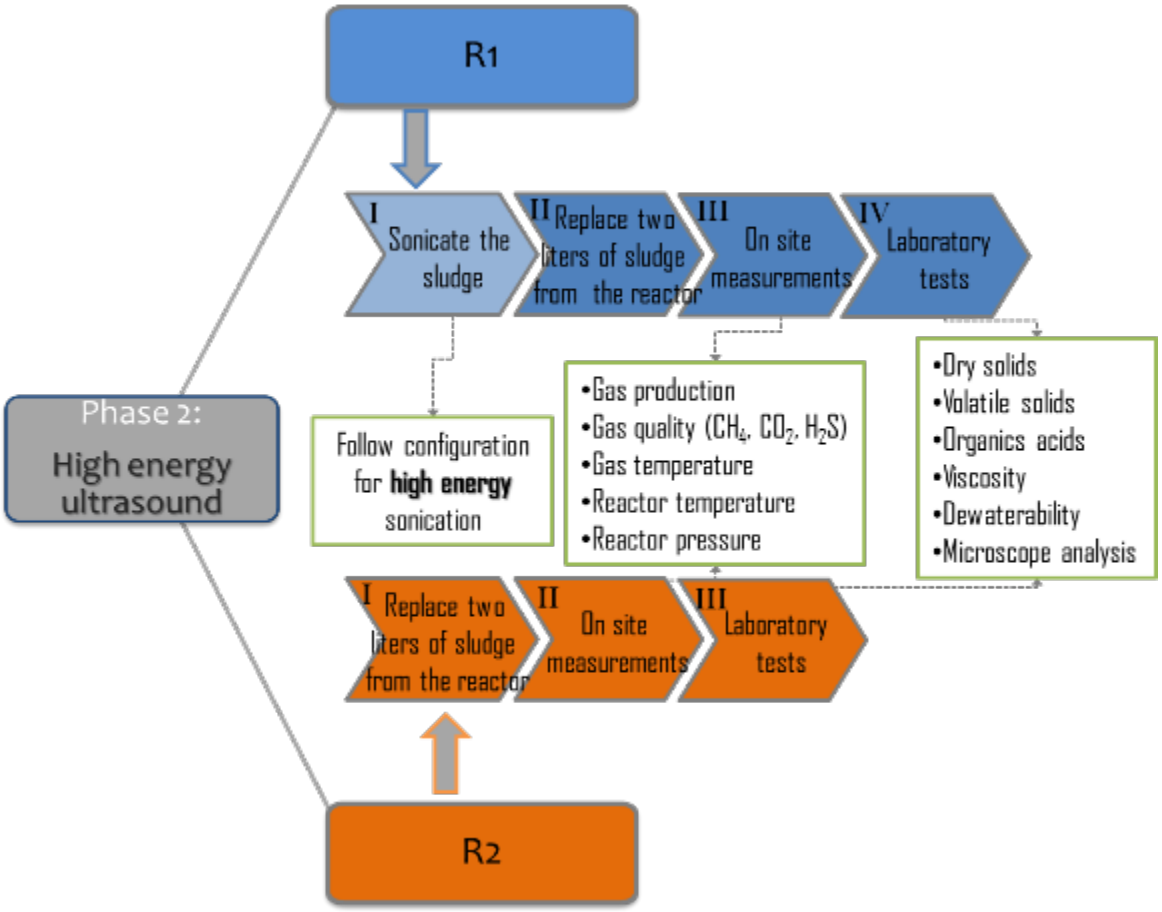


Figure 16. Steps followed during phase 3 (by the author, 2014).

7.3. Partial replacement of the sludge from R1 and R2.

This was done during the three phases of the project, and it follows three basic steps:

- First two liters of sludge were collected from the bottom of the reactors as shown on figure 17a and it is done with a measured container to withdraw the exact quantity of sludge.

- Second, two liters of sludge are collected from the thickener to feed the reactor; even though the treatment plant counts with two disk thickeners for waste activated sludge, the collection was always done from the same thickener "SD 2" (figure 17 b y c).

- Third, the reactor is fed using a peristaltic pump ISMATEC – MCP-Process IP65 at a velocity of 240 rpm (figure 17e) with two hoses of about 150 cm large and

a diameter of 1,5 cm (figure 17f). During this step it was very important to avoid the entrance of air into the hose during the feeding process to keep away the oxygen from the interior of the reactor. In phases 1 and 2 before feeding the sludge to R1 and R1 this was mixed with the disintegration enzymes (CR Bioaktive 2, Hydro Pro 3 and Celluferm Ultra), while in phase 3 the application of enzymes was replaced and instead surfactant was added to the raw sludge previous the disk thickener.

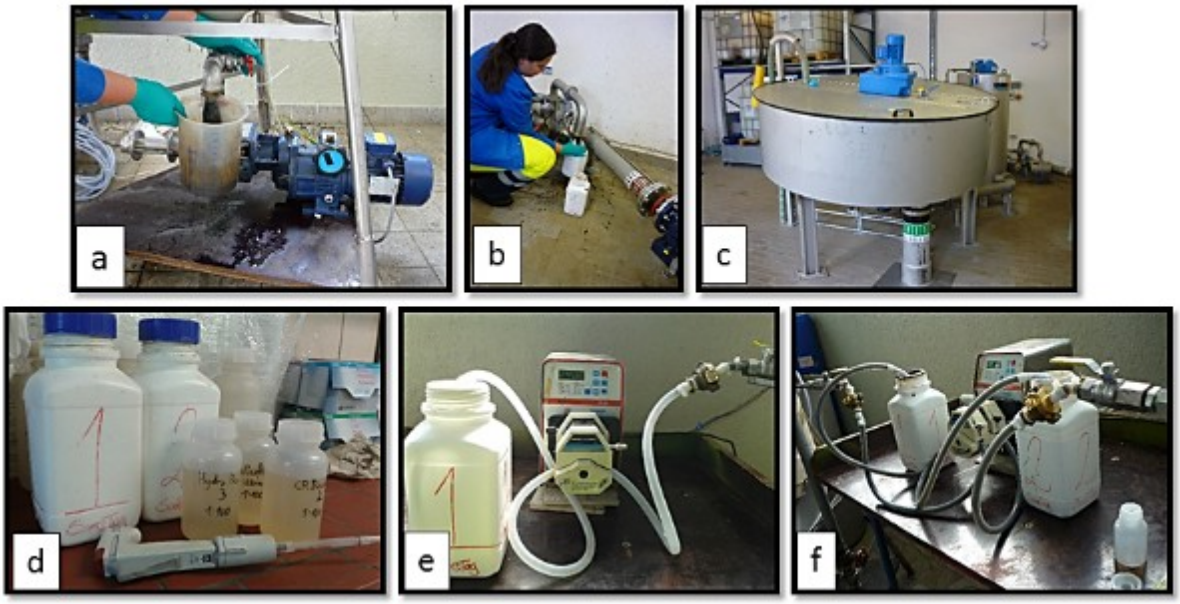


Figure 17 Feeding of the digester reactors in the pilot plant (by the author, 2014).

Figures 18 and 19 illustrate the scheme follow for the feeding of R1 and R2 in phases 1, 2 and 3. Here is illustrated the main difference during this phases, that is the application of the ultrasound pretreatment for R1.

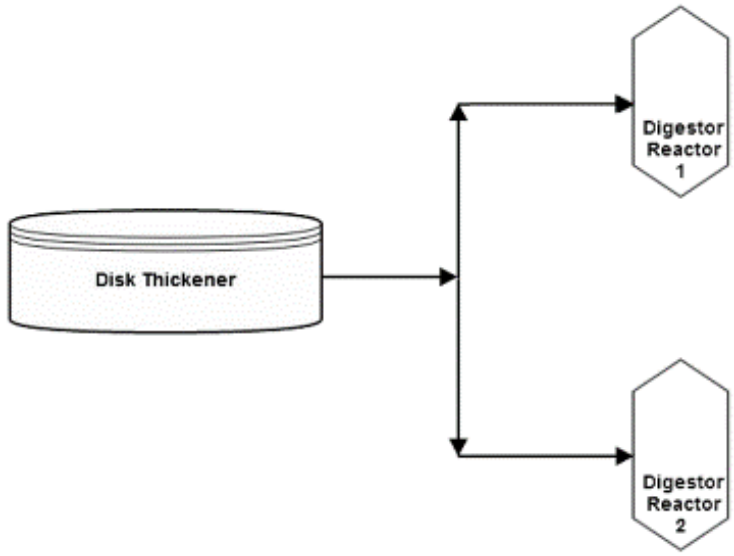


Figure 18. Scheme of the experimental configuration for phase 1 (by the author, 2014).

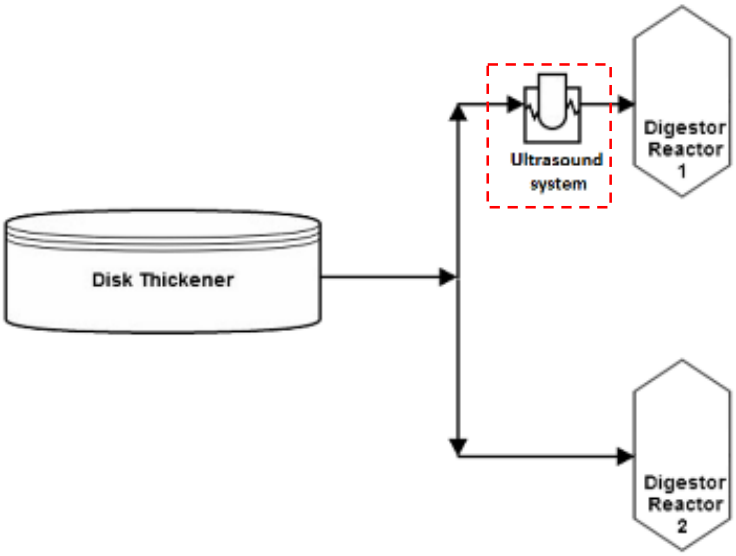


Figure 19. Scheme of the experimental configuration for phases 2 and 3 (by the author, 2014).

For the **application of the ultrasound pretreatment** the procedure was to separate one liter of the raw sludge and sonicate it in an ultrasound oscillating unit from Ultrawaves at a frequency of 20 kHz for two minutes with agitation following the configuration in figure 20, to later mix it with the other liter and feed it to R1. During the application of the ultrasound treatment the energy consumption of the system was registered.

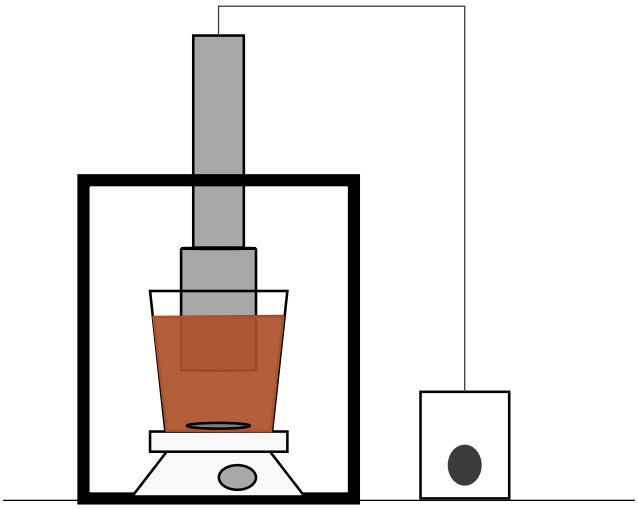


Figure 20.Configuration of the ultrasonic reactor (by the author, 2014).

Figure 21. Application of the ultrasound treatment (by the author, 2014).

The Ultrawaves ultrasound system used in the project was equipped with an oscillating unit consisting of a converter, booster and sonotrode (ULTRAWAVES GmbH, 2012b).

The sonotrode is the piece of the equipment in direct contact with the sludge and as it is shown on figure 22, its deepness level into the sludge during the sonication determined the total energy input.

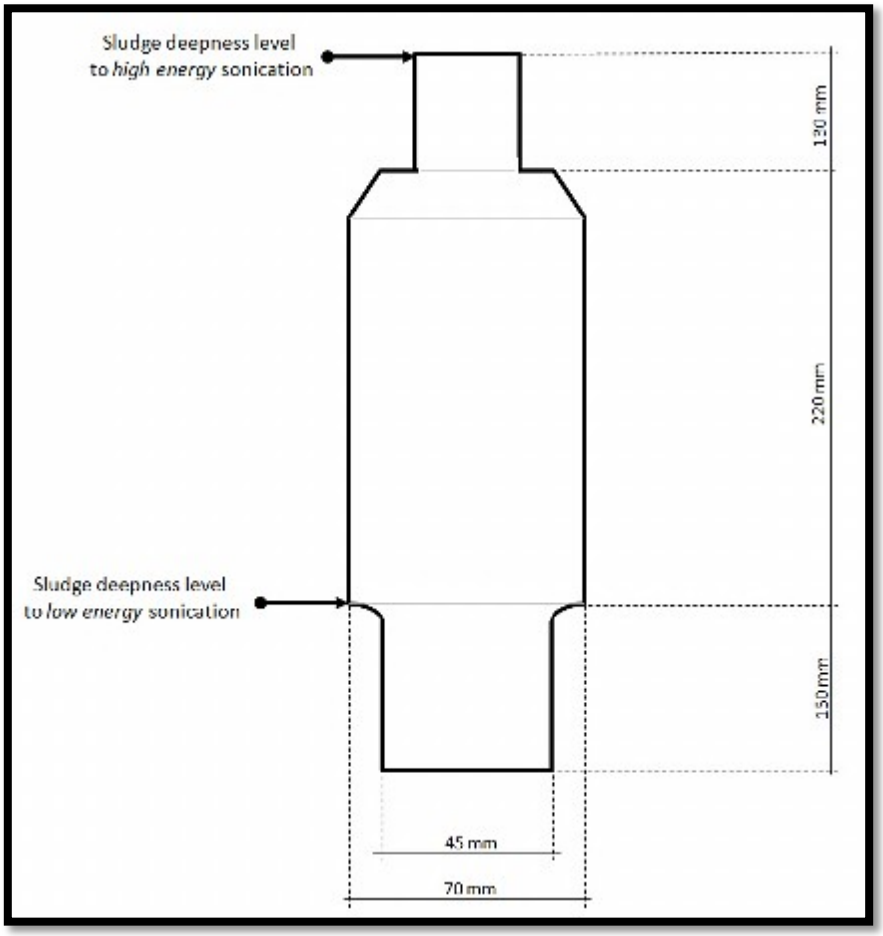


Figure 22. Diagram of the sonotrode used for the application of the ultrasound pretreatment (by the author, 2014).

During phase 2, where low energy sonication was used the sonotrode was deepened into the sludge until the slowest level indicated in the figure which is close 140mm, obtaining with this an input energy of about 300 W.

Throughout phase 3 the sonotrode was deepened into the sludge up to the highest level as shown in figure 22, close to 500mm, resulting from this an energy input of about 550 W.

In order to calculate the specific energy applied to the sludge it is necessary to consider the sonication time and the total volume of sludge sonicated, which in both phases was 2 minutes and 1 liter respectively, however the total volume of sludge fed into the

reactor was 2 liter per day, this means that the energy input should be divided by two liters instead of only one.

The following equation exemplifies the specific energy input during the ultrasound pretreatment.

With a power of about 400 W and a sonication time of 2 min for 1 liter of sludge, then:

$$\frac{400\ \mathrm{W} * \frac{2\ \mathrm{min} * 1\mathrm{h}}{60\ \mathrm{min}}}{2\ \mathrm{l}} = 6.7\ \mathrm{Wh/l}$$

In the results will be presented the definite energy input given to the sludge of R1 during each phase.

7.4. On site measurements;

During phases 1, 2 and 3 daily measurement were done to the digesters in order to control their behavior and performance, the parameters measured were:

Gas production: this was measured by determining the centimeters the gas displaced the water in the tank; by design, it is known that one centimeter equals two liters of biogas in the tank. The measured volume is then normalized in order to create comparable measurements. Following there is a calculation example for the normalized volume (nVolume):

$$\mathrm{n\ Volume} = \frac{\mathrm{absolut\ pressure\ (mbar)} * \mathrm{net\ volume\ (l)} * 273.15\ \mathrm{K}}{\mathrm{gas\ temperature\ (K)} * 1013\ \mathrm{mbar}}$$

If,
Net volume = 16 liters
Manometric pressure = 11.5 mbar
Atmospheric pressure = 1003 mbar
Gas temperature = 19.9 °C

Then,

$$\text{Absolut pressure (mbar)} = \text{manometric pressure (mbar)} + \text{atmospheric pressure (mbar)}$$

$$\text{Absolut pressure} = 11.5\text{mbar} + 1003\ \text{mbar} = 1014.5\ \text{mbar}$$

$$\text{Gas temperature (K)} = \text{gas temperature (°C)} + 273.15$$

$$\text{Gas temperature (K)} = 19.9\ °\text{C} + 273.15 = 293.05\ \text{K}$$

Finally,

$$\text{n Volume} = \frac{1014.5\ \text{mbar} * 16\ \text{l} * 273.15\ \text{K}}{293.05\ \text{K} * 1013\ \text{mbar}} = 14.94\ \text{l}$$

With these calculations it was possible to obtain the nVolume for both reactors in the pilot plant.

Gas quality: the parameters to measure gas quality were methane (CH_4) content and carbon dioxide (CO_2) content in percentage (%) and hydrogen sulfide (H_2S) content in parts per million (ppm). The CH_4 and H_2S content were measured with a Dräger X-am® device (figure 23a), whilst the CO_2 content was measured with a BRIGON CO_2 Indicator ® device (figure 23b). The measurements were made by connecting both devices to the gas outlet at the top of the gas tanks as shown on the figure

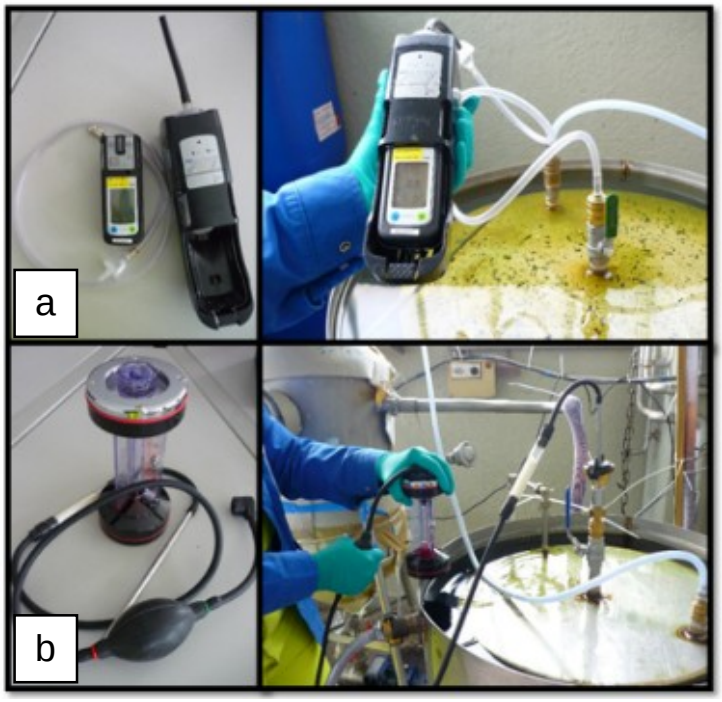


Figure 23. Measurement of gas quality (by the author, 2014).

Gas temperature: as the biogas produced is in direct contact with the water in the gas tank, their temperature is the same; therefore, by measuring the temperature from the water, it was possible to know the exact temperature of the gas stored in the tank. This was done with a contact thermometer TESTO 720 by introducing the probe in the water as shown on figure 24.

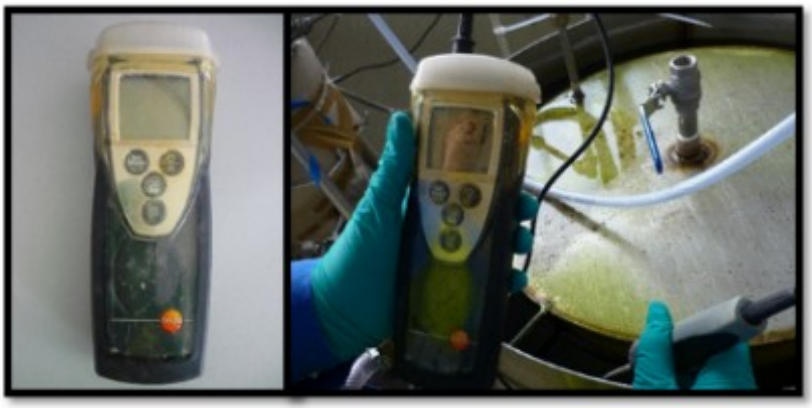


Figure 24. Measurement of gas temperature (by the author, 2014).

Reactor temperature: this value was obtained directly from the automatic control panel, where the temperature for R1 and R2 was shown in °C. .

Reactor pressure: this value was given in mbar by the manometer connected to the pipe connecting the reactor and the gas storage tank (figure 10d).

7.5. Laboratory tests

The next step was carried out in the laboratory of the treatment plant were a series of tests were done in order to control the digestion process in both reactors.

Dry solids and organic solids content.

In this test, the sample is dried in an oven at 105°C and the difference in mass is registered and used to determine the solids and water content of the sample.

The materials needed for this procedure were: porcelain crucible, analytical scale Sartorius with a precision of 0.001 g, drying oven HERATHERM and desiccator. The sample in the crucible is weighted on the analytical scale, later it is placed in the oven at 105°C for approximately 24 hours and cooled down to ambient temperature in the desiccator with the lid closed to avoid humidity. After cooled down, the crucible is weighted and the mass difference is calculated. The result corresponds to the water lost in the oven (figure 25).

Afterwards, the same sample is used to determine the content of organic matter; this test is known as *loss on ignition* and is done by burning the sample in a muffle oven at 550°C for 3 hrs, as shown on figure 26. After this time the sample is cooled down in the desiccator to ambient temperature and weighted. The difference in mass registered in the sample before and after the muffle oven is interpreted as the content of volatile or organic matter.

Figure 25. Dry solids test (by the author, 2014).

Figure 26. Loss on ignition test (by the author, 2014).

Once the samples were weighted after oven and muffle, the calculations to obtain the dry solids percentages of the samples are as follows,

$$\text{Dry solids content (\%)} = \frac{\text{dry sample (after oven)} * 100}{\text{fresh sample}}$$

$$\text{Inorganics residues (\%)} = \frac{\text{burned sample (after muffle)} * 100}{\text{dry sample (after oven)}}$$

$$\text{Organic solids (\%)} = 100 - \text{inorganics residues}$$

With the following data it is possible to make an example calculation,

Fresh sludge

Origin: Digester 1

Sample: 14.55 gr.

After 24 hrs. in the oven at 105°C

Sample: 0.45 gr.

After 3 hrs. in the muffle at 550°C

Sample: 0.196 gr.

$$\text{Dry solids content (\%)} = \frac{0.45\ \text{gr} * 100}{14.55\ \text{gr}} = 3.09\ \%$$

$$\text{Inorganics residues (\%)} = \frac{0.19\ \text{gr} * 100}{0.45\ \text{gr}} = 43.46\%$$

$$\text{Organic solids (\%)} = 100 - 43.46\% = 56.54\%$$

The dry solids and organic matter or volatile solids were determined in the thickened sludge used to feed the reactors as well as in the digested sludge taken as a sample from the reactors in the pilot plant.

Volatile organic acids (VOA) and Total inorganic carbon (TIC).

The VOA/TIC parameters are determined through the *Nordmann method*, in which a sample of digested sludge is filtrated using vacuum until obtaining 20 ml of water (figure 27a) that later is titrated with a solution 0.05M of H_2SO_4 to a pH value of 5.0 (being 7 – 8 the initial value) while constantly agitating (figure 27b). When this is reached, a stop watch is set for 30 min during which the aqueous solution is constantly stirred and the electrode of the pH meter is kept in it. The amount of sulfuric acid in ml necessary to reach pH 5.0 is known as A. After the 30 min, the pH has risen and it should be taken again to 5.0, which gives the value of A'. This value in ml of sulfuric acid, allows the calculation of the lime reserve or carbonate buffer capacity of the sludge given by CO_2 in the form of bicarbonate alkalinity (Clisso, 2014).

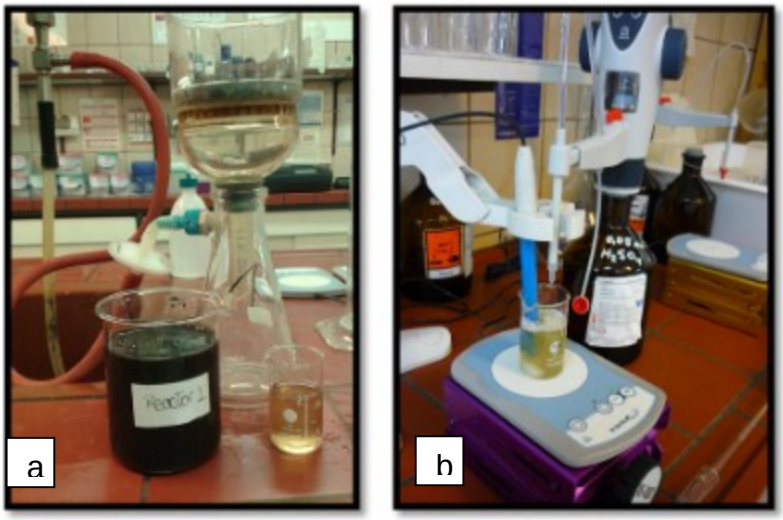


Figure 27. Nordmann method for VOA/TIC determination (by the author, 2014).

Immediately after reaching the pH value of 5.0 for the second time (A'), it is registered the amount of sulfuric acid consumed to lower the pH to 4.0, this value is known as B and it allows to calculate the volatile fatty acids in the system.

After obtaining the values of A' and B, the calculations are done as it follows,

$$\text{Bicarbonate alcalinity concentration } (CaCO_3 \text{ in mg/L}) = A' * 250$$

With the following data it is possible to make an example calculation,

A: 15.5 mL
A': 16.07 mL

$$\text{Bicarbonate alcalinity concentration} = 16{,}07 \quad * 250 = 4017{,}5 \text{ mg/L } CaCO_3$$

This result should go from 2000 to 5000 mg/L $CaCO_3$

$$\text{Volatile acids concentration (Acetic acid in mg/L)} = \big((B * 1.66) - 0.15\big) * 500$$

If,
B: 0,26 mL

$$\text{Volatile acids concentration} = \big((0.26 * 1.66) - 0.15\big) * 500 = 140.8 \text{ mg/L Acetic acid}$$

This result should not go over 500 mg/L HAc

pH.

As part of the daily control pH was also measured in the digested sludge with a Hanna Instruments pH meter 209. This one must remain neutral in order to favor the methanogenic activity.

The measurement was done by introducing the electrode into the sludge and reading the value on the screen of the instrument as shown on figure 28.

Figure 28. pH measurement in the laboratory (by the author, 2014).

Viscosity

Viscosity of the sludge was tested with a rotational viscosimeter Haake VT-02 (figure 29). For the measurement 150ml sample of the sludge were filled in the measuring cup and the selected rotor was introduced, the result is shown in the indicator and it should be read in the right scale according to the rotator selected.

Figure 29. Viscosity test (by the author, 2014).

For the selection of the rotor it was used the following table from the user's manual of the equipment

VT02:		
3	0.3 ... 13 dPas (P)	3
1	3 ... 150 dPas (P)	1
2	100 ... 4000 dPas (P)	2

According to the characteristics of the sludge Rotor 3 was used.

The scale of the viscosimeter is given in dPa.s, which is equal to 1 Poise (P), with this the measured values were transformed to cP as it follows:

If measured viscosity = 0,3 dPa.s

Then,

$$0{,}3\ \text{dPa.s} * \frac{1\ \text{P}}{1\text{dPa.s}} * \frac{100\ \text{cP}}{1\ \text{P}} = 30\ \text{cP}$$

Dewaterability.

The dewaterabilty of the sludge was tested through the capillary suction time test (CST) with a HeGo Biotec CST 101/A equipment shown on figures 30 and 31.

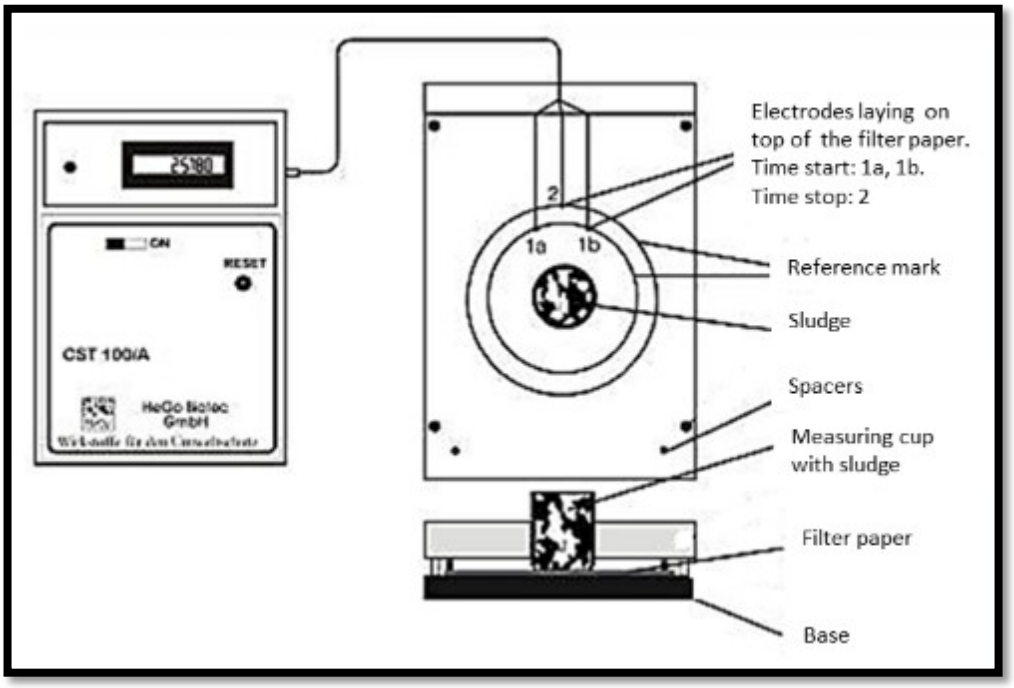


Figure 30. Diagram of the CST test device (by the author, 2014).

Figure 31. CST test for measuring sludge dewaterability (by the author, 2014).

The CST is obtained by introducing a sample of sludge in the cylinder centered in the middle of the concentric electrodes; under the cylinder there is a filter paper that absorbs the water from the sludge. When the waterfront reaches the electrodes 1 and 2 the timer starts running until the water reaches electrode 3, located in the border of the larger diameter, the time registered is known as the Capillary Suction Time of the sample and gives a measure of the sludge filterability.

Dewaterability was also measured through Vacuum Filtration, this test just as CST, considered time and volume of water filtrated and was designed for the present project.

The materials needed for this test were: vacuum flask, graduated cylinder (50 ml), a Büchner funnel, filter paper, stop watch, rubber hose, air filter, syringe (12ml) and rubber cuff.

The test was done with the set up on figure 32. Here the volume filtrated was an independent variable, and consisted on measuring the time it took a 50 ml sample of sludge to filtrate 12 ml of water.

Figure 32. Set up for vacuum filtration test (by the author, 2014).

Microscope

The miscroscope was ised to analyze three samples of sludge:

1. Sludge withouth ultrasonic treatment
2. Sludge with low energy ultrasonic treatment
3. Sludge with high energy ultrasonic treatment.

The observations were done in raw, live sludge with a Zeiss Micro Star Microscope with a 100x lens. The samples were prepared by mixing 1ml of sludge with 3 ml of water so they could be visible under the microscope. Figure 33 shows the microscope and the prepared samples.

Figure 33. Microscope and sludge samples for observation (by the author, 2014).

Chapter 8. Results and discussions

In the following sections the results of the project will be presented in a concise way in order to facilitate the visualization of the results. The complete data is presented in the annexes section.

8.1. Results for biogas yield and quality

Biogas gas yield was evaluated by measuring daily gas production in both reactors and then taking the net produced volume to normal conditions in order to create standardized and comparable measures.

Table 4 shows the extreme and average values for the gas production during the different phases of the project. The complete data can be found in annexes 4 and 8.

Table 4. Gas production values for R1 and R2 during phases 1, 2 and 3 of the project.

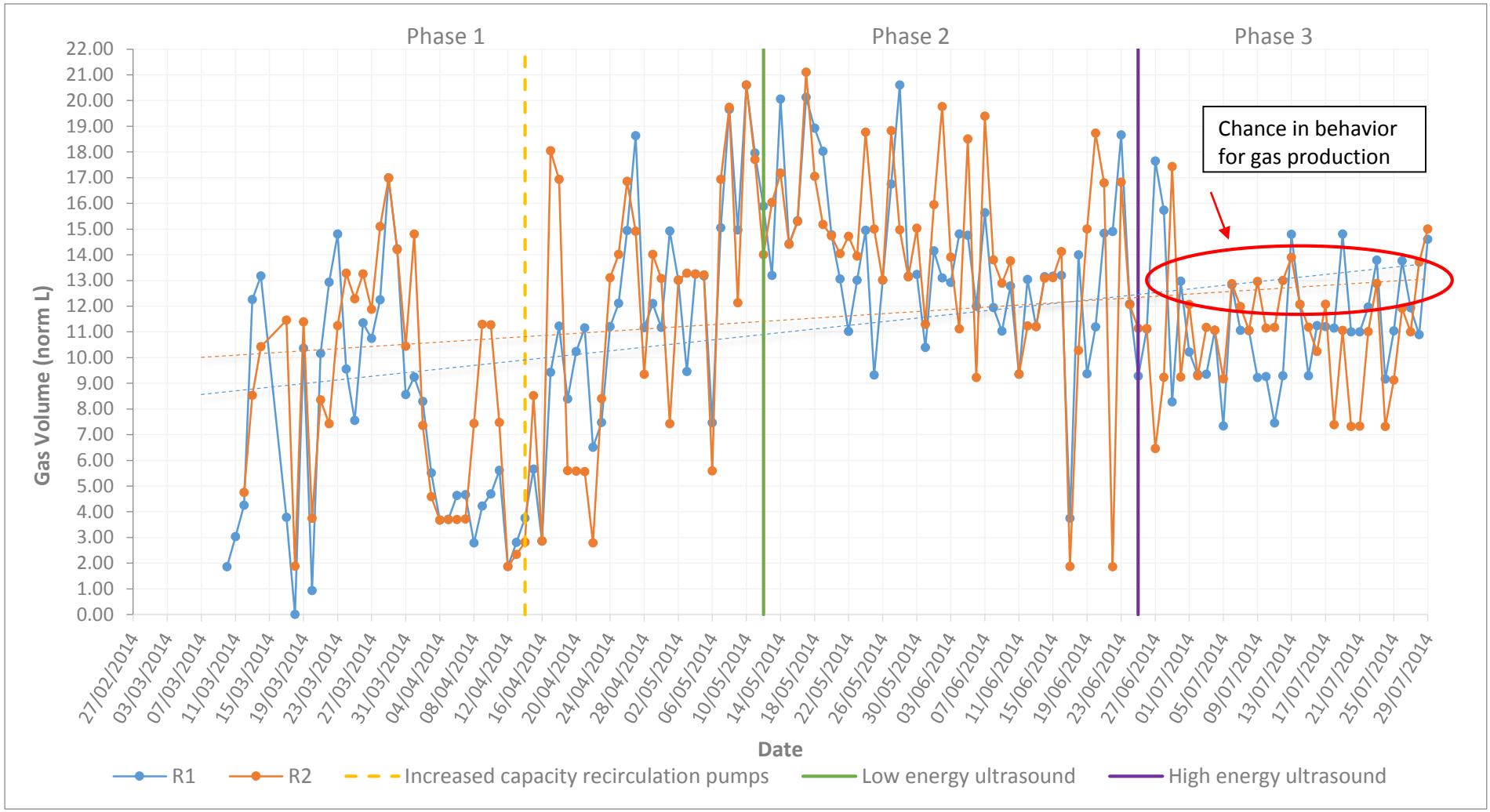
Phase of the project	R1 nVolume (l/d)				R2 nVolume (l/d)			
	Min.	**Max.**	**Average**	**Sum (l)**	**Min.**	**Max.**	**Average**	**Sum (l)**
Phase 1.1 07/03/2014 – 10/04/2014	0	17.0	7.7	230.1	1.9	17.0	9.2	258.0
Phase 1.2 11/04/2014 – 11/05/2014	1.9	20.6	10.9	337.7	1.9	20.6	10.9	336.9
Phase 2 12/05/2014 – 24/06/2014	3.7	20.6	13.7	604.1	1.9	21.1	14.1	621.4
Phase 3 25/06/2014 – 29/07/2014	7.3	17.6	11.3	396.0	6.5	17.4	11.0	386.0

The table shows the evolution of the stabilization process of the reactors within phases 1 and 2, it is possible to see the clear increase in gas production for both reactors without any special visible effect of the low energy (4.83Wh/l) ultrasonic pretreatment applied to R1, in fact, a higher gas production is evident for R2 during phase 2, even

though the sludge in this reactor had no pretreatment. However, for phase 3, where the ultrasound applied to R1 had a higher energy level (9.44 Wh/l), the total gas production for R1 was 10 liters higher than in R2 which could be evidence of the effects of the ultrasonic pretreatment or could just be the result of fluctuations in the generation of gas. This behavior is also possible to observe on the graph 1 with the daily gas production, where the tendency line of R1 spikes up at the end of the graph, corresponding to phase 3, while for the previous phases always remained lower than the tendency line for R2.

As mentioned before graph 1 shows the evolution in the gas production for both reactors within each phase. Fluctuations are evident but not unexpected, it is known that gas production usually presents fluctuations depending on factors such as volatile solids content of the sludge fed and the performance of the microorganisms in the reactor (Metcalf & Eddy, 2003) or even mixing, which is an important factor in this project.

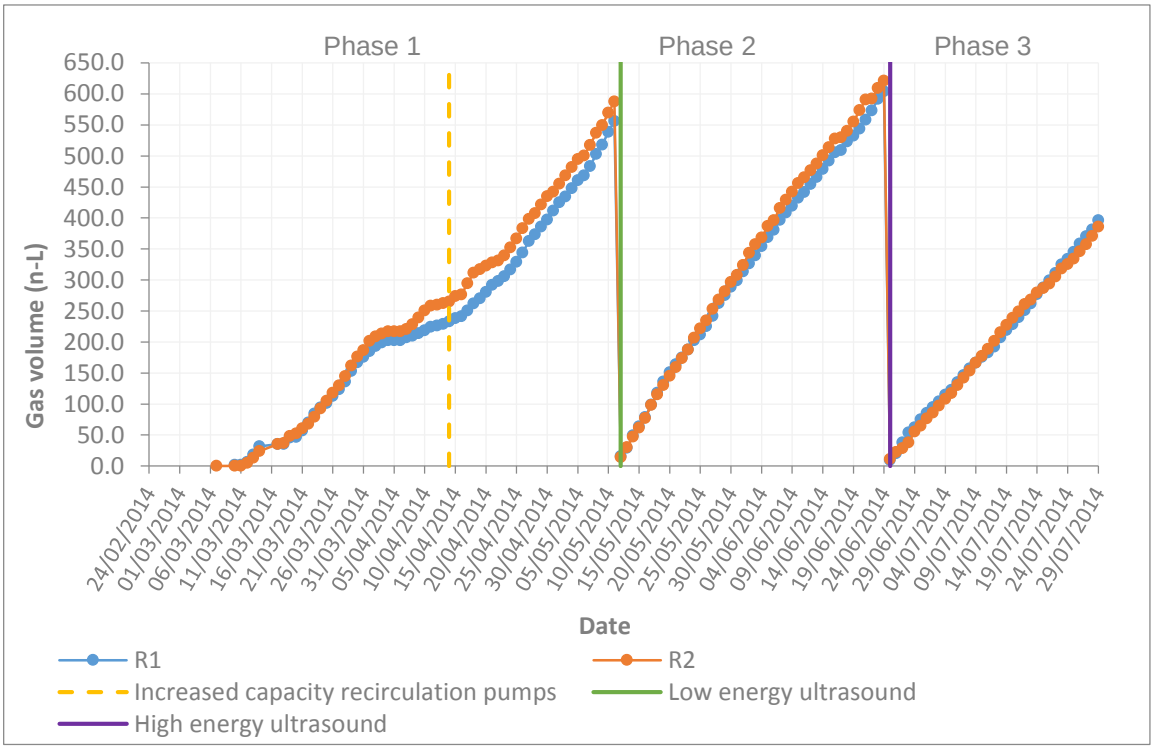
Despite these clear fluctuations, it is possible to observe that during phase 1 both systems show a general increase in production, being R2 the one with the higher production values. During this phase the recirculation pumps of both systems were changed in order to increase recirculation energy and improve mixing within the reactors, as shown in the graph, this affected positively both systems increasing gas production. Phase 2 was steadier than phase 1, here R1 was more stable than R2 which showed a small decrease in tendency. Phase 3 finally shows a slightly increment for R1 over R2, possibly for the action of the ultrasonic pretreatment, this phase was much more stable than the previous two. This is reasonable due to anaerobic digestion systems need a long time to perform in a stable way.



Graph 1. Daily gas production for R1 and R2 during phases 1, 2 and 3.

In the case of the experiments developed by Tiehm, Nickel, & Neis, (1997, p.5) it was reported that “Significantly higher amounts of biogas were produced in the fermenters fed with disintegrated sludge and operated at reduced residence times. Despite the more pronounced reduction of volatile solids in the fermenter operated with disintegrated sludge at a residence time of 22 days there is no increased production of biogas as compared to the control fermenter operated with untreated sludge”. This last one is the closest case to the present project, where the SRT is of 30 days. Moreover they also added “This may be due to changes in the biochemical fermentation process. Further investigations are required to enlighten anaerobic biodegradation under these conditions”.

Graph 2 shows the total gas production per phase for both reactors, here it is possible to visualize how the gas production of R2 was higher in phases 1 and 2 but this behavior changed slightly during phase 3.



Graph 2. Total gas production sum for R1 and R2 both reactors in phases 1, 2 and 3.

It is possible to appreciate how phase 1 was longer and much more unstable than the other two, this is normal owing to this is the startup phase.

The results presented up to this point consider the total time involved in each phase (62, 44 and 35 days respectively), however there is a difference in these periods and considering that the sum values are highly important in this section, is why in order to establish a more accurate comparison the following analysis will consider from days 1 to 30 - period of time corresponding to a complete cycle of solids retention time (SRT) - for both reactors in phases 1, 2 and 3.

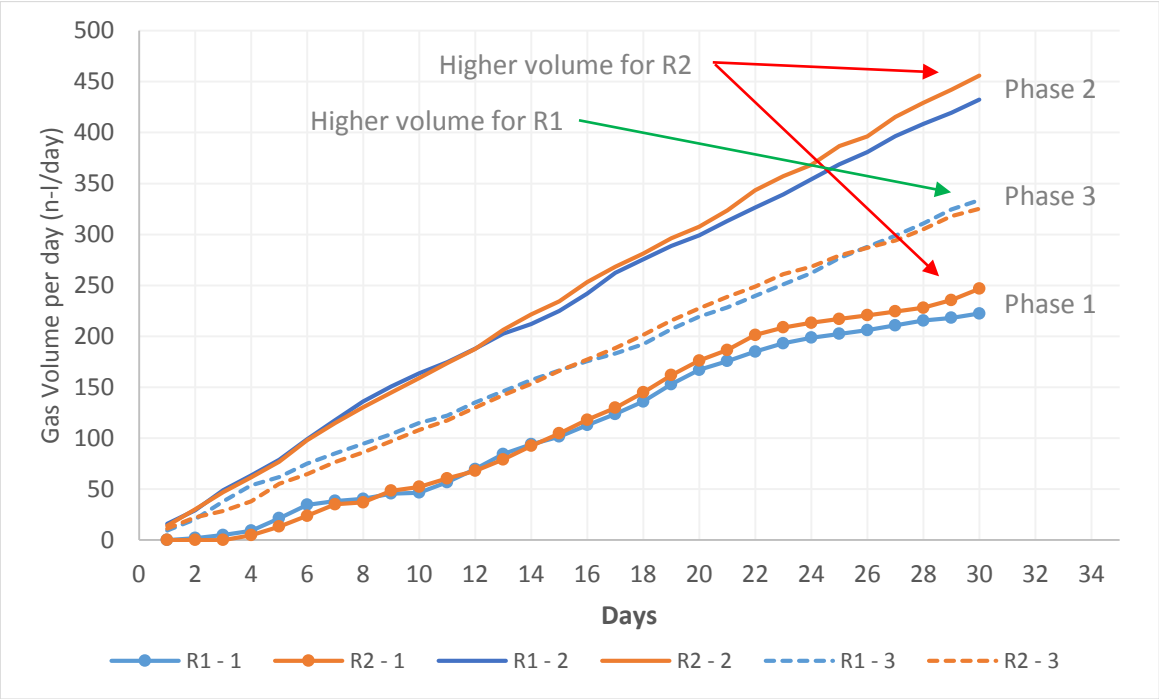
Table 5 summarizes the sum in gas production from day 1 to day 30 for both reactors during phases 1, 2 and 3. The full table can be found in annex 11.

Table 5. Gas production values for R1 and R2 from days 1 to 30 of phases 1, 2 and 3.

Days	R1 nVolume (l/day)			R2 nVolume (l/day)		
	Phase 1	Phase 2	Phase 3	Phase 1	Phase 2	Phase 3
1	0	15.88	9.27	0.00	14.00	11.13
5	21.39	78.86	62.01	13.27	76.90	55.36
10	46.59	163.75	114.92	52.14	158.99	108.17
15	101.57	225.03	166.39	104.71	234.43	166.20
20	167.11	299.15	219.24	176.11	307.66	227.47
25	202.38	368.87	276.91	216.95	386.88	279.39
30	**222.37**	**432.24**	**333.80**	**246.77**	**455.93**	**325.22**

This table allows to make a more accurate comparison considering the first 30 days of every phase. For both reactors it is possible to see an increment in gas production during phase 2 to later decrease during phase 3. The explanation for this could be that the beginning of phase 3 coincide with the elimination of the disintegration enzymes previously used in the systems and its replacement with the addition of surfactants prior the digestion step, causing a drop in gas production for both reactors, however more research time is needed to confirm this theory.

Here is also very important to observe how during phases 1 and 2 R2 has a higher gas production. This result somehow relate to the findings of Tiehm et al. (1997), who reported the lack of increase in gas production in reactor with long residence times (22 days) compared to the control reactor operated with untreated sludge and it is attributed to changes in the fermentation process therefore further research was recommended in this study.



Graph 3. Sum in gas production of R1 and R2 for the first 30 days of each phase of the project.

Reasons for the behavior observed during phases 1 and 2, where there is no evident effect of the ultrasound applied to R1 could also be the selected combination of parameters for the application of the ultrasonic pretreatment, being a laboratory scale reactor, exist different parameters that can be modified and affect the overall result as is the case. Starting from the frequency set for the treatment, agitation, sonication time, the amount of sludge treated, the materials used, etc. Every factor involved in the process plays an important part in the general results.

As stated by Chu et al. (2001, p. 2) “Effects of sonication depend largely upon the sample volume, container geometry and the probe position”, such an observation closely corresponds to the reasons that led that in the present project a further phase

was done experimenting with a higher energy input in the ultrasonic pretreatment applied to R1, and in fact, the higher gas production presented by R2 changes during phase 3, as mentioned before, in this last phase R1, with about 8 liters more of gas produced could be showing some preliminary results of the effect of the ultrasonic disintegration. The behavior of the numbers in the table can be easily observe in graph 3, where again it is possible to see how the phase with the lowest gas production was the first one, this attributable to being a stabilization phase, where the reactors are slowly improving its performance.

Phase 2 is in the top of the graph 3 with the highest values of gas production and a small difference between R1 and R2. Finally phase 3 in the middle of the graph shows the same tendency for both systems being very difficult to notice the slight superiority on gas production for R1, as opposite to the table 5.

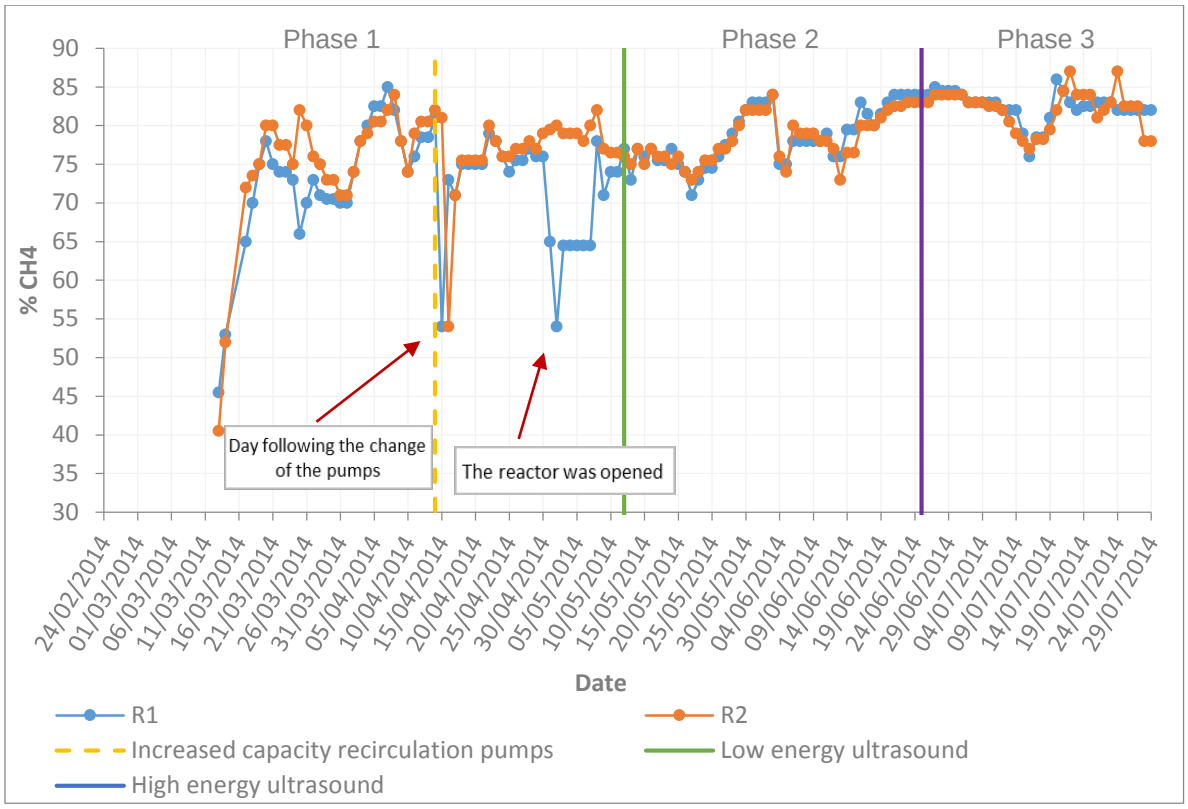
Concerning the temperature, the literature reported increases in the sludge caused by the process of ultrasonic treatment of up to 30°C. For Tiehm et al. (1997) the temperature of the sludge increased from about 15°C to nearly 45°C, while in this project the increase in the temperature suffered by the treated sludge hardly reached the 10°C and unevenly distributed through the whole sludge.

Regarding gas quality, table 6 shows the main results obtained for methane (CH_4) during the three phases.

Table 6. Methane content per phase for R1 and R2.

Phase of the project	R1 % CH_4			R2 % CH_4		
	Min.	**Max.**	**Average**	**Min.**	**Max.**	**Average**
Phase 1.1 07/03/2014 – 10/04/2014	45.5	85.0	72.6	40.5	84.0	74.6
Phase 1.2 11/04/2014 – 11/05/2014	54.0	81.0	72.2	54.0	82.0	77.2
Phase 2 12/05/2014 – 24/06/2014	71.0	84.0	78.5	73.0	84.0	78.2
Phase 3 25/06/2014 – 29/07/2014	76.0	86.0	82.5	77.0	87.0	82.1

The production of CH_4 shows a very slight increase within time during the three phases of the project as it is possible to see in the figure below. The average value of methane content in the biogas produced was about 80% which is close to 10% higher than the value reported on the big scale. Graph 4 shows two low peaks, the first one, on both reactors corresponds to the day following the increase of the pumps capacity, and therefore it corresponds to a radical change in the recirculation pattern. The second one, reported only for R1 was a result of opening the reactor to reduce its volume and clean the foam on the surface of the sludge, by doing this air entered the system and therefore the CH_4 concentration was reduced. It is possible to observe that during the second phase, no drastic changes were observed and the behavior was very similar in both reactors.



Graph 4. Methane content for R1 and R2 during phases 1, 2 and 3.

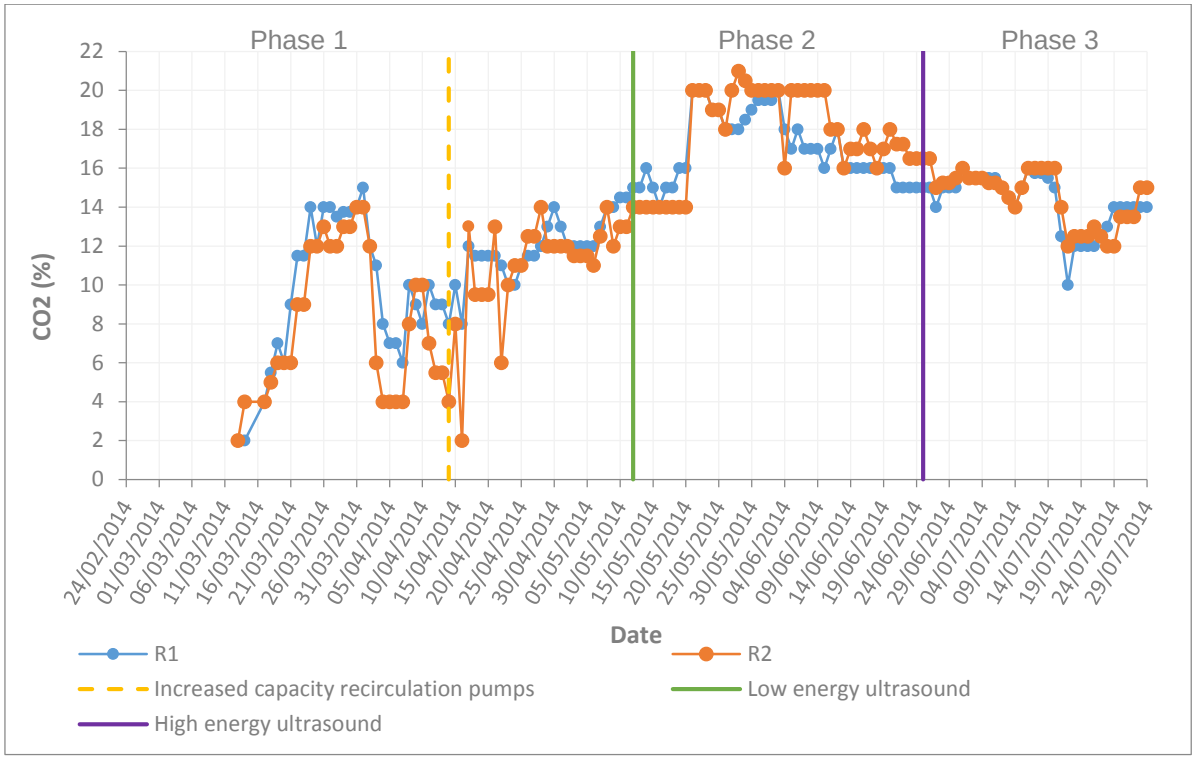
Methane content is highly important since this is the factor upon which energy production will depend on. This will be shown later on in the energy analysis section.

Regarding the carbon dioxide (CO_2) content in the biogas, table 7 shows the values for R1 and R2 during the three phases.

Table 7. Carbon dioxide content per phase for R1 and R2.

Phase of the project	R1 % CO_2			R2 % CO_2		
	Min.	Max.	Average	Min.	Max.	Average
Phase 1.1 07/03/2014 – 10/04/2014	2.0	15.0	9.6	2.0	14.0	8.4
Phase 1.2 11/04/2014 – 11/05/2014	8.0	14.5	11.6	2.0	14.0	10.4
Phase 2 12/05/2014 – 24/06/2014	14.0	20.0	17.0	14.0	21.0	17.7
Phase 3 25/06/2014 – 29/07/2014	10.0	16.0	14.3	12.0	16.5	14.5

The CO_2 production clearly increased from phases 1 to 2 to later drop a little during phase 3, this is shown in the table above as well as in the diagram 5. It was a scaled increase until reaching a top average value of 17% which it is still lower than the average of 30% registered in the large scale digesters.



Graph 5. Carbon dioxide content for R1 and R2 during phases 1, 2 and 3.

Usually the gas produced in anaerobic digestion contains from 65 to 70% CH_4 and 25 to 30% CO_2. (Metcalf & Eddy, 2003). This is not the case for R1 and R2. In the graphs

it is evident that the CH_4 concentration remained fairly constant during the phases of the project with average values from 75 to 80%, which is about 10% higher than expected. The CO_2 concentration presented a gradual increase and then decreased, however the average values always remained under the average mentioned in the theory and observed in the treatment plant. This is explained with Henry's law that defines the solubility of a gas in a solution considering the partial pressure of the gas. According to this law the solubility of the gas in the liquid depends directly on Henry's constant of the gas, and in this case, the constant in water is higher for CO_2 than for CH_4, this means that higher amounts of CO_2 are solubilized in the water contained in the gas tanks. Besides it should be point out that even though the sludge is the same, the pilot scale systems do not behave just as the one on the big scale.

Hydrogen sulfide (H_2S) was also measured but the results showed no evidence of H_2S in the reactors during treatment time, the reason for this could be the use of iron chloride ($FeCl_2$) in the biological treatment of the water for the removal of phosphorous. This compound reacts with the H_2S forming FeS, a non-soluble compound that precipitates and is removed with the solids of the reactor.

8.2. Results for dry solids and volatile solids

After the calculations it is possible to present this table with the average results for both reactors and for the inflow during the three phases. The complete data can be found in annexes 1, 2 and 6.

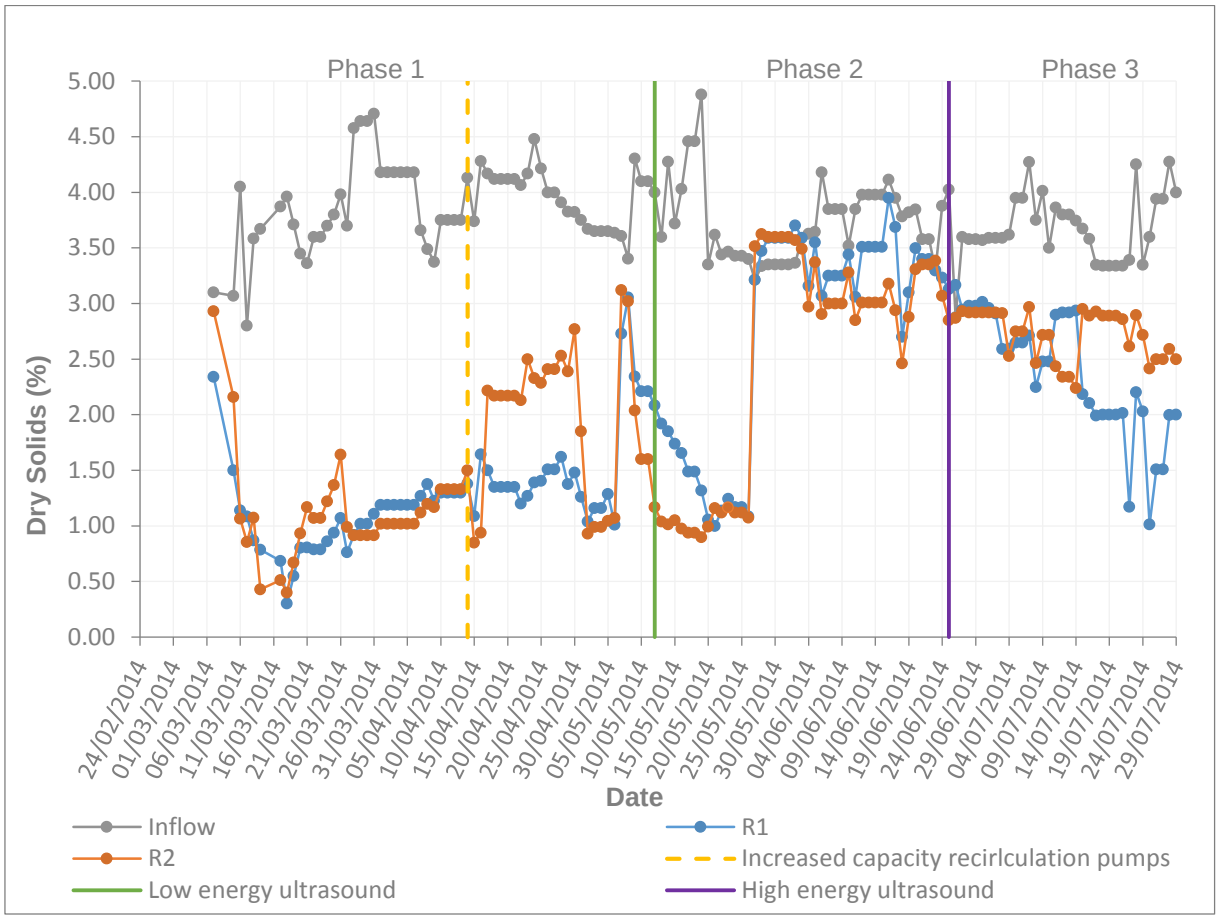
Table 8. Dry solids values for the inflow, R1 and R2 during phases 1, 2 and 3.

Phase of the project	Inflow % Dry solids			R1 % Dry solids			R2 % Dry solids		
	Min.	Max.	Average	Min.	Max.	Average	Min.	Max.	Average
Phase 1.1 07/03/2014 – 10/04/2014	2.8	4.7	3.8	0.3	2.3	1.1	0.4	2.9	1.1
Phase 1.2 11/04/2014 – 11/05/2014	3.4	4.5	3.9	1.0	3.1	1.5	0.9	3.1	1.9
Phase 2 12/05/2014 – 24/06/2014	3.2	4.9	3.7	1.0	4.0	2.7	0.9	3.6	2.5
Phase 3 25/06/2014 – 29/07/2014	2.9	4.3	3.7	1.0	3.2	2.4	2.2	3.0	2.7

The analysis of the dry solids content is rather complex due to an important mixing problem within the reactors. However, a clear tendency to stabilization is observed in the table above.

The average solids value of R1 decrease from phase 2 to phase 3, being in this last one lower than the average value for R2, this could imply some solubilization as an effect of the ultrasonic pretreatment, which is a likely effect according to the research of Kidak et al. (2009) or could be just an effect of the fluctuations due to the mixing difficulties.

The table shows that the average values for dry solids in the inflow is about 15 – 20 % higher than the values for R1 and R2 during phases 2 and 3 behavior that remained fairly constant.



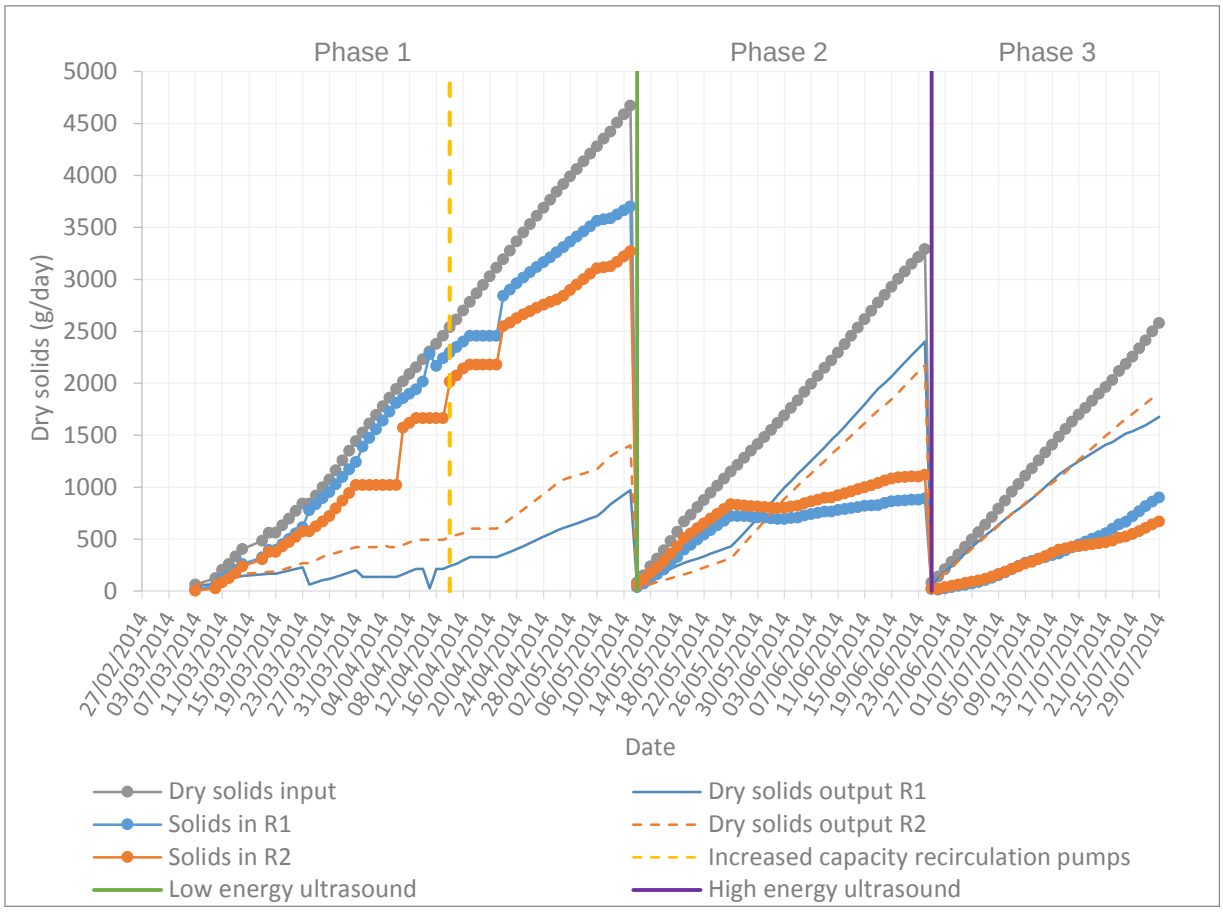
Graph 6. Dry solids content for the inflow, R1 and R2 during phases 1, 2 and 3.

The diagram shows the mentioned fluctuations having very short periods of stability for R1, while R2 shows a stable solids content since the middle of phase 2 and extended to phase 3.

The big change in tendency occurred in the middle of phase 2 could respond to a variation in the recirculation pattern, from a fixed way to daily alternation between the side and of the reactor, including manual shaking right after the feeding.

Graph 7 with the solids balance in the inflow and in R1 and R2 show the mentioned tendency to stability in the content of solids inside the reactors regarding the solids input, and the evidence of the possible overcome of the mixing problems, which makes sense considering the mentioned changes in recirculation pattern applied during the last weeks and the manual agitation of the reactors.

In the graph it is appreciated how after the middle of phase 2 and during phase 3 the number of solids in the output is more corresponding with the ones in the input, the lines corresponding to these parameters run in a parallel way controlling the accumulation of solids inside the systems, evident during phase 1 and the first half of phase 2.



Graph 7. Solids balance from the inflow, R1 and R2 during phases 1, 2 and 3.

Volatile solids.

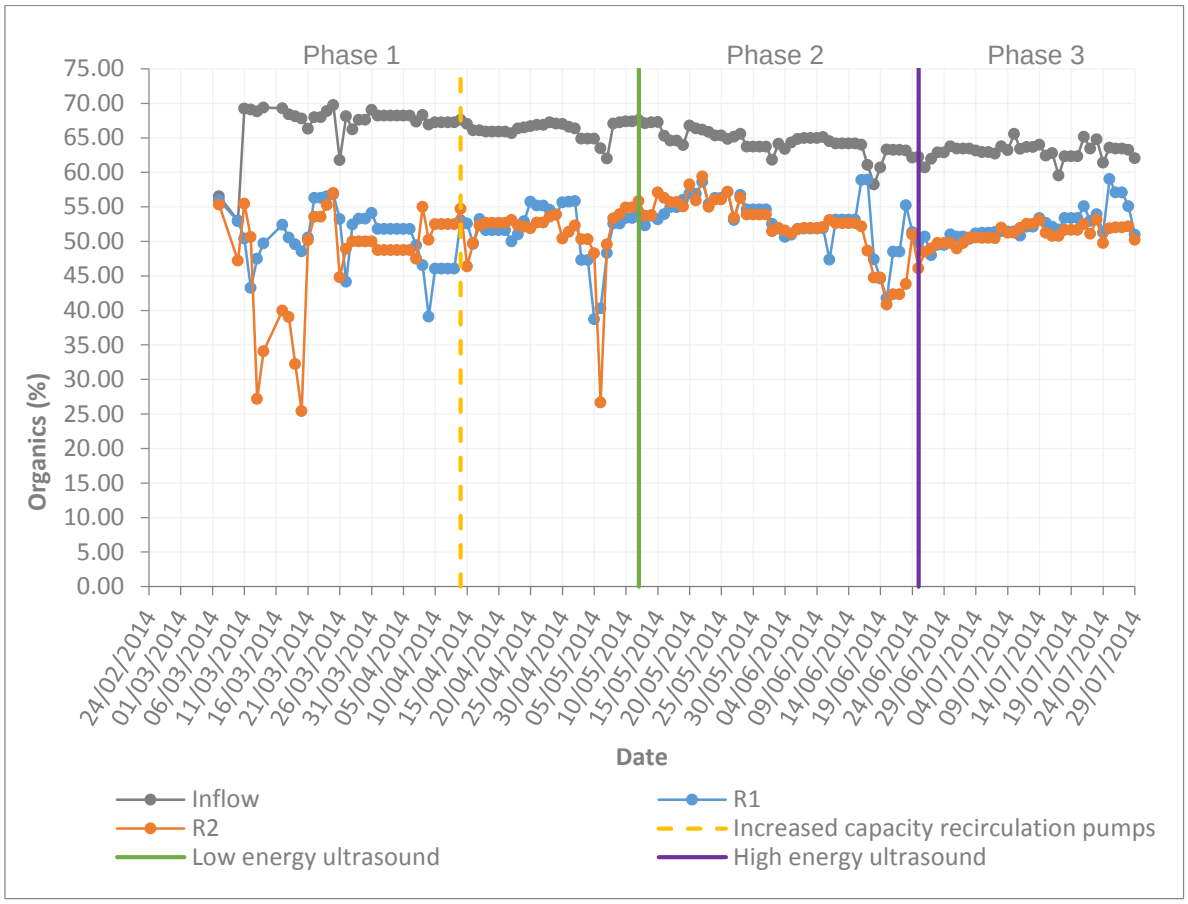
The content of volatile solids is very important due to it is an indication of the amount of solids that will be transformed into biogas by the action of the bacteria. Table 9 shows the values of volatile solids in R1, R2 and the inflow during both phases.

Table 9. Volatile solids values for the inflow, R1 and R2 during phases 1, 2 and 3.

Phase of the project	Inflow % Volatile solids			R1 % Volatile solids			R2 % Volatile solids		
	Min.	Max.	Average	Min.	Max.	Average	Min.	Max.	Average
Phase 1.1 07/03/2014 – 10/04/2014	53.0	69.8	67.1	39.1	56.8	51.0	25.4	57.0	47.4
Phase 1.2 11/04/2014 – 11/05/2014	62.0	67.7	66.3	38.7	55.7	51.1	26.7	54.9	51.3
Phase 2 12/05/2014 – 24/06/2014	58.3	67.6	64.4	41.8	59.0	53.2	40.9	59.4	52.4
Phase 3 25/06/2014 – 29/07/2014	59.5	65.6	63.0	48.0	59.1	52.2	46.09	53.16	50.9

Both, table 9 and graph 8 show a very steady content of volatile solids during the complete duration of the project. The values of volatile solids are highly similar for both system throughout the experiments, which opposes to the findings in other projects, for example Tiehm et al. (1997, p. 5) reported that “Remarkably volatile solids in the effluent of the digester fed with disintegrated sludge was 10 % less than in the conventional process.” They added, “Average volatile solids content in the raw sludge decreased within the first two months of the semi-continuous fermentation. Afterwards average volatile solids content increased again”. This results do not correspond to the stability showed for the volatile solids in R1 and R2 throughout the project.

As the content of volatile solids is in direct relation with gas production, it is necessary to mention the small likelihood that the risen in gas volume of R1 during phase 3 is a consequence of the ultrasound instead of just part of the common fluctuations. If there is no depletion in volatile solids then it is very unlikely that there is an increase in gas production.



Graph 8. Volatile solids content for R1 and R2 during phases 1, 2 and 3.

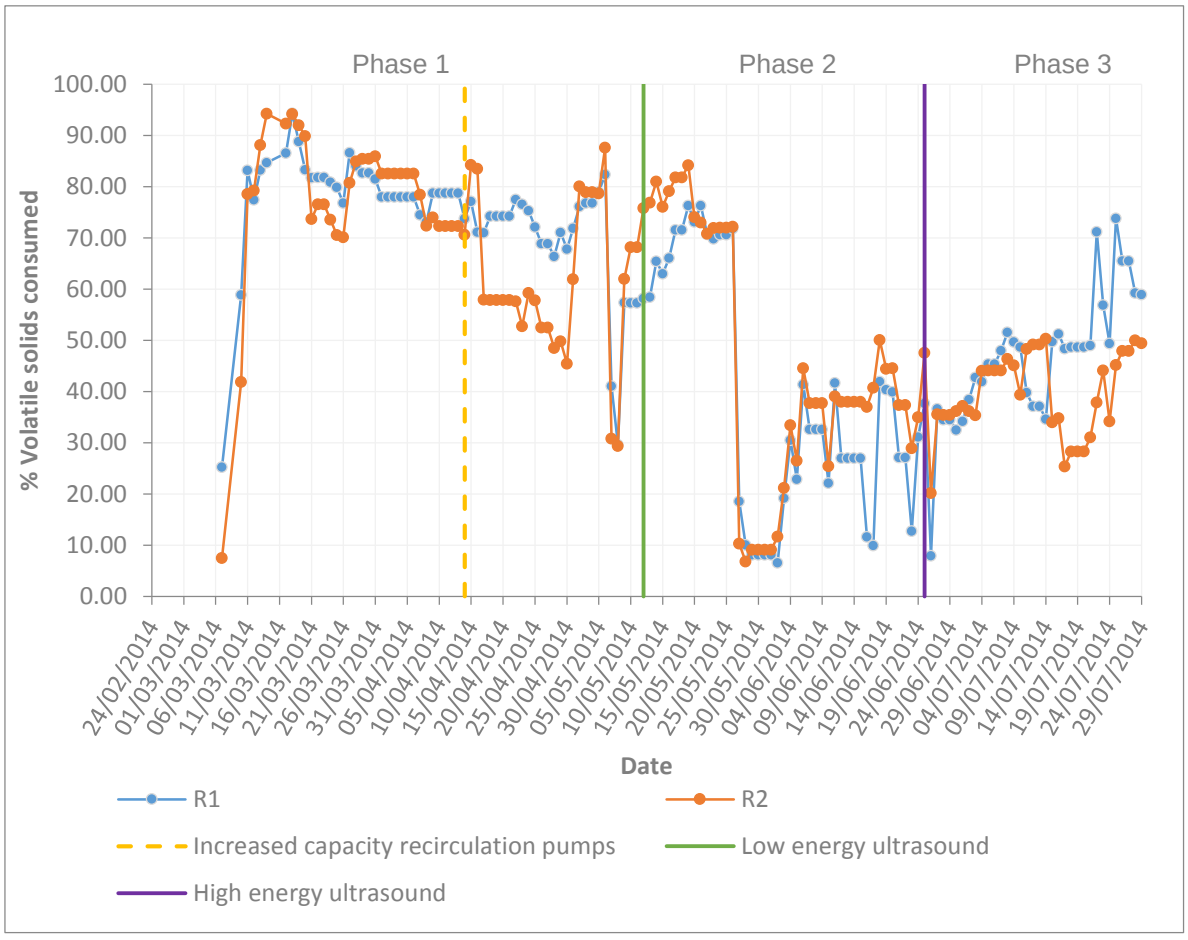
Volatile solids consumption

Regarding the actual consumption of organics by the action of the microorganisms table 10 summarizes the calculated values.

Table 10. Volatile solids consumption for R1 and R2 during phases 1, 2 and 3.

Phase of the project	R1 % Volatile solids consumption			R2 % Volatile solids consumption		
	Min.	Max.	Average	Min.	Max.	Average
Phase 1.1 07/03/2014 – 10/04/2014	25.2	94.3	78.7	7.5	94.3	77.9
Phase 1.2 11/04/2014 – 11/05/2014	29.6	82.4	70.2	29.4	87.6	62.8
Phase 2 12/05/2014 – 24/06/2014	6.5	76.3	39.2	6.8	84.2	45.9
Phase 3 25/06/2014 – 29/07/2014	7.9	73.8	46.4	20.2	50.3	39.7

During phase 1 the average values found do not actually correspond to what is expected in this process, however, while the project moved forward, this values were adapting more to the expected behavior in the reality which is close to 40%, this could have been another consequence of the mixing problem, which implied obtaining samples not entirely representative of what was going on in reality inside the reactors. The improvement of these values coincide with the stabilization of the solids content and therefore also respond to a better mixing pattern in both systems.



Graph 9. Volatile solids consumption for R1 and R2 during phases 1, 2 and 3.

What it is also important to mention is the non significative difference between both systems up until the last weeks of phase 3, where there is a bigger difference between R1 and R2, showing a greater consumption for R1, which could be coincident with the slightly higher production of biogas that this system had in the same period of time.

Throughout the project the results do not report a significant difference regarding the consumption of volatile solids between the two reactors. Although there is an important difference between phases 1.2 and 2 and 3 in reactor 1, there is no evident difference in behavior compared to reactor 2, where no ultrasound was applied, meaning that again this difference responds to the change in recirculation pattern and the stabilization of solids within the reactors.

Conversion of volatile solids into biogas

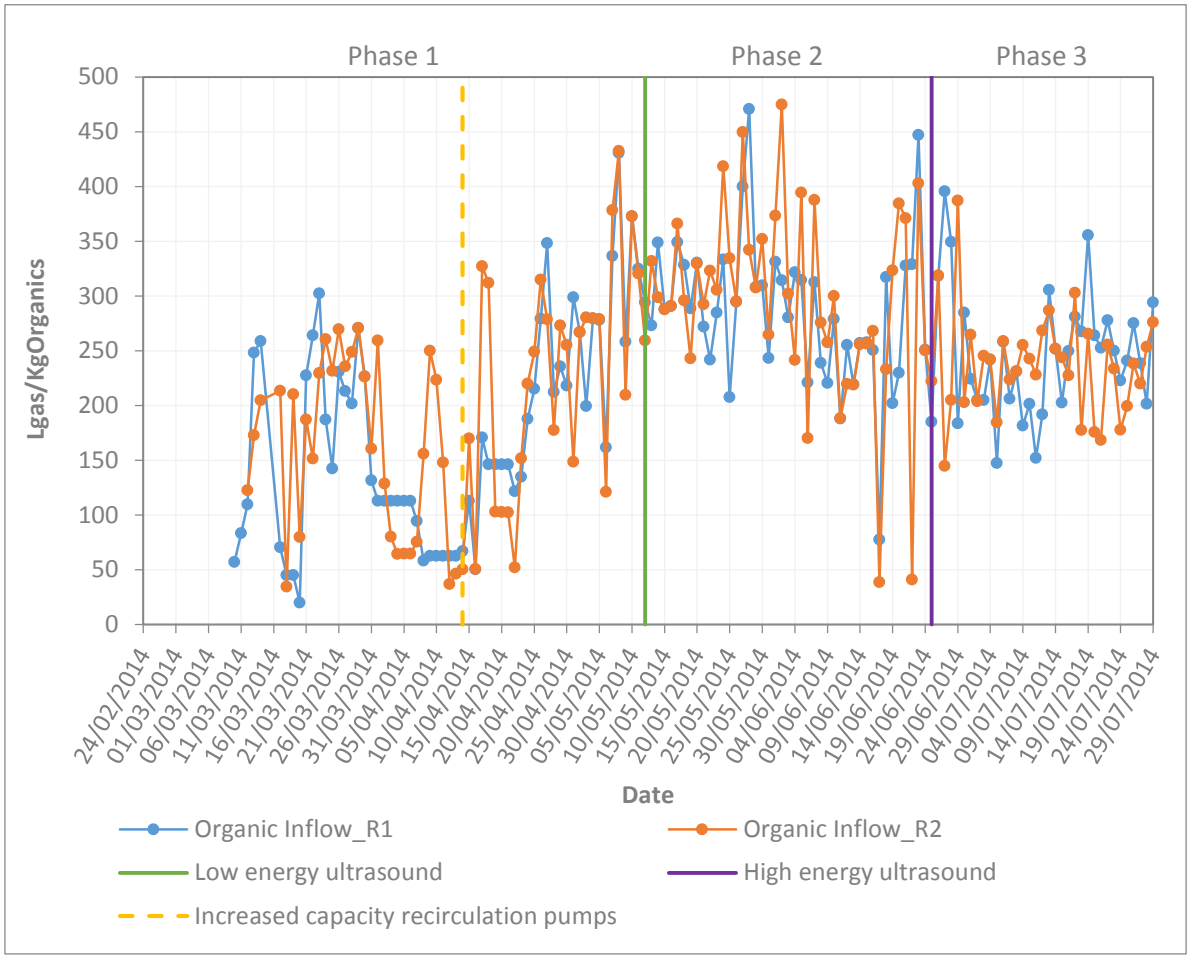
In the analysis of the actual quantity of volatile solids that are converted into biogas, tables 11 and 12 show the amount of conversion regarding the organics fed into the reactors and the organics consumed inside of them.

Table 11. Conversion of volatile solids in the inflow into biogas for R1 and R2

Phase of the project	R1 Gas volume/organic content inflow (L gas/kg organic content)			R2 Gas volume/organic content inflow (L gas/kg organic content)		
	Min.	Max.	Average	Min.	Max.	Average
Phase 1.1 07/03/2014 – 10/04/2014	19.95	302.4	143.1	34.6	270.6	174.2
Phase 1.2 11/04/2014 – 11/05/2014	50.4	430.7	204.4	36.9	432.3	210.0
Phase 2 12/05/2014 – 24/06/2014	77.5	470.6	286.4	38.6	474.6	295.8
Phase 3 25/06/2014 – 29/07/2014	147.5	395.5	245.5	144.8	387.2	236.6

Table 11 shows the amount of gas production from the digestion process based on the volatile solids added in the feeding. The values commonly used as a reference go from 0.5 to 0.75 m^3/kg volatiles solids fed (Taricska et al., 2009). The average values obtained in the project for R1 and R2 during phases 2 and 3 go from 0.236 to 0.295 m^3/kg volatiles solids which means that both reactors produce less than typically expected for this process. However, the reference values do not specify if they are used for primary, excess or mixed sludge, and the values showed on the table are acceptable for the treatment of excess sludge, which is the case of the project.

Graph 10 show a diagram with a lot of fluctuations which respond to the variability in gas production and the uneven mixing inside the reactors. However, as seen before, starting from the middle of phase 2 it is evident some sort of stabilization in the behavior tendency.



Graph 10. Conversion of volatile solids in the inflow into gas volume for R1 and R2 during phases 1, 2 and 3.

Volatile solids consumed

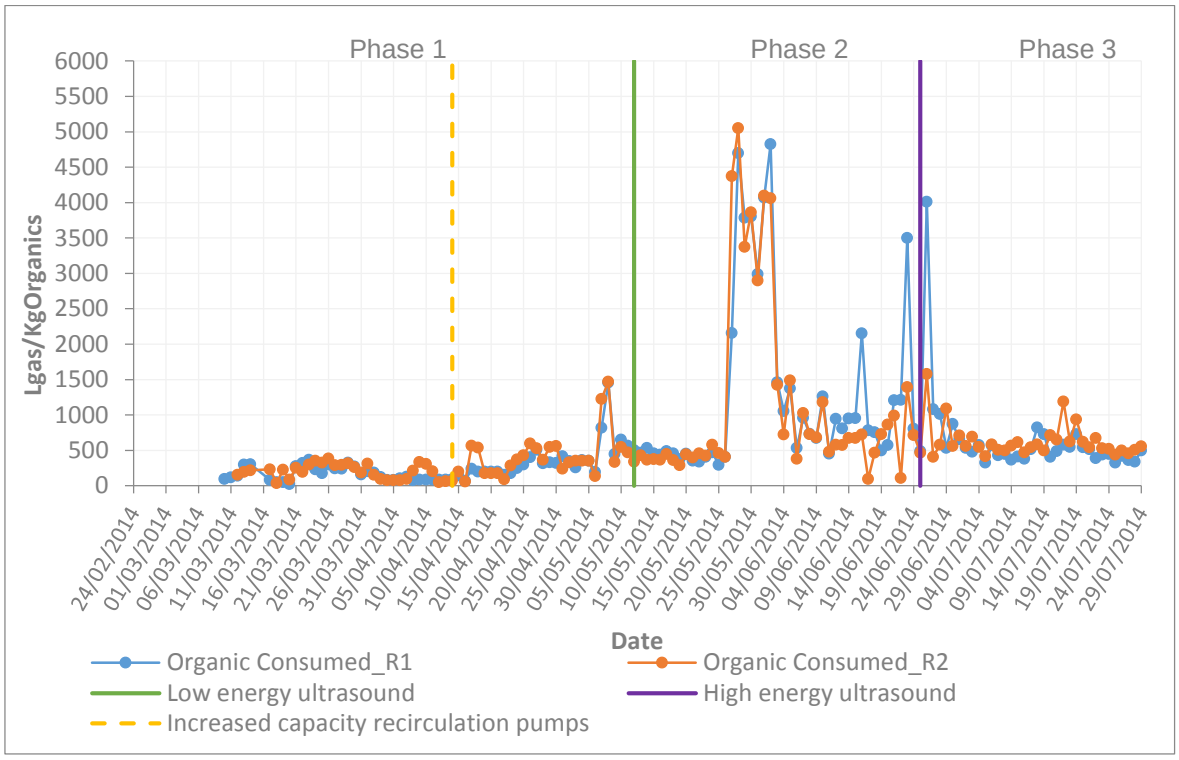
Table 12. Conversion of volatile solids consumed into biogas for R1 and R2

Phase of the project	R1 Gas volume/organic content consumed (L gas/kg organic consumed)			R2 % Gas volume/organic content consumed (L gas/kg organic consumed)		
	Min.	Max.	Average	Min.	Max.	Average
Phase 1.1 07/03/2014 – 10/04/2014	23.9	369.5	175.4	36.7	384.3	217.3
Phase 1.2 11/04/2014 – 11/05/2014	70.8	1455.3	330.5	51.0	1470.7	384.0
Phase 2 12/05/2014 – 24/06/2014	294.1	4824.4	1283.3	94.8	5052.7	1150.1
Phase 3 25/06/2014 – 29/07/2014	325.1	4011.2	636.9	407.0	1579.0	627.8

Table 12 shows the amount of gas production from the digestion process based on the volatile solids consumed. As stated by Taricska et al. (2009) and Metcalf & Eddy (2003) the values commonly used as a reference in this case go from 0.75 to 1.12 m^3/kg volatiles solids destroyed. The average values obtained for R1 and R2 during phases 2 and 3 of the project varied significantly, during phase 2, R1 and R2 achieved a gas production of 1.28 and 1.15 m^3/kg volatiles destroyed respectively, this means that both reactors were slightly over the superior limit of the typical values, being R2 the closest to this limit. However, during phase 3 the values dropped down to 0.636 and 0.627 m^3/kg volatiles destroyed respectively for R1 and R2. In this case both vales are very similar and both under the inferior limit of the range mentioned in the literature.

It is important to consider that the values mentioned by Taricska et al. (2009) are just a reference value from common practice, however sludge vary from plant to plant which means that the results are not restrictively wrong.

Graph 11 show a fairly stable production except from a few high peak mostly during phase 2 and the beginning of phase 3.



Graph 11. Conversion of volatile solids consumed into gas volume for R1 and R2 during phases 1, 2 and 3.

Alternatively, tables 13 and 14 show the values of energy generated according to the gas volume production and the volatile organics fed and consumed in each system.

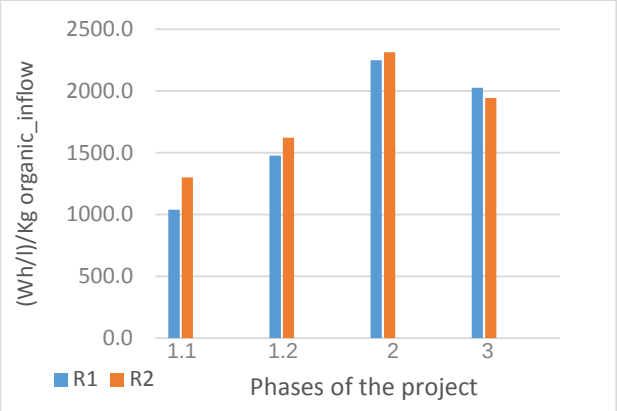
Table 13. Conversion of volatile solids fed into energy for R1 and R2

Phase of the project	R1 (Wh/l)/kg organic inflow			R2 (Wh/l)/kg organic inflow		
	Min.	Max.	Average	Min.	Max.	Average
Phase 1.1 07/03/2014 – 10/04/2014	90.8	2570.4	1038.9	140.1	2273.0	1299.5
Phase 1.2 11/04/2014 – 11/05/2014	272.2	3488.7	1475.8	199.3	3544.9	1621.2
Phase 2 12/05/2014 – 24/06/2014	550.3	3953.0	2248.2	281.8	3986.6	2313.2
Phase 3 25/06/2014 – 29/07/2014	1121.0	3401.3	2025.4	1115.0	3368.6	1942.5

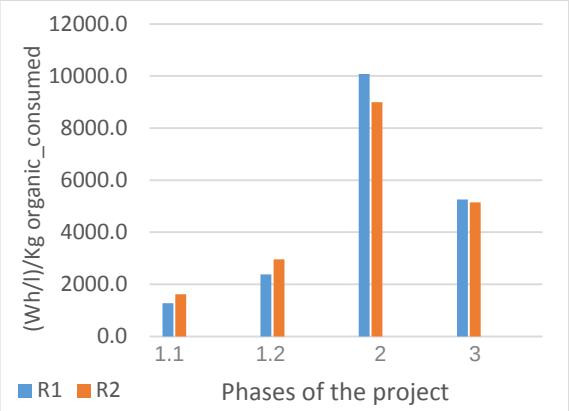
Table 14. Conversion of volatile solids consumed into energy for R1 and R2

Phase of the project	R1 (Wh/l)/kg organic consumed			R2 (Wh/l)/kg organic consumed		
	Min.	Max.	Average	Min.	Max.	Average
Phase 1.1 07/03/2014 – 10/04/2014	108.7	3140.8	1273.4	148.6	3228.1	1621.1
Phase 1.2 11/04/2014 – 11/05/2014	382.3	11787.9	2386.2	275.4	12059.7	2964.5
Phase 2 12/05/2014 – 24/06/2014	2088.1	40525.0	10073.9	692.0	42442.7	8993.8
Phase 3 25/06/2014 – 29/07/2014	2470.8	34496.3	5254.4	3133.9	13737.3	5154.2

In both tables 13 and 14 as well as in graphs 12 and 13 it is possible to appreciate barely no difference in the energy generation of both systems, and the slight differences found respond to the fluctuations in the volatile solids as a consequence of the mixing inconvenient.



Graph 12. Conversion of volatile solids fed into energy for R1 and R2 during phases 1, 2 and 3.



Graph 13. Conversion of volatile solids consumed into energy for R1 and R2 during phases 1, 2 and 3.

In the graphs 12 and 13 its evident that the higher potential for energy generation corresponds to phase 2, for both systems, this behavior is similar to the one found throughout the project, where phase 1 for being of stabilization present very low values, phase 2 spikes up for both systems with barely no difference between them and phase

3 reporting a drop in the values, very likely in response to the changes made in the system regarding the elimination of the enzymes.

8.3 Other parameters.

Other parameter used to evaluate the performance of digestion process during the three phases was the content of volatile acids and lime reserve. These are key parameters that indicate whether the digestion process is being soundly effective or not.

Table 15. Organic acids for R1 and R2 during phases 1, 2 and 3.

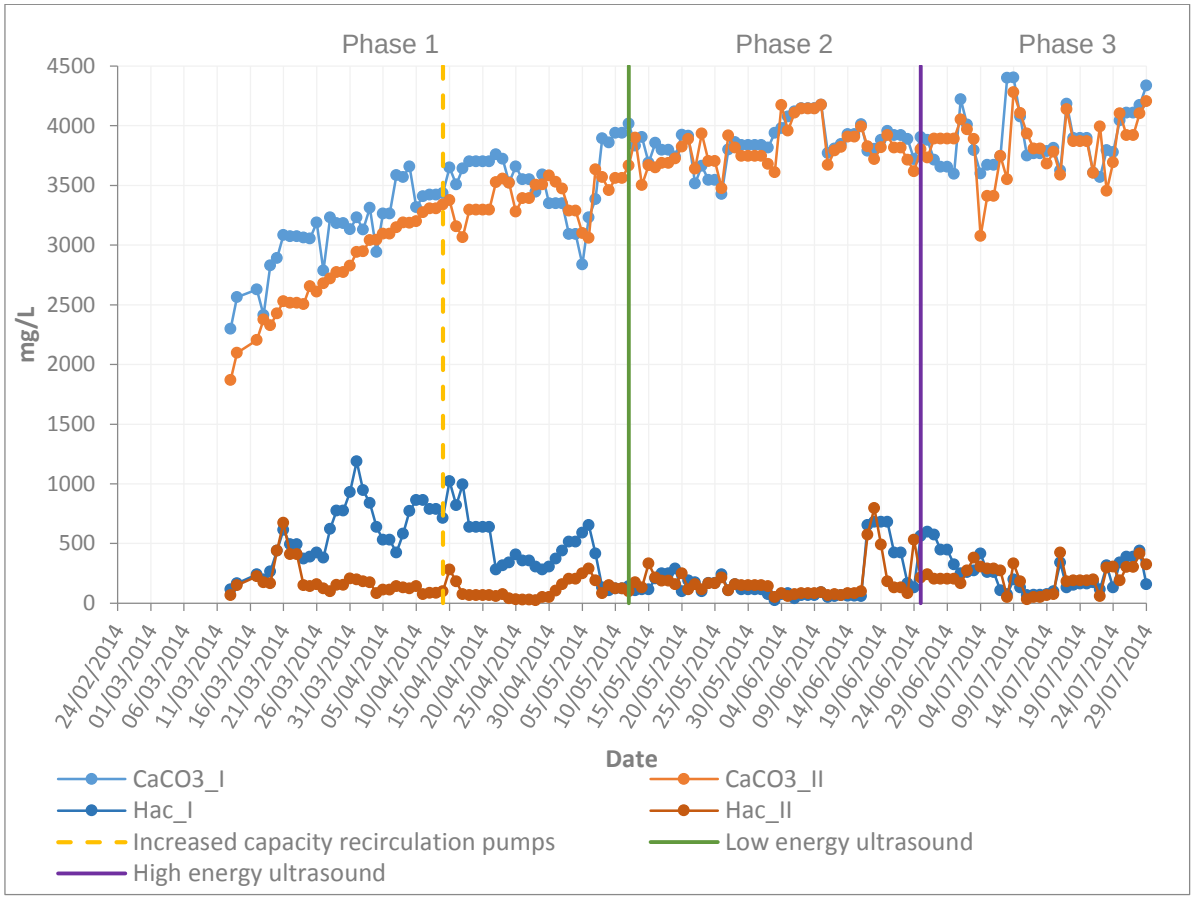
Phase of the project	R1 Organics acids – HAc (mg/L)			R2 Organics acids – HAc (mg/L)		
	Min.	Max.	Average	Min.	Max.	Average
Phase 1.1 07/03/2014 – 10/04/2014	115.9	1186.6	555.8	66.1	672.0	196.1
Phase 1.2 11/04/2014 – 11/05/2014	107.6	1020.6	499.6	24.6	290.2	110.1
Phase 2 12/05/2014 – 24/06/2014	24.6	680.3	184.8	49.5	769.5	174.2
Phase 3 25/06/2014 – 29/07/2014	66.1	597.3	256.4	32.9	423.0	218.8

Table 16. Lime reserve for R1 and R2 during phases 1, 2 and 3.

Phase of the project	R1 Lime buffer – $CaCO_3$ (mg/L)			R2 Lime buffer – $CaCO_3$ (mg/L)		
	Min.	Max.	Average	Min.	Max.	Average
Phase 1.1 07/03/2014 – 10/04/2014	2297.5	3657.5	3071.4	1870.0	3200.0	2713.9
Phase 1.2 11/04/2014 – 11/05/2014	2837.5	3937.5	3528.5	3060.0	3632.5	3379.8
Phase 2 12/05/2014 – 24/06/2014	3427.5	4175.0	3860.4	3475.0	4175.0	3814.0
Phase 3 25/06/2014 – 29/07/2014	3567.5	4402.5	3881.8	3075.0	4280.0	3826.1

As mentioned in the theory, the value corresponding to the organic acids should not go over 500mg/l; table 15 shows the rough patch for R1 during the stabilization phase,

where the content of organic acids was beyond this limit. However, after some time, the process in the reactor was stable and the content of acids inside of it decreased to far more acceptable values.



Graph 14. Organics acids and lime reserve for R1 and R2 during phases 1, 2 and 3.

The alkalinity in the reactor is defined by the presence of substances such as calcium, magnesium and ammonium bicarbonates. As mentioned by WEF (1996) in Tchobanogous et al., (2003, p. 1507) “a well-established digester has a total alkalinity of 2000 to 5000 mg/L“. According to the results obtained in the tests, the reactors had a good performance regarding their buffering capacity from the beginning of the project.

A good factor no indicate the stability of the process is obtaining a ratio ration between the volatile acids in mg/L of acetic acid and the bicarbonate alkalinity in mg/L of CaCO3≤ 0.25, according to the results obtained, the calculated ratio for phases 1, 2 and 3 for both reactors meet the parameter.

8.4. Dewaterability

The dewaterability of the sludge was tested in two different ways, through Capillary Suction Time (CST) and through vacuum filtration. The results for are presented in table 17.

Table 17. Dewaterability values for R1 and R2 with CST and vacuum filtration tests.

Sample	Phase of the project	CST Average	Vacuum Filtration
Sludge without ultrasound	1	19.7	27.5
Sludge with low energy ultrasound	2	21.3	81.8
Sludge with high energy ultrasound	3	40.7	132.7
Digested Sludge R1	-	357.6	310.2
Digested Sludge R2	-	357.5	663.2

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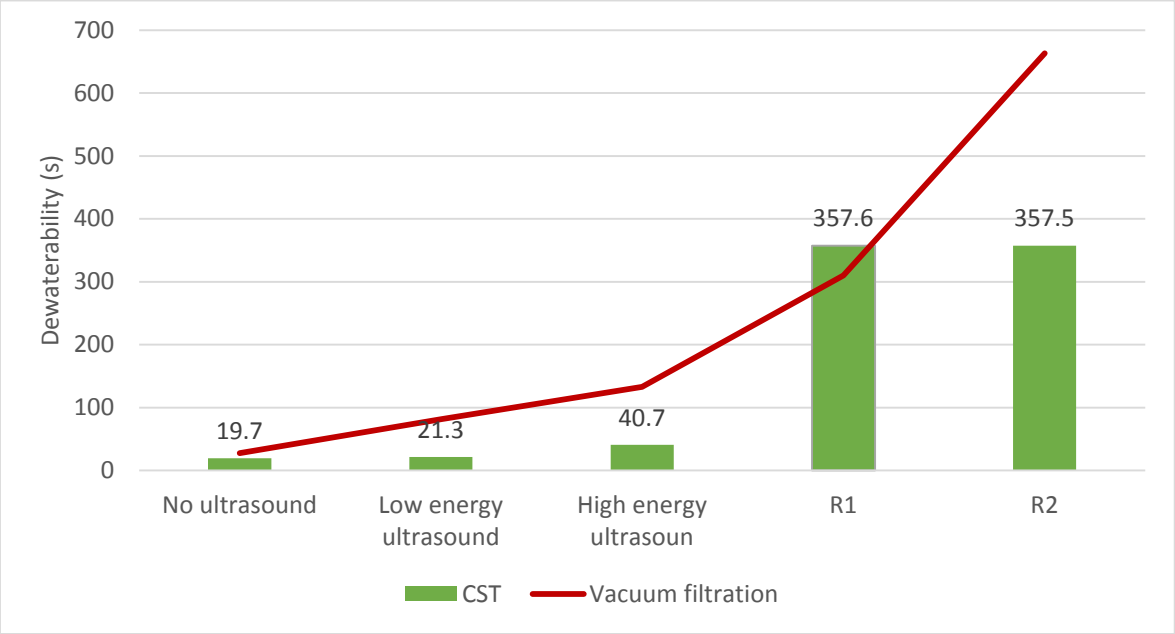
Proportionally speaking the results are similar except for the important difference found on the dewaterability of the digested sludge that has been pretreated with ultrasound. According to the table it is evident that the raw sludge requires the shortest time to separate from water, which is very logical considering its physical characteristics while the digested sludge has a stronger mixture with water needing larger times. According to the CST, there is no difference between the digested sludge pretreated and the non-pretreated one, while the vacuum filtration points out an important difference between the two of them.

Yin, Han, Lu, & Wang, (2004) reported from Poxon and Darby (1997) a mean CST for digested sludge of about 270–380 s. and from Bien et al. (1997) a kind of digested sludge with mean CST of 390 s., which is very close to the results obtained for CST in this project.



Graph 15. Dewaterability times for different samples of sludge measured with CST and vacuum filtration.

The results for dewaterability are corresponding to the findings of Lee and Liu in Yin et al. (2004), who reported higher times for dewaterability of digested sludge than for raw sludge, being the last one easier to dewater.

Regarding the effects of the ultrasound, its effects in the structure and properties of the sludge are expected to influence the efficiency of the dewatering process of the digested sludge (Yin et al., 2004) and this could be observed in the results of the vacuum filtration but it was not reflected in CST test. Graph 15 shows a red line much higher dewatering time for the digested sludge without pretreatment according to the vacuum filtration test, while the CST test showed visually no difference between both digested sludge.

However, according to other studies, this result is not always the case and strongly depends on the energy input of the treatment. As concluded by Feng et al. (2009, p.7) “each energy dosage led to a different dewatering result. Low-energy dosage slightly enhanced sludge dewaterability, while high-energy dosage significantly deteriorated sludge dewaterability”

As stated by C.P. Chu et. al (2001) in Huan, Yiying, Mahar, Zhiyu, & Yongfeng, (2009, p. 1), “Ultrasonic stresses produce a kind of sponge effect and facilitate the migration of moisture through natural channels or other channels created by wave propagation“. They presented a CST data where low energy sonication (0.11 W/ml) “only slightly deteriorates the sludge’s filterability”, while high energy sonication (0.33 W/ml) increased significantly the CST, this is due to the breakup of flocs and the increase of fine particles that enlarge the spaces for bound water.

Finally Yin et al., (2004, p.9) added “Some research work have found out that the low frequency ultrasound can put the sludge particles together and make them easier to dewater”.

8.5. Viscosity

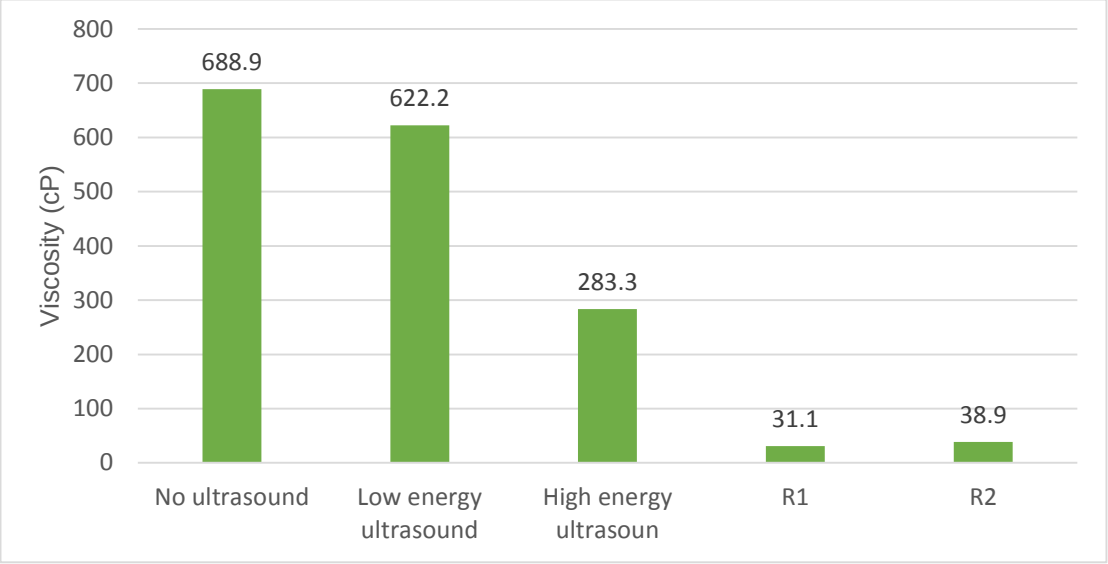
Table 18 shows the values obtained for viscosity of the different samples of sludge tested, however, it is important to mention that as sludge is a non-Newtonian fluid it is necessary to establish comparative and descriptive measures between samples rather than giving an specific value for each one of them, due to this values could be non-reproducible as sludge characteristics vary day to day and from one treatment plant to another.

Table 18. Viscosity values for R1 and R2.

Sample	Phase of the project	Viscosity (cP) Average
Sludge without ultrasound	1	688.9
Sludge with low energy ultrasound	2	622.2
Sludge with high energy ultrasound	3	283.3
Digested Sludge R1	-	31.1
Digested Sludge R2	-	38.9

According to the values presented on the table the viscosity of the sample goes from higher value to lower values in the following way: Sludge without ultrasound > Sludge with low energy ultrasound > Sludge with high energy ultrasound > Digested Sludge R2 > Digested Sludge R1.

The results show a clear decrease in the viscosity values with the use of the ultrasound. According to the results, the sludge treated with low energy ultrasound is very similar to the non-treated sludge, this implied no important effects of the ultrasound at this level, however, treating the sludge with high energy ultrasound produced a decrease in viscosity of more than 50%, these results can also be appreciated in graph 16. Here is also appreciated that the digested sludge of R1 reported a slightly lower viscosity value than R2, which could also be an effect of the ultrasound applied.



Graph 16. Viscosity values for different samples of sludge.

This results agree to the ones offered by the company Ultrawaves, who provided figure 34 where is evident the decrease of the viscosity with the increment of the energy applied in the ultrasound.

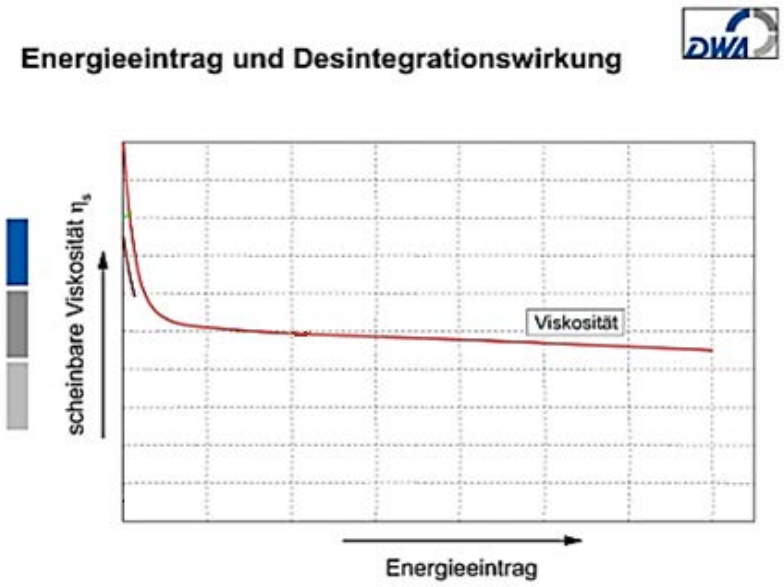


Figure 34. Effects of the ultrasonic disintegration over the sludge viscosity (Image provided by *Ultrawaves*).

8.6. Microscopic analysis.

Different samples of the sludge with and without ultrasound pretreated were analyzed in the microscope in order to appreciate the effects of the sonication.

Raw sludge without ultrasonic pretreatment

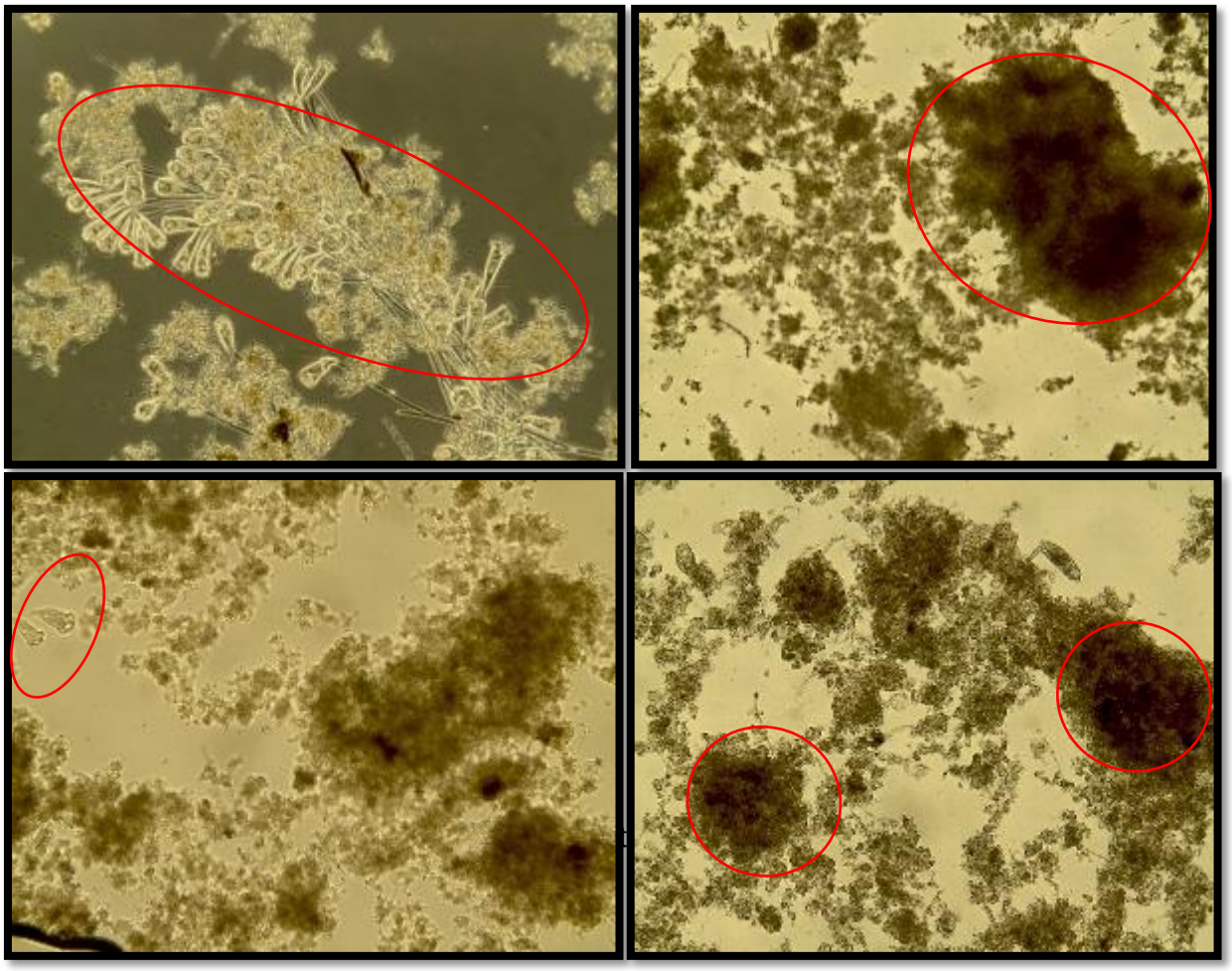


Figure 35. Microscopic view of sludge without ultrasonic pretreatment (by the author/personnel BG treatment plant, 2014).

The figures show the presence of bacteria and other microorganisms both alive and active. It is also evident the existence of sludge flocs quite big and thick, this is a consequence of the use of polymers in the treatment plant for the conditioning of the sludge.

Raw sludge with low-energy ultrasonic pretreatment

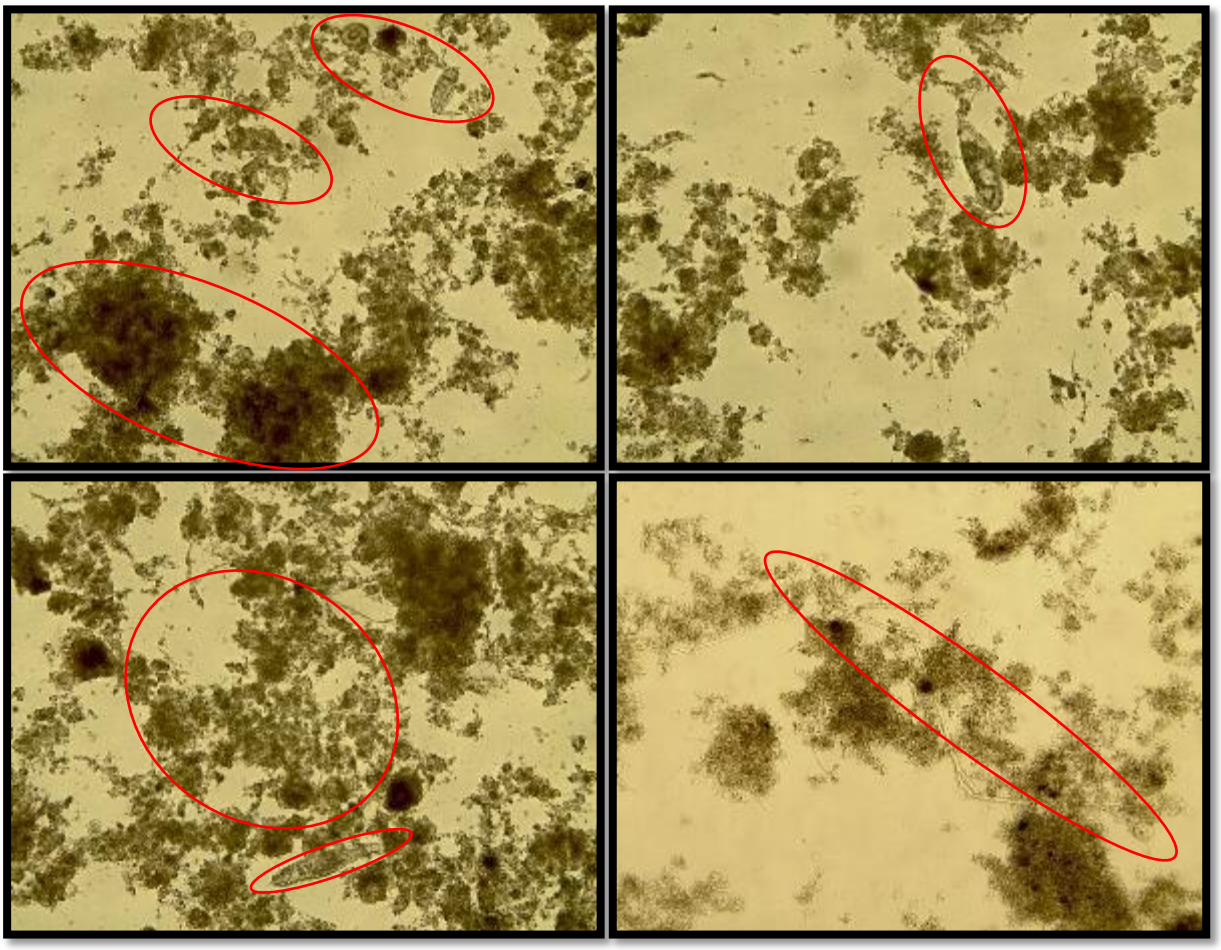


Figure 36. Microscopic view of sludge pretreated with low energy ultrasound (≈ 300 W for 2 min), (by the author/personnel BG treatment plant, 2014).

After sonicating the sludge for two minutes with about 300W of energy it is possible to find bacterial cells from which some were alive and some did not show movements but were not entirely destroyed which could imply there just deactivated. It is still evident the presence of thick flocs even though there are already some signs of disintegrated particles.

Raw sludge with high-energy ultrasonic pretreatment

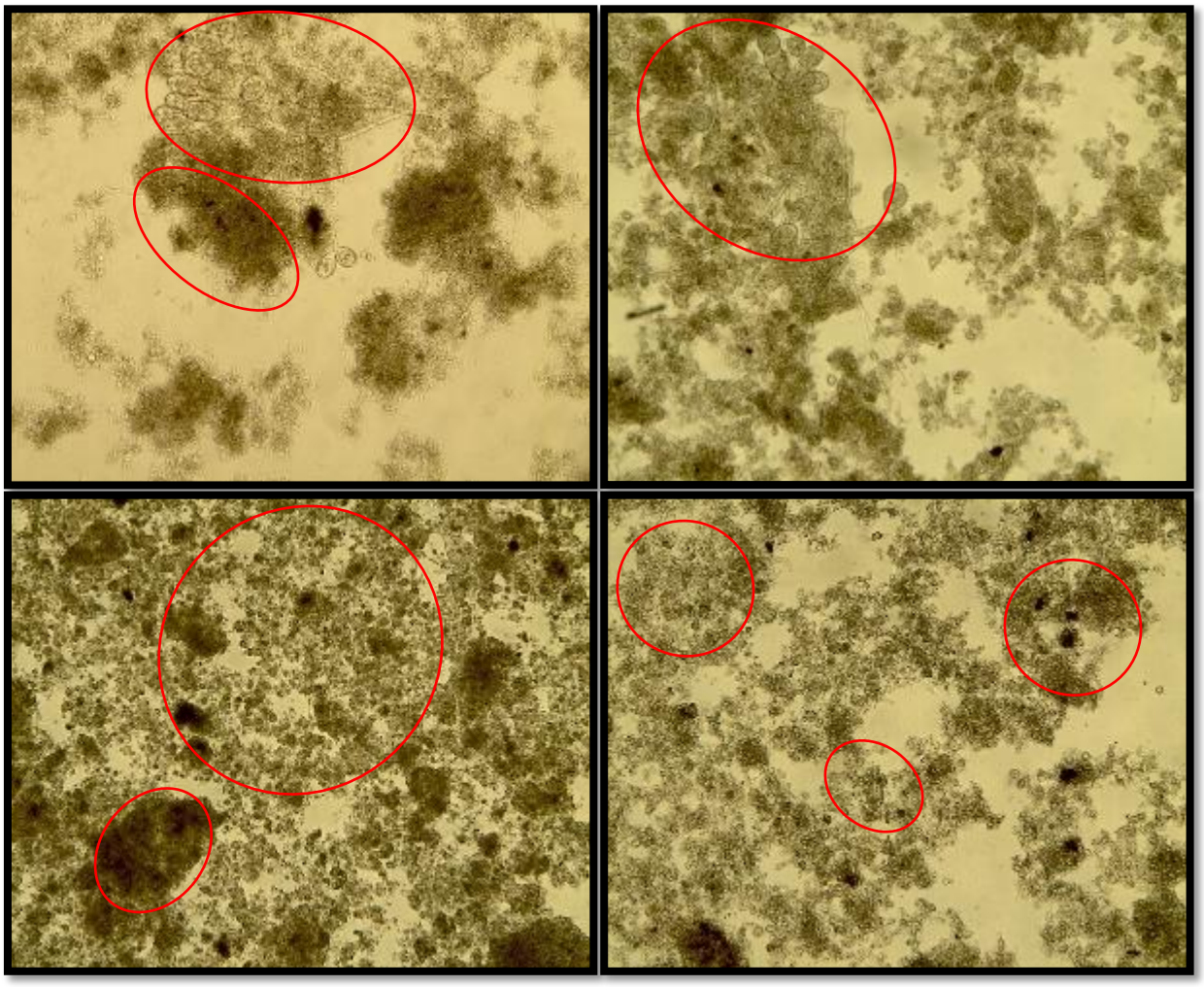


Figure 37. Microscopic view of sludge pretreated with high energy ultrasound (≈ 560 W for 2 min), (by the author/personnel BG treatment plant, 2014).

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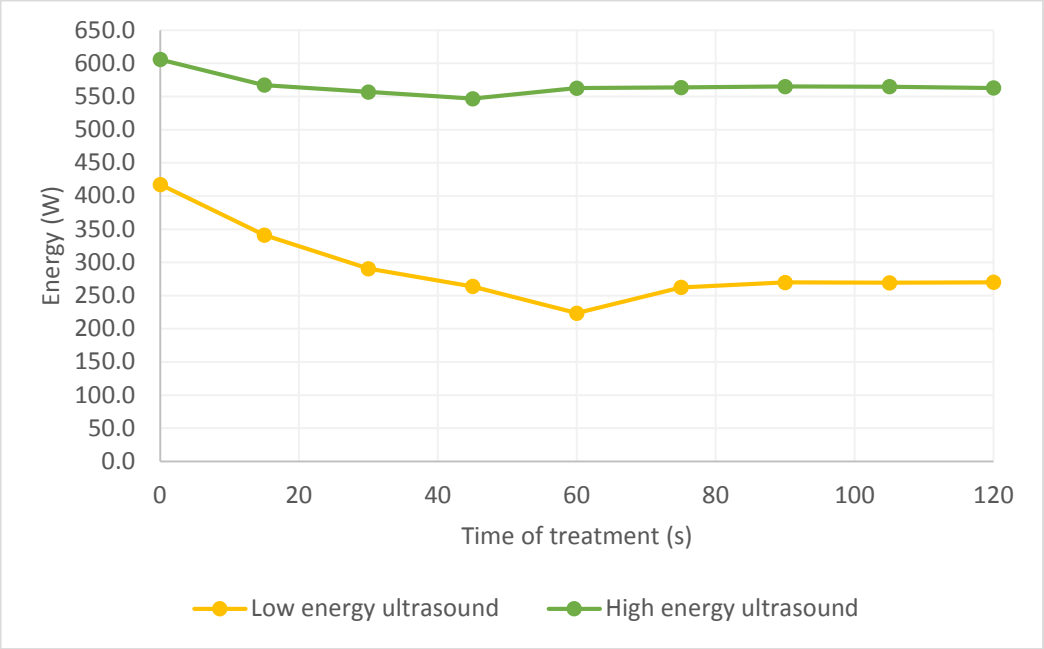
The pictures show the presence of bacteria cells most of them destroyed with a very few exceptions that even manage to remain alive. Most of the sludge is disintegrated in small particles although it is possible to see a few flocs of smaller size. All of these are an evidence of the action of the ultrasound pretreatment, which as mentioned by Tiehm et al., (1997, p. 5) acts “causing aggregate deagglomeration and microbial cell disruption”.

8.7. Energy consumption and costs

The energy consumption was obtained by using an electricity meter during the sonication time. Table 19 shows the average values obtained during sonication for each phase and graph 17 shows the behavior of this values throughout the two minutes of treatment. The complete values can be found in annexes 12 and 13.

Table 19. Energy values given as an input to the sludge during phases 2 and 3.

Time (s)	Energy (W)	
	Phase 2	Phase 3
0	417.5	605.9
15	341.3	567.3
30	290.6	556.8
45	263.7	546.9
60	223.4	562.7
75	262.4	563.6
90	269.7	565.1
105	269.4	564.8
120	270.0	562.8
Average	**289.8**	**566.2**



Graph 17. Energy input values given to the sludge during phases 2 and 3.

As shown in the diagram, the energy input during phase 3, with the higher values, was more stable than the registered with the low values, during phase 2.

Low energy phase.

Net energy input: 289.8 W

$$\frac{289.8\ W * \frac{2\ min * 1h}{60\ min}}{2L} = 4.83\ Wh/l$$

The total daily energy input given to R1 was of 4.98 Wh/l during phase 2.

High energy phase.

Net energy input: 298.8 W

$$\frac{566.2\ W * \frac{2\ min * 1h}{60\ min}}{2L} = 9.44\ Wh/l$$

The total daily energy input given to R1 was of 9.44 Wh/l during phase 3, this is equal to 9.44 kWh/m^3.

Current energy consumption in the treatment plant.

Currently the treatment plant of Bergisch Gladbach consumes about 4 million kWh a year, producing 70% of this and paying for the remaining 30%.

This is,
Daily gas production: 3700 m^3/d
Methane content in the gas: 60% CH_4; which has an equivalent of 6kWh/m^3
Efficiency in electricity generation: 35%

Then,

$$3700\frac{\mathrm{m}^3}{\mathrm{d}} * 6\frac{\mathrm{kWh}}{\mathrm{m}^3} * 0.35 = 7800\ \frac{\mathrm{kWh}}{\mathrm{d}}$$

This amount of biogas produces about 7800 kWh/d, this is a little bit more than 2.8 million kWh/year and as mentioned before it is equivalent to 70% of the yearly consumption.

The remaining 30% is bought to the local electricity company at a price of 0.18 €/kWh

This is,

$$1\ million\frac{kWh}{year} * 0.18\ \frac{€}{kWh} \approx 200\ 000\ \frac{€}{year}$$

This means that the treatment plant pays close to 200 000 €/year for the delivery of external electricity.

Projected energy consumption in the treatment plant.

Projection according to the manufacturer.

A report published by ULTRAWAVES GmbH, (2012) claims that the energy consumption in a similar treatment plant in Bamberg, Germany for such equipment is roughly 2.4 kWh/m^3

According to this information it is possible to estimate the consumption and costs of implementation of the system in the big scale in Bergisch Gladbach.

The treatment plant processes about 110 m^3/d of waste activated sludge, then the following calculation is made:

$$110\,\frac{\mathrm{m}^3}{\mathrm{d}} * 2.4\,\frac{\mathrm{kWh}}{\mathrm{m}^3} \approx 264\ \frac{\mathrm{kWh}}{\mathrm{d}}$$

The daily consumption for the treatment plant is estimated in not much more than 250 kWh/day with the implementation of the ultrasonic system.

Considering now that 1 m^3 biogas contains about 60 %methane this is 6 kWh/m^3 and the efficiency of the combined heat and power station (CHP) is around 35%, then:

$$6\,\frac{\mathrm{kWh}}{\mathrm{m}^3} * 0.35 \approx 2.1\ \frac{\mathrm{kWh}}{\mathrm{m}^3}$$

Dividing now the daily consumption calculated by the daily generation, there is:

$$264\ \frac{\mathrm{kWh}}{\mathrm{d}} * \frac{\mathrm{m}^3}{2.1\ \mathrm{kWh}} = 125\ \frac{\mathrm{m}^3}{\mathrm{d}}$$

The extra gas volume that should be generated in order to run the ultrasonic system is 125 m^3/d, which represents about 3.4% more than the current generation.

Projection according to the present research.

On the other hand if instead of considering the valued claimed by Ultrawaves for the consumption, it is considered the last energy value used in this project, corresponding to the high energy ultrasound (phase 3) which is 9.44 Wh/l = 9.44 kWh/m^3, then:

$$110\,\frac{\mathrm{m}^3}{\mathrm{d}} * 9.4\frac{\mathrm{kWh}}{\mathrm{m}^3} \approx 1034\ \frac{\mathrm{kWh}}{\mathrm{d}}$$

Dividing now this value by the daily generation of the treatment plant, this is:

$$1034\ \frac{\mathrm{kWh}}{\mathrm{d}} * \frac{\mathrm{m}^3}{2.1\ \mathrm{kWh}} = 492.4\ \frac{\mathrm{m}^3}{\mathrm{d}}$$

According to the present research the extra gas volume that should be generated in order to run the ultrasonic system is 492.4 m^3/d, which represents about 13.5% more than the current generation.

Summarizing, table 20 shows the key values for both estimations presented in this section, according to the manufacturer information and according to findings of this project.

Table 20. Key value for estimations considered

Parameter	Source of the estimation	
	Manufacturer	Present research
Energy consumption of the equipment (kWh/m^3)	2.4	9.4
Daily projected extra consumption (kWh/day)	264	1034
Extra needs in gas generation (m^3/day)	125	492.4
Extra percentage over current gas generation	3.4	13.5
Effective extra gas generation with the extra energy input	0	0

With the last results obtained in the project it is not possible to guarantee extra production in gas volume due to there are several doubts that the extra production reported for R1 is due to fluctuations of the system. Therefore according to previous results, the following calculation will be made estimating an energy input and consumption of the ultrasound of 15 kWh/m^3 which is conservatively about 50 % more than the last value found in the research.

Now, with a daily consumption of 15 kWh/m^3 and treating 110 m^3 sludge/day, taking it to a yearly basis then:

$$110\,\frac{\mathrm{m}^3}{\mathrm{d}} * 15\,\frac{\mathrm{kWh}}{\mathrm{m}^3} * \frac{365\ \mathrm{d}}{1\ \mathrm{year}} \approx 600\,000\,\frac{\mathrm{kWh}}{\mathrm{year}}$$

The extra energy consumption for the treatment plant would be estimated in not much more than 600 000 kWh/year with the implementation of the ultrasonic systems which is about 15% of the 4 000 000 consumed yearly

This amount is added to the current energy consumption giving a total of 4 600 000 kWh/year.

Regarding the gas production, assuming that the consumption of 15 kWh/m^3 would increase the daily gas production about 23% with the implementation of the ultrasonic system and the same content of methane (60%), then the following calculation is made:

$$850\,\frac{\mathrm{m}^3}{\mathrm{d}} * 6\,\frac{\mathrm{kWh}}{\mathrm{m}^3} * \frac{365\ \mathrm{d}}{1\ \mathrm{year}} * 0.35 \approx 650\,000\ \frac{\mathrm{kWh}}{\mathrm{year}}$$

Altogether, adding up the extra consumption and the extra generation in electricity as a consequence of the implementation of the ultrasonic pretreatment to the anaerobic digestion of secondary sludge, the following estimations can be made:

Consumption			
4 000 000 kWh/year	+	600 000 kWh/year	= 4 600 000 kWh/year
Current consumption		**Estimated consumption of the ultrasonic reactor**	**Estimated total consumption**

Generation			
3 000 000 kWh/year	+	650 000 kWh/year	= 3 650 000 kWh/year
Current generation		**Estimated extra generation with the use of the ultrasonic pretreatment**	**Estimated total generation**

Currently the treatment plant produces about 70% of it consumption, with the estimations done, this value will increase to approximately 80%.

With these estimations, close to 15% of the amount that is currently paid to the local electricity company yearly would be saved, this means that instead of paying for 1 000 000 kWh/year, the plant would need to buy about 950 000 kWh/year, which is a total of about 170 000 €/year that compared to the 200 000 €/year that are currently paid represents no major difference.

Considering that the costs of inversion is about 100 000 €, this means that the treatment plant would need more than 3 years of operation to recover this cost Moreover this estimations do not include maintenance nor replacement of the wearing parts costs that are needed after a while of continuous operation.

An example of this is shown on figure 38, where is possible to compare a new sonotrode and one after 3 years of operation.

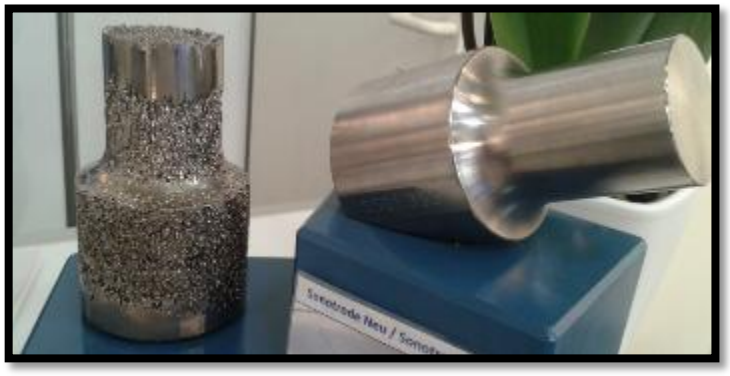


Figure 38. Comparison between a new sonotrode and one after three years of operation (by the author, 2014).

Summarizing, the application of this technology could imply economic benefits for the treatment plant, as long as the real behavior go far beyond the estimations made regarding gas production and electricity consumption, otherwise the benefits will not be significant enough to justify its implementation on the big scale considering the specific characteristics and conditions of their excess sludge.

Chapter 9. Conclusions and recommendations

Up until now ultrasonic disintegration has arisen as a top notch tool to the improvement of the anaerobic digestion process for the stabilization of waste activated sludge and many studies back this up. However, the overall results obtained in this project do not reflect its efficiency on the treatment of the secondary sludge of the treatment plant in Bergisch Gladbach. During the development of almost the entire project, there was no clear evidence of the positive effects of the ultrasonic pretreatment over the performance of the anaerobic digestion process in R1. In the results obtained for the gas yield it is possible to see that just up to the last weeks there was some slight improvement in the gas production of the reactor pretreated with the ultrasound, nevertheless, it is not quite clear that this is an effect of the ultrasonic pretreatment or just an effect of the typical fluctuations observed during the project, and further experimenting time is required, especially considering the lack of reduction in volatile solids during the same weeks for R1 system. In the same way, the concentration of methane remained fairly stable and similar for both systems during the entire project.

Regarding the behavior of the solids, evidently the problem in the mixing of the reactors produces results not entirely trustworthy, even though this appeared to be overcome at the end of the project, however more treatment time is necessary to verify this. Nonetheless, in a general way it is possible to appreciate an increment and stabilization of the solids inside the reactors, while the consumption of volatile solids had a radical change by the middle of phase 2 and at the end showed a more stable and reasonable behavior, evidencing the regularization of the mixing situation.

While analyzing the gas production regarding the volatile solids fed and destroyed, the average production values remained mostly under the typically known values, however it is not entirely accurate to compare the pilot plant performance to the one in the regular big scale systems, but what was fairly evident was the lack of difference between the two systems, again reflecting no effects of the ultrasonic pretreatment applied to R1.

Still, even though the ultrasonic pretreatment had no clear effects over the anaerobic digestion process of the r1, it did have an effect over the physical characteristics of the treated sludge. Evidence of this was the slightly decrease in dewaterability time when treating the raw sludge with low energy contrasted with the treatment with high energy and the lower time partially reported by one of the tests performed on the digested sludge of the treated reactor.

Just as dewaterability, viscosity of the sludge treated with the ultrasound also decreased, in this case with a significant difference between the sludge treated with low energy, and the one treated with high energy. According to the values obtained the viscosity of the analyzed sample goes from higher to lower values in the following way: Sludge without ultrasound > Sludge with low energy ultrasound > Sludge with high energy ultrasound > Digested Sludge R2 > Digested Sludge R1.

The physical changes were also evident when analyzing the samples under the microscope, where it was possible to observe the effects of the ultrasonic applied in the disruption of bacterial cells and flocs being possible to distinguish between the sludge without pretreatment, the one treated with low energy and the one treated with high energy ultrasound.

Even though in the present project the ultrasonic pretreatment had no clear effects over gas production, the plant continues with the development of the experiments varying the energy input of the ultrasound, this is why it was important to carry out some cost – benefit calculations that will allow the treatment plant analyze whether it is advisable or not the implementation on the long run of the system in the big scale. Based on these calculations it is possible to conclude that not even an increment of about 20% in the gas production as an effect of the ultrasonic pretreatment will justify the installation of the system, because the costs involved would be too high, reducing its profitability.

From the results obtained and the studies analyzed it is concluded that several factors play an important role in the performance and effects of the ultrasonic treatment. The tricky part relies on the perfect combination of all of this factors adapted to the particular system of one treatment plant or another. Frequency, energy level, characteristics of the sludge, residence time, sludge volume, probe position, additives in the sludge, among other, are some of the factors that become the experiments in an iteration process, which, when they do not perform as expected not necessarily means that the ultrasound treatment does not work, but instead it means that one or several of this factors most be changed to continue with a new round of experiments.

Doing an overall analysis of the project, despite the fact that the results offered no evident benefit from the ultrasonic pretreatment, the development of the project was fairly sound. Except for a short period of instability in R1 during the first phase, both systems behaved as expected, with the continuous monitoring of the control variables such as temperature, pH, organic acids and lime reserve, after stabilization, the reactors managed to perform a satisfactory digestion process, with clear characteristics of a pilot plant.

Recommendations to the treatment plant, where the experiments currently continue in development are, firstly increase the volume of the treated sludge from one to two liters and carry on the experiments in this way for at least one complete cycle of SRT (30 days), the time is important due to the system needs to reach stabilization after changing some conditions. If this change does not report any evident effect then the treatment time of the sludge in the ultrasonic reactor should be increased from 2 to 4 minutes, always recording the changes in energy input. Regarding the mixing and the recirculation, it is important to continue with the daily change in recirculation pattern, alternating with recirculation from the top and recirculation from the side and continue with the manual agitation of the reactors. And as a final point, it is important to continue with the periodic monitoring of the performance and behavior of the reactors to detect on time any abnormality and not affect the overall results of the experiments.

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Annexes

Annex 1. INFLOW DATA.

Measurement	Date	Inflow for both reactors. Table 1/4							
		Q inflow	Total sludge fed	Dry solids	Organic content	Inorganic content	Dry solids	Dry solids sum	Organic content
		(l/min)	L/d	%	%	%	g/d	gr	g/d
1	07-03-2014	0.66	2	3.10	56.54	43.46	61.99	61.99	35.05
2	10-03-2014	0.66	2	3.07	53.01	46.99	61.40	123.39	32.55
3	11-03-2014	0.50	2	4.05	69.26	30.74	81.00	204.39	56.10
4	12-03-2014	0.90	2	2.80	69.11	30.89	56.00	260.39	38.70
5	13-03-2014	1.00	2	3.59	68.84	31.16	71.70	332.09	49.36
6	14-03-2014	0.96	2	3.67	69.37	30.63	73.40	405.49	50.92
7	17-03-2014	0.82	2	3.87	69.28	30.72	77.43	482.92	53.65
8	18-03-2014	1.05	2	3.96	68.39	31.61	79.23	562.14	54.18
9	19-03-2014			3.71	68.11	31.89	74.10	562.14	54.18
10	20-03-2014	1.07	2	3.45	67.83	32.17	68.98	631.12	46.79
11	21-03-2014	0.65	2	3.36	66.33	33.67	67.28	698.40	44.63
12	22-03-2014	0.65	2	3.60	68.00	32.00	72.00	770.40	48.96
13	23-03-2014	0.65	2	3.60	68.00	32.00	72.00	842.40	48.96
14	24-03-2014			3.71	68.88	31.12	74.00	842.40	50.99
15	25-03-2014	0.64	2	3.80	69.75	30.25	76.00	918.40	53.01
16	26-03-2014	0.49	2	3.98	61.77	38.23	79.62	998.02	49.18
17	27-03-2014	0.56	2	3.70	68.14	31.86	74.00	1072.02	50.42
18	28-03-2014	0.32	2	4.58	66.25	33.75	91.53	1163.55	60.64
19	29-03-2014	0.25	2	4.64	67.60	32.40	92.80	1256.35	62.73
20	30-03-2014	0.25	2	4.64	67.60	32.40	92.80	1349.15	62.73
21	31-03-2014	0.19	2	4.71	69.04	30.96	94.16	1443.31	65.01
22	01-04-2014			4.18	68.20	31.80	83.67	1526.98	57.06
23	02-04-2014			4.18	68.20	31.80	83.67	1610.65	57.06
24	03-04-2014			4.18	68.20	31.80	83.67	1694.32	57.06
25	04-04-2014			4.18	68.20	31.80	83.67	1777.99	57.06
26	05-04-2014			4.18	68.20	31.80	83.67	1861.66	57.06
27	06-04-2014			4.18	68.20	31.80	83.67	1945.33	57.06
28	07-04-2014	0.31	2	3.66	67.36	32.64	73.18	2018.51	49.29
29	08-04-2014	0.56	2	3.49	68.33	31.67	69.78	2088.29	47.68
30	09-04-2014	0.56	2	3.37	66.91	33.09	67.48	2155.77	45.15
31	10-04-2014			3.75	67.27	33.09	75.04	2230.81	50.48
32	11-04-2014			3.75	67.27	33.09	75.04	2305.85	50.48

Measurement	Date	Inflow for both reactors. Table 2/4							
		Q inflow	Total sludge fed	Dry solids	Organic content	Inorganic content	Dry solids	Dry solids sum	Organic content
		(l/min)	L/d	%	%	%	g/d	gr	g/d
33	12/04/2014			3.75	67.27	33.09	75.04	2380.89	50.48
34	13/04/2014			3.75	67.27	33.09	75.04	2455.93	50.48
35	14/04/2014	0.46	2	4.13	67.63	32.37	82.60	2538.53	55.86
36	15/04/2014	0.28	2	3.74	67.02	32.98	74.80	2613.33	50.13
37	16/04/2014	0.18	2	4.28	66.07	33.93	85.60	2698.93	56.56
38	17/04/2014	0.21	2	4.17	66.11	33.89	83.40	2782.33	55.14
39	18/04/2014			4.12	65.89	33.89	82.36	2864.69	54.27
40	19/04/2014			4.12	65.89	33.89	82.36	2947.05	54.27
41	20/04/2014			4.12	65.89	33.89	82.36	3029.41	54.27
42	21/04/2014			4.12	65.89	33.89	82.36	3111.77	54.27
43	22/04/2014	0.24	2	4.07	65.67	34.33	81.32	3193.09	53.40
44	23/04/2014	0.19	2	4.17	66.38	33.62	83.40	3276.49	55.36
45	24/04/2014	0.16	2	4.48	66.53	33.47	89.60	3366.09	59.61
46	25/04/2014	0.19	2	4.21	66.70	33.30	84.29	3450.39	56.23
47	26/04/2014	0.21	2	4.00	66.90	33.10	80.00	3530.39	53.52
48	27/04/2014	0.21	2	4.00	66.90	33.10	80.00	3610.39	53.52
49	28/04/2014	0.24	2	3.91	67.27	32.73	78.18	3688.57	52.59
50	29/04/2014	0.20	2	3.83	67.08	32.92	76.52	3765.09	51.33
51	30/04/2014	0.24	2	3.82	67.00	33.00	76.44	3841.53	51.21
52	01/05/2014	0.28	2	3.75	66.60	33.40	75.00	3916.53	49.95
53	02/05/2014	0.32	2	3.67	66.38	33.63	73.42	3989.95	48.73
54	03/05/2014	0.38	2	3.65	64.90	35.10	73.00	4062.95	47.38
55	04/05/2014	0.38	2	3.65	64.90	35.10	73.00	4135.95	47.38
56	05/05/2014	0.38	2	3.65	64.90	35.10	73.00	4208.95	47.38
57	06/05/2014	0.38	2	3.64	63.51	36.50	72.70	4281.65	46.17
58	07/05/2014	0.38	2	3.61	62.03	37.97	72.12	4353.77	44.73
59	08/05/2014	0.44	2	3.40	67.06	32.95	68.06	4421.83	45.64
60	09/05/2014	0.13	2	4.31	67.24	32.76	86.10	4507.93	57.90
61	10/05/2014	0.13	2	4.10	67.40	32.60	82.00	4589.93	55.27
62	11/05/2014	0.13	2	4.10	67.40	32.60	82.00	4671.93	55.27
63	12/05/2014	0.14	2	4.00	67.55	32.45	79.96	4751.89	54.02
64	13/05/2014	0.17	2	3.60	67.12	32.88	72.00	4823.89	48.32
65	14/05/2014	0.13	2	4.28	67.26	32.74	85.50	4909.39	57.51
66	15/05/2014	0.18	2	3.72	67.28	32.72	74.40	4983.79	50.06
67	16/05/2014	0.13	2	4.03	65.31	34.69	80.60	5064.39	52.64
68	17/05/2014	0.21	2	4.46	64.60	35.40	89.20	5153.59	57.62
69	18/05/2014	0.21	2	4.46	64.60	35.40	89.20	5242.79	57.62
70	19/05/2014	0.29	2	4.88	63.98	36.02	97.60	5340.39	62.44

Measurement	Date	Inflow for both reactors. Table 3/4							
		Q inflow	Total sludge fed	Dry solids	Organic content	Inorganic content	Dry solids	Dry solids sum	Organic content
		(l/min)	L/d	%	%	%	g/d	gr	g/d
71	20/05/2014	0.18	2	3.35	66.77	33.23	67.00	5407.39	44.74
72	21/05/2014	0.20	2	3.62	66.37	33.63	72.35	5479.74	48.02
73	22/05/2014	0.25	2	3.44	66.19	33.81	68.80	5548.54	45.54
74	23/05/2014	0.33	2	3.47	65.88	34.12	69.30	5617.84	45.65
75	24/05/2014	0.28	2	3.43	65.37	34.63	68.60	5686.44	44.84
76	25/05/2014	0.28	2	3.43	65.3+7	34.63	68.60	5755.04	44.84
77	26/05/2014	0.23	2	3.40	64.86	35.15	68.00	5823.04	44.10
78	27/05/2014	0.23	2	3.21	65.17	34.83	64.24	5887.28	41.87
79	28/05/2014	0.23	2	3.34	65.60	34.40	66.72	5954.00	43.77
80	29/05/2014	0.23	2	3.35	63.73	36.27	67.00	6021.00	42.70
81	30/05/2014	0.23	2	3.35	63.73	36.27	67.00	6088.00	42.70
82	31/05/2014	0.23	2	3.35	63.73	36.27	67.00	6155.00	42.70
83	01/06/2014	0.23	2	3.35	63.73	36.27	67.00	6222.00	42.70
84	02/06/2014	0.23	2	3.37	61.83	38.17	67.34	6289.34	41.63
85	03/06/2014	0.16	2	3.59	64.14	35.86	71.81	6361.15	46.06
86	04/06/2014	0.15	2	3.63	63.42	36.58	72.56	6433.71	46.02
87	05/06/2014	0.17	2	3.65	64.34	35.67	72.90	6506.61	46.90
88	06/06/2014	0.18	2	4.18	64.84	35.16	83.62	6590.23	54.22
89	07/06/2014	0.23	2	3.85	64.97	35.03	77.00	6667.23	50.03
90	08/06/2014	0.23	2	3.85	64.97	35.03	77.00	6744.23	50.03
91	09/06/2014	0.23	2	3.85	64.97	35.03	77.00	6821.23	50.03
92	10/06/2014	0.27	2	3.52	65.11	34.89	70.40	6891.63	45.84
93	11/06/2014	0.18	2	3.85	64.50	35.50	77.00	6968.63	49.67
94	12/06/2014	0.21	2	3.98	64.20	35.80	79.60	7048.23	51.10
95	13/06/2014	0.22	2	3.98	64.20	35.80	79.60	7127.83	51.10
96	14/06/2014	0.21	2	3.98	64.20	35.80	79.60	7207.43	51.10
97	15/06/2014	0.21	2	3.98	64.20	35.80	79.60	7287.03	51.10
98	16/06/2014	0.20	2	4.11	64.01	35.99	82.28	7369.32	52.67
99	17/06/2014	0.20	2	3.95	61.10	38.90	79.00	7448.32	48.27
100	18/06/2014	0.22	2	3.78	58.28	41.73	75.68	7523.99	44.10
101	19/06/2014	0.18	2	3.82	60.70	39.30	76.40	7600.39	46.37
102	20/06/2014	0.18	2	3.85	63.31	36.69	76.95	7677.34	48.72
103	21/06/2014	0.23	2	3.58	63.25	36.75	71.60	7748.94	45.29
104	22/06/2014	0.23	2	3.58	63.25	36.75	71.60	7820.54	45.29
105	23/06/2014	0.29	2	3.30	63.18	36.82	66.07	7886.61	41.74
106	24/06/2014	0.25	2	3.88	62.14	37.86	77.56	7964.16	48.19
107	25/06/2014	0.23	2	4.03	62.24	37.76	80.50	8044.66	50.10
108	26/06/2014	0.23	2	2.88	60.69	39.31	57.50	8102.16	34.90

Measurement	Date	Inflow for both reactors. Table 4/4							
		Q inflow	Total sludge fed	Dry solids	Organic content	Inorganic content	Dry solids	Dry solids sum	Organic content
		(l/min)	L/d	%	%	%	g/d	gr	g/d
109	27/06/2014	0.23	2	3.60	61.98	38.02	71.96	8174.12	44.60
110	28/06/2014	0.23	2	3.58	62.87	37.13	71.60	8245.72	45.01
111	29/06/2014	0.23	2	3.58	62.87	37.13	71.60	8317.32	45.01
112	30/06/2014	0.23	2	3.57	63.77	36.23	71.40	8388.72	45.53
113	01/07/2014	0.23	2	3.59	63.46	36.54	71.80	8460.52	45.56
114	02/07/2014	0.20	2	3.59	63.46	36.54	71.80	8532.32	45.56
115	03/07/2014	0.18	2	3.59	63.46	36.54	71.80	8604.12	45.56
116	04/07/2014	0.20	2	3.62	63.15	36.85	72.36	8676.48	45.70
117	05/07/2014	0.20	2	3.95	62.93	37.07	79.00	8755.48	49.71
118	06/07/2014	0.20	2	3.95	62.93	37.07	79.00	8834.48	49.71
119	07/07/2014	0.22	2	4.27	62.70	37.30	85.47	8919.96	53.59
120	08/07/2014	0.20	2	3.75	63.75	36.25	75.00	8994.96	47.81
121	09/07/2014	0.33	2	4.01	63.23	36.77	80.24	9075.19	50.73
122	10/07/2014	0.30	2	3.50	65.60	34.40	70.00	9145.19	45.92
123	11/07/2014	0.38	2	3.86	63.40	36.60	77.25	9222.45	48.98
124	12/07/2014	0.38	2	3.80	63.70	36.30	76.00	9298.45	48.41
125	13/07/2014	0.38	2	3.80	63.70	36.30	76.00	9374.45	48.41
126	14/07/2014	0.38	2	3.75	63.99	36.01	74.93	9449.38	47.95
127	15/07/2014	0.38	2	3.67	62.41	37.59	73.45	9522.83	45.84
128	16/07/2014	0.38	2	3.58	62.79	37.21	71.65	9594.48	44.99
129	17/07/2014	0.38	2	3.35	59.54	40.46	66.95	9661.44	39.86
130	18/07/2014	0.38	2	3.34	62.34	37.66	66.80	9728.24	41.64
131	19/07/2014	0.38	2	3.34	62.34	37.66	66.80	9795.04	41.64
132	20/07/2014	0.38	2	3.34	62.34	37.66	66.80	9861.84	41.64
133	21/07/2014	0.38	2	3.34	65.14	34.86	66.81	9928.65	43.52
134	22/07/2014	0.38	2	3.39	63.46	36.54	67.83	9996.48	43.04
135	23/07/2014	0.38	2	4.25	64.79	35.21	85.07	10081.55	55.12
136	24/07/2014	0.38	2	3.35	61.40	38.60	66.96	10148.51	41.12
137	25/07/2014	0.38	2	3.60	63.60	36.40	71.95	10220.46	45.76
138	26/07/2014	0.38	2	3.94	63.43	36.57	78.80	10299.26	49.98
139	27/07/2014	0.38	2	3.94	63.43	36.57	78.80	10378.06	49.98
140	28/07/2014	0.38	2	4.27	63.25	36.75	85.49	10463.55	54.07
141	29/07/2014	0.38	2	4.00	62.06	37.94	80.00	10543.55	49.65

Annex 2. SOLIDS DATA – Reactor 1.

Measurement	Date	REACTOR 1 - Solids. Table 1/4							
		Total extracted sludge	Dry solids	Organic content	Inorganic content	Dry solids	Dry solids summ	Solids in the reactor	Organic content
		L/d	%	%	%	g/d	g	g	g/d
1	07/03/2014	2	2.34	55.99	44.01	46.80	46.80	15.19	26.20
2	10/03/2014	2	1.50	52.93	49.15	25.30	72.10	51.29	13.39
3	11/03/2014	2	1.14	50.42	52.44	20.78	92.88	111.51	9.43
4	12/03/2014	2	1.09	43.27	56.74	20.13	113.00	147.39	8.72
5	13/03/2014	2	0.87	47.50	52.50	17.37	130.37	201.72	8.25
6	14/03/2014	2	0.79	49.70	50.30	15.71	146.07	259.41	7.81
7	17/03/2014	2	0.69	52.41	47.59	13.73	159.81	323.11	7.20
8	18/03/2014	2	0.30	50.57	49.43	6.07	165.88	396.26	3.07
9	19/03/2014		0.55	49.57	50.43	11.00	165.88	396.26	5.43
10	20/03/2014	2	0.80	48.57	51.43	16.05	181.93	449.19	7.80
11	21/03/2014	2	0.81	50.56	49.44	16.11	198.04	500.36	8.15
12	22/03/2014	2	0.79	56.30	43.70	15.80	213.84	556.56	8.90
13	23/03/2014	2	0.79	56.30	43.70	15.80	229.64	612.76	8.90
14	24/03/2014		0.86	56.56	43.44	17.28	63.76	778.64	9.77
15	25/03/2014	2	0.94	56.83	43.17	18.76	82.52	835.88	10.66
16	26/03/2014	2	1.07	53.23	46.78	21.44	103.96	894.06	11.41
17	27/03/2014	2	0.76	44.14	55.86	15.28	119.24	952.78	6.75
18	28/03/2014	2	0.92	52.44	47.56	18.40	137.64	1025.91	9.65
19	29/03/2014	2	1.02	53.29	46.71	20.40	158.04	1098.31	10.87
20	30/03/2014	2	1.02	53.29	46.71	20.40	178.44	1170.71	10.87
21	31/03/2014	2	1.11	54.14	45.86	22.20	200.64	1242.67	12.02
22	01/04/2014		1.19	51.79	48.21	23.80	136.88	1390.10	12.02
23	02/04/2014		1.19	51.79	48.21	23.80	136.88	1473.77	12.02
24	03/04/2014		1.19	51.79	48.21	23.80	136.88	1557.44	12.02
25	04/04/2014		1.19	51.79	48.21	23.80	136.88	1641.11	12.02
26	05/04/2014		1.19	51.79	48.21	23.80	136.88	1724.78	12.02
27	06/04/2014		1.19	51.79	48.21	23.80	136.88	1808.45	12.02
28	07/04/2014	2	1.27	49.44	50.56	25.40	162.28	1856.23	12.56
29	08/04/2014	2	1.38	46.55	53.45	27.52	189.80	1898.49	12.81
30	09/04/2014	2	1.23	39.08	60.92	24.54	214.34	1941.43	9.59
31	10/04/2014		1.30	46.08	53.92	24.54	214.34	2016.47	9.59
32	11/04/2014		1.30	46.08	53.92	24.54	214.34	2091.51	9.59
33	12/04/2014		1.30	46.08	53.92	24.54	214.34	2166.55	9.59
34	13/04/2014		1.30	46.08	53.92	24.54	214.34	2241.59	9.59
35	14/04/2014	2	1.38	53.07	46.93	27.60	241.94	2296.59	14.65
36	15/04/2014	2	1.09	52.58	47.42	21.80	263.74	2349.59	11.46
37	16/04/2014	2	1.65	49.62	50.39	32.90	296.64	2402.29	16.32

Beginning of phase 1.2

Measurement	Date	REACTOR 1 - Solids. Table 2/4							
		Total extracted sludge	Dry solids	Organic content	Inorganic content	Dry solids	Dry solids summ	Solids in the reactor	Organic content
		L/d	%	%	%	g/d	g	g	g/d
38	17/04/2014	2	1.50	53.26	46.74	30.00	326.64	2455.69	15.98
39	18/04/2014		1.35	51.63	48.37	27.00	326.64	2455.69	13.94
40	19/04/2014		1.35	51.63	48.37	27.00	326.64	2455.69	13.94
41	20/04/2014		1.35	51.63	48.37	27.00	326.64	2455.69	13.94
42	21/04/2014		1.35	51.63	48.37	27.00	326.64	2455.69	13.94
43	22/04/2014	2	1.20	50.00	50.00	24.02	350.66	2842.43	12.01
44	23/04/2014	2	1.27	51.04	48.96	25.40	376.06	2900.43	12.96
45	24/04/2014	2	1.39	52.94	47.06	27.80	403.86	2962.23	14.72
46	25/04/2014	2	1.40	55.76	44.25	28.08	431.94	3018.45	15.66
47	26/04/2014	2	1.51	55.18	44.82	30.20	462.14	3068.25	16.66
48	27/04/2014	2	1.51	55.18	44.82	30.20	492.34	3118.05	16.66
49	28/04/2014	2	1.62	54.60	45.40	32.40	524.74	3163.83	17.69
50	29/04/2014	2	1.38	53.91	46.09	27.54	552.28	3212.81	14.85
51	30/04/2014	2	1.48	55.64	44.36	29.60	581.88	3259.65	16.47
52	01/05/2014	2	1.26	55.75	44.25	25.20	607.08	3309.45	14.05
53	02/05/2014	2	1.04	55.86	44.14	20.80	627.88	3362.07	11.62
54	03/05/2014	2	1.16	47.30	52.70	23.20	651.08	3411.87	10.97
55	04/05/2014	2	1.16	47.30	52.70	23.20	674.28	3461.67	10.97
56	05/05/2014	2	1.29	38.74	61.26	25.74	700.02	3508.93	9.97
57	06/05/2014	2	1.01	40.29	59.71	20.20	720.22	3561.43	8.14
58	07/05/2014	2	2.73	48.31	51.69	54.60	774.82	3578.95	26.38
59	08/05/2014	2	3.05	52.61	47.39	61.08	835.90	3585.93	32.13
60	09/05/2014	2	2.35	52.60	47.40	46.90	882.80	3625.13	24.67
61	10/05/2014	2	2.21	53.40	46.60	44.20	927.00	3662.93	23.60
62	11/05/2014	2	2.21	53.40	46.60	44.20	971.20	3700.73	23.60
63	12/05/2014	2	2.08	54.20	45.80	41.68	1012.88	3739.01	22.59
64	13/05/2014	2	1.92	52.30	47.70	38.40	1051.28	3772.61	20.08
65	14/05/2014	2	1.85	53.69	46.31	37.00	1088.28	3821.11	19.86
66	15/05/2014	2	1.74	53.18	46.82	34.80	1123.08	3860.71	18.51
67	16/05/2014	2	1.66	53.95	46.05	33.10	1156.18	3908.21	17.86
68	17/05/2014	2	1.49	54.98	45.02	29.80	1185.98	3967.61	16.38
69	18/05/2014	2	1.49	54.98	45.02	29.80	1215.78	4027.01	16.38
70	19/05/2014	2	1.32	56.01	43.99	26.40	1242.18	4098.21	14.79
71	20/05/2014	2	1.06	56.97	43.03	21.12	1263.30	4144.09	12.03
72	21/05/2014	2	1.00	56.93	43.07	19.96	1283.26	4196.48	11.36
73	22/05/2014	2	1.14	58.64	41.36	22.77	1306.03	4242.51	13.35
74	23/05/2014	2	1.24	55.45	44.55	24.86	1330.89	4286.95	13.78
75	24/05/2014	2	1.17	56.32	43.68	23.40	1354.29	4332.15	13.18
76	25/05/2014	2	1.17	56.32	43.68	23.40	1377.69	4377.35	13.18

Beginning of phase 2

Measurement	Date	REACTOR 1 - Solids. Table 3/4							
		Total extracted sludge	Dry solids	Organic content	Inorganic content	Dry solids	Dry solids summ	Solids in the reactor	Organic content
		L/d	%	%	%	g/d	g	g	g/d
77	26/05/2014	2	1.09	57.19	42.82	21.74	1399.43	4423.61	12.43
78	27/05/2014	2	3.21	53.10	46.90	64.24	1463.67	4423.61	34.11
79	28/05/2014	2	3.47	56.70	43.30	69.46	1533.13	4420.87	39.38
80	29/05/2014	2	3.59	54.63	45.37	71.80	1604.93	4416.07	39.22
81	30/05/2014	2	3.59	54.63	45.37	71.80	1676.73	4411.27	39.22
82	31/05/2014	2	3.59	54.63	45.37	71.80	1748.53	4406.47	39.22
83	01/06/2014	2	3.59	54.63	45.37	71.80	1820.33	4401.67	39.22
84	02/06/2014	2	3.70	52.55	47.45	74.06	1894.39	4394.95	38.92
85	03/06/2014	2	3.59	51.84	48.16	71.81	1966.20	4394.95	37.23
86	04/06/2014	2	3.16	50.66	49.34	63.16	2029.36	4404.35	32.00
87	05/06/2014	2	3.55	50.98	49.02	70.98	2100.34	4406.27	36.18
88	06/06/2014	2	3.07	51.83	48.17	61.36	2161.70	4428.53	31.80
89	07/06/2014	2	3.25	51.87	48.13	65.00	2226.70	4440.53	33.72
90	08/06/2014	2	3.25	51.87	48.13	65.00	2291.70	4452.53	33.72
91	09/06/2014	2	3.25	51.87	48.13	65.00	2356.70	4464.53	33.72
92	10/06/2014	2	3.44	51.91	48.09	68.80	2425.50	4466.13	35.71
93	11/06/2014	2	3.06	47.35	52.65	61.20	2486.70	4481.93	28.98
94	12/06/2014	2	3.51	53.13	46.87	70.20	2556.90	4491.33	37.30
95	13/06/2014	2	3.51	53.13	46.87	70.20	2627.10	4500.73	37.30
96	14/06/2014	2	3.51	53.13	46.87	70.20	2697.30	4510.13	37.30
97	15/06/2014	2	3.51	53.13	46.87	70.20	2767.50	4519.53	37.30
98	16/06/2014	2	3.95	58.91	41.09	79.02	2846.52	4522.79	46.55
99	17/06/2014	2	3.69	58.97	41.03	73.74	2920.26	4528.05	43.48
100	18/06/2014	2	2.70	47.39	52.61	54.02	2974.28	4549.71	25.60
101	19/06/2014	2	3.10	44.60	55.40	62.00	3036.28	4564.11	27.65
102	20/06/2014	2	3.50	41.81	58.19	69.96	3106.25	4571.10	29.25
103	21/06/2014	2	3.40	48.53	51.47	68.00	3174.25	4574.70	33.00
104	22/06/2014	2	3.40	48.53	51.47	68.00	3242.25	4578.30	33.00
105	23/06/2014	2	3.30	55.25	44.75	65.91	3308.16	4578.45	36.41
106	24/06/2014	2	3.23	51.33	48.67	64.66	3372.81	4591.35	33.19
107	25/06/2014	2	3.13	49.87	50.13	62.58	3435.39	4609.27	31.21
108	26/06/2014	2	3.17	50.71	49.29	63.36	3498.75	4603.41	32.13
109	27/06/2014	2	2.94	48.00	52.00	58.88	3557.63	4616.49	28.26
110	28/06/2014	2	2.98	49.50	50.50	59.60	3617.23	4628.49	29.50
111	29/06/2014	2	2.98	49.50	50.50	59.60	3676.83	4640.49	29.50
112	30/06/2014	2	3.01	51.00	49.00	60.26	3737.09	4651.63	30.73
113	01/07/2014	2	2.96	50.68	49.32	59.20	3796.29	4664.23	30.00
114	02/07/2014	2	2.91	50.68	49.32	58.20	3854.49	4677.83	29.50
115	03/07/2014	2	2.59	50.37	49.63	51.80	3906.29	4697.83	26.09
116	04/07/2014	2	2.59	51.14	48.86	51.88	3958.17	4718.31	26.53
117	05/07/2014	2	2.65	51.25	48.75	53.00	4011.17	4744.31	27.16

Beginning of phase 3.

Measurement	Date	REACTOR 1 - Solids. Table 4/4							
		Total extracted sludge	Dry solids	Organic content	Inorganic content	Dry solids	Dry solids summ	Solids in the reactor	Organic content
		L/d	%	%	%	g/d	g	g	g/d
118	06/07/2014	2	2.65	51.25	48.75	53.00	4064.17	4770.31	27.16
119	07/07/2014	2	2.71	51.36	48.64	54.23	4118.40	4801.55	27.85
120	08/07/2014	2	2.25	51.50	48.50	44.99	4163.39	4831.57	23.17
121	09/07/2014	2	2.48	51.43	48.57	49.61	4213.00	4862.20	25.52
122	10/07/2014	2	2.48	51.43	48.57	49.61	4262.61	4882.59	25.52
123	11/07/2014	2	2.90	50.83	49.17	58.01	4320.62	4901.83	29.49
124	12/07/2014	2	2.92	52.11	47.89	58.40	4379.02	4919.43	30.43
125	13/07/2014	2	2.92	52.11	47.89	58.40	4437.42	4937.03	30.43
126	14/07/2014	2	2.94	53.38	46.62	58.75	4496.17	4953.21	31.36
127	15/07/2014	2	2.19	52.70	47.30	43.72	4539.89	4982.94	23.04
128	16/07/2014	2	2.10	52.14	47.86	42.07	4581.95	5012.53	21.93
129	17/07/2014	2	1.99	51.70	48.30	39.83	4621.78	5039.66	20.59
130	18/07/2014	2	2.00	53.40	46.60	40.00	4661.78	5066.46	21.36
131	19/07/2014	2	2.00	53.40	46.60	40.00	4701.78	5093.26	21.36
132	20/07/2014	2	2.00	53.40	46.60	40.00	4741.78	5120.06	21.36
133	21/07/2014	2	2.01	55.09	44.91	40.28	4782.06	5146.59	22.19
134	22/07/2014	2	1.17	52.98	47.02	23.42	4805.48	5190.99	12.41
135	23/07/2014	2	2.20	53.96	46.04	44.06	4849.54	5232.01	23.77
136	24/07/2014	2	2.03	51.29	48.71	40.58	4890.12	5258.39	20.81
137	25/07/2014	2	1.01	59.06	40.94	20.29	4910.41	5310.05	11.98
138	26/07/2014	2	1.51	57.09	42.91	30.20	4940.61	5358.65	17.24
139	27/07/2014	2	1.51	57.09	42.91	30.20	4970.81	5407.25	17.24
140	28/07/2014	2	2.00	55.12	44.88	39.96	5010.77	5452.78	22.03
141	29/07/2014	2	2.00	50.96	49.04	40.00	5050.77	5492.78	20.38

Annex 3. REACTOR PARAMETERS - Reactor 1.

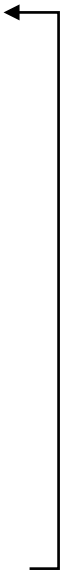
Measurement	Date	REACTOR 1 – Reactor parameters. Table 1/4			
		Temperature	Manometric pressure	Atmospheric pressure	Absolute pressure
		°C	mbar	mbar	mbar
1	07/03/2014			1018	1018.0
2	10/03/2014	38.7		1017	1017.0
3	11/03/2014	31.5	0	1020	1020.0
4	12/03/2014	36.47	0	1023	1023.0
5	13/03/2014	36.66	0	1020	1020.0
6	14/03/2014	36.56	0	1017	1017.0
7	17/03/2014	35.88	0	1012	1012.0
8	18/03/2014	37	0	1005	1005.0
9	19/03/2014	36.91	0	1013	1013.0
10	20/03/2014	37.4	0	1007	1007.0
11	21/03/2014	37.18	0	1000	1000.0
12	22/03/2014	36.96	0	996	996.0
13	23/03/2014	36.32	0	998	998.0
14	24/03/2014	37	22	1003	1025.0
15	25/03/2014	36.42	8	1003	1011.0
16	26/03/2014	36.52	9.5	1004	1013.5
17	27/03/2014	37.53	9	1003	1012.0
18	28/03/2014	37.53	9.5	1006	1015.5
19	29/03/2014	37.88	11	1011	1022.0
20	30/03/2014	38.57	21	1006	1027.0
21	31/03/2014	37.54	28.5	1005	1033.5
22	01/04/2014	37.05	9	1001	1010.0
23	02/04/2014	37.2	8	999	1007.0
24	03/04/2014	37	7	996	1003.0
25	04/04/2014	37.1	5	1000	1005.0
26	05/04/2014	37.25	8.5	1003	1011.5
27	06/04/2014	37.25	8.5	1003	1011.5
28	07/04/2014	37.4	12	1006	1018.0
29	08/04/2014	35.7	5	1006	1011.0
30	09/04/2014	37.4	5.5	1016	1021.5
31	10/04/2014	37.6	6	1013	1019.0
32	11/04/2014	37.8	6	1010	1016.0
33	12/04/2014	37.59	5	1008	1013.0
34	13/04/2014	37.79	8	1009	1017.0
35	14/04/2014	36.6	11	1006	1017.0
36	15/04/2014	37.9	5	1015	1020.0
37	16/04/2014	37.3	5	1020	1025.0
38	17/04/2014	36.9	8	1011	1019.0
39	18/04/2014	38.27	9.5	1002	1011.5

Beginning of phase 1.2

Measurement	Date	REACTOR 1 – Reactor parameters. Table 2/4			
		Temperature	Manometric pressure	Atmospheric pressure	Absolute pressure
		°C	mbar	mbar	mbar
40	19/04/2014	37.35	5.5	1002	1007.5
41	20/04/2014	37.15	7	999	1006.0
42	21/04/2014	37	8	997	1005.0
43	22/04/2014	37.9	3	1002	1005.0
44	23/04/2014	36.3	8	1008	1016.0
45	24/04/2014	38.3	9	1008	1017.0
46	25/04/2014	37.7	10	1003	1013.0
47	26/04/2014	37.3	11.5	1003	1014.5
48	27/04/2014	36.93	12.5	1000	1012.5
49	28/04/2014	36	8	1002	1010.0
50	29/04/2014	37.8	9	1002	1011.0
51	30/04/2014	37.9	8	1003	1011.0
52	01/05/2014	37.49	13	1002	1015.0
53	02/05/2014	37.9	10	1003	1013.0
54	03/05/2014	37.44	9	1014	1023.0
55	04/05/2014	37.48	9	1014	1023.0
56	05/05/2014	37.54	9	1007	1016.0
57	06/05/2014	37.4	6	1001	1007.0
58	07/05/2014	37.4	13.5	1002	1015.5
59	08/05/2014	38.37	12.5	1003	1015.5
60	09/05/2014	37.6	12	1003	1015.0
61	10/05/2014	37.79	15	1000	1015.0
62	11/05/2014	37.44	27.5	997	1024.5
63	12/05/2014	38.03	10	1001	1011.0
64	13/05/2014	37.7	12	1005	1017.0
65	14/05/2014	37.7	14	1017	1031.0
66	15/05/2014	37	12	1026	1038.0
67	16/05/2014	38.1	12	1023	1035.0
68	17/05/2014	37.88	28	1015	1043.0
69	18/05/2014	38.17	26	1004	1030.0
70	19/05/2014	38.3	38.5	1001	1039.5
71	20/05/2014	37.1	10	1003	1013.0
72	21/05/2014	37.4	10	1003	1013.0
73	22/05/2014	38.1	10	1001	1011.0
74	23/05/2014	37.8	10	1002	1012.0
75	24/05/2014	37.4	14	1005	1019.0
76	25/05/2014	38.6	6	1010	1016.0
77	26/05/2014	38	9	1004	1013.0
78	27/05/2014	37.5	13	1002	1015.0
79	28/05/2014	36.8	9	1002	1011.0
80	29/05/2014	37	10	1005	1015.0

Beginning of phase 2

Measurement	Date	REACTOR 1 – Reactor parameters. Table 3/4			
		Temperature	Manometric pressure	Atmospheric pressure	Absolute pressure
		°C	mbar	mbar	mbar
81	30/05/2014	38.4	8	1012	1020.0
82	31/05/2014	37.2	9	1014	1023.0
83	01/06/2014	37.5	10	1012	1022.0
84	02/06/2014	36.7	9	1011	1020.0
85	03/06/2014	37.9	8	1003	1011.0
86	04/06/2014	37.7	16	1000	1016.0
87	05/06/2014	37.5	11	1002	1013.0
88	06/06/2014	37.5	10	1002	1012.0
89	07/06/2014	37.7	11	1006	1017.0
90	08/06/2014	38.42	8	1008	1016.0
91	09/06/2014	37.64	8	1008	1016.0
92	10/06/2014	37.7	8	1010	1018.0
93	11/06/2014	37.9	12	1016	1028.0
94	12/06/2014	37.5	10	1019	1029.0
95	13/06/2014	37.2	10	1015	1025.0
96	14/06/2014	37.2	10	1013	1023.0
97	15/06/2014	37.2	10	1015	1025.0
98	16/06/2014	37.2	10	1015	1025.0
99	17/06/2014	37.6	8	1014	1022.0
100	18/06/2014	36.9	9	1014	1023.0
101	19/06/2014	37.6	8	1013	1021.0
102	20/06/2014	36.6	7	1012	1019.0
103	21/06/2014	37.9	5	1012	1017.0
104	22/06/2014	39.8	6	1013	1019.0
105	23/06/2014	37.4	10	1015	1025.0
106	24/06/2014	37.7	9	1010	1019.0
107	25/06/2014	36.76	8	1009	1017.0
108	26/06/2014	37.15	7	1008	1015.0
109	27/06/2014	38.2	12	1007	1019.0
110	28/06/2014	37.8	12	1004	1016.0
111	29/06/2014	37.2	8	1001	1009.0
112	30/06/2014	36.52	9	1008	1017.0
113	01/07/2014	37.3	8	1012	1020.0
114	02/07/2014	37.7	12	1013	1025.0
115	03/07/2014	36.6	11	1015	1026.0
116	04/07/2014	36.9	9	1006	1015.0
117	05/07/2014	37.8	9	1001	1010.0
118	06/07/2014	36.9	8	1002	1010.0
119	07/07/2014	37.9	8.5	1009	1017.5
120	08/07/2014	37.1	10.5	1002	1012.5
121	09/07/2014	36.52	10.5	1000	1010.5



Measurement	Date	REACTOR 1 – Reactor parameters. Table 4/4			
		Temperature	Manometric pressure	Atmospheric pressure	Absolute pressure
		°C	mbar	mbar	mbar
122	10/07/2014	36.7	10	1002	1012.0
123	11/07/2014	37.8	9	1007	1016.0
124	12/07/2014	36.03	10	1006	1016.0
125	13/07/2014	38.67	9	1002	1011.0
126	14/07/2014	36.89	9	1006	1015.0
127	15/07/2014	36.56	6	1013	1019.0
128	16/07/2014	37.93	8.5	1015	1023.5
129	17/07/2014	38.05	8.5	1014	1022.5
130	18/07/2014	38.16	9.5	1010	1019.5
131	19/07/2014	38.71	12	1006	1018.0
132	20/07/2014	37.2	7	1003	1010.0
133	21/07/2014	36.91	7	1005	1012.0
134	22/07/2014	37.06	9	1009	1018.0
135	23/07/2014	38.42	9	1010	1019.0
136	24/07/2014	36.91	9	1008	1017.0
137	25/07/2014	36.91	12	1007	1019.0
138	26/07/2014	38.27	11	1007	1018.0
139	27/07/2014	37.44	8	1008	1016.0
140	28/07/2014	37.15	8	1005	1013.0
141	29/07/2014	37.9	11	1004	1015.0

Annex 4. GAS PARAMETERS - Reactor 1.

Measurement	Date	REACTOR 1 – Gas parameters. Table 1/4							
		Volume measured	Gas tank temp.	Gas tank temp.	Volume normal conditions	Summ n-volume	CO_2	CH_4	H_2S
		L	°C	K	L	L	%	%	%
1	07/03/2014								
2	10/03/2014	2	22	295.15	1.86	1.86			
3	11/03/2014	3.25	22	295.15	3.03	4.89			
4	12/03/2014	4.5	19	292.15	4.25	9.14			
5	13/03/2014	13	18.7	291.85	12.25	21.39	2	45.5	0
6	14/03/2014	14	18.4	291.55	13.17	34.55	2	53	0
7	17/03/2014	4	15.7	288.85	3.78	38.33	4	65	0
8	18/03/2014	0	16.5	289.65	0.00	40.48	5.5	70	0
9	19/03/2014	11	17	290.15	10.36	45.66	7	75	0
10	20/03/2014	1	17.8	290.95	0.93	46.59	6	78	0
11	21/03/2014	11	19	292.15	10.15	56.75	9	75	0
12	22/03/2014	14	17.7	290.85	12.93	69.67	11.5	74	0
13	23/03/2014	16	17.7	290.85	14.80	84.48	11.5	74	0
14	24/03/2014	10	16.4	289.55	9.55	94.02	14	73	0
15	25/03/2014	8	15.7	288.85	7.55	101.57	12	66	0
16	26/03/2014	12	15.8	288.95	11.35	112.92	14	70	0
17	27/03/2014	11.4	16.4	289.55	10.74	123.67	14	73	0
18	28/03/2014	13	17.7	290.85	12.24	135.90	13.5	71	0
19	29/03/2014	18	18.9	292.05	16.98	152.89	13.75	70.5	0
20	30/03/2014	15	18.9	292.05	14.22	167.11	13.75	70.5	0
21	31/03/2014	9	20.2	293.35	8.55	175.66	14	70	0
22	01/04/2014	10	21.8	294.95	9.23	184.90	15	70	0
23	02/04/2014	9	21.5	294.65	8.29	193.19	12	74	0
24	03/04/2014	6	21.4	294.55	5.51	198.70	11	78	0
25	04/04/2014	4	21.7	294.85	3.68	202.38	8	80	0
26	05/04/2014	4	21.5	294.65	3.70	206.08	7	82.5	0
27	06/04/2014	5	21.5	294.65	4.63	210.71	7	82.5	0
28	07/04/2014	5	21.4	294.55	4.66	215.37	6	85	0
29	08/04/2014	3	20.9	294.05	2.78	218.15	10	82	0
30	09/04/2014	4.5	20.6	293.75	4.22	222.37	9	78	0
31	10/04/2014	5	20.2	293.35	4.68	227.05	8	74	0
32	11/04/2014	6	20.3	293.45	5.60	232.65	10	76	0
33	12/04/2014	2	19.8	292.95	1.86	234.52	9	78.5	0
34	13/04/2014	3	19.8	292.95	2.81	237.32	9	78.5	0
35	14/04/2014	4	19.4	292.55	3.75	241.07	8	81	0
36	15/04/2014	6	18.5	291.65	5.66	246.73	10	54	0
37	16/04/2014	3	17.8	290.95	2.85	249.58	8	73	0
38	17/04/2014	10	18.5	291.65	9.42	259.00	12	71	0

Beginning of phase 1.2

Measurement	Date	REACTOR 1 – Gas parameters. Table 2/4							
		Volume measured	Gas tank temp.	Gas tank temp.	Volume normal conditions	Summ n-volume	CO_2	CH_4	H_2S
		L	°C	K	L	L	%	%	%
39	18/04/2014	12	18.5	291.65	11.22	270.23	11.5	75	0
40	19/04/2014	9	18.5	291.65	8.38	278.61	11.5	75	0
41	20/04/2014	11	18.5	291.65	10.23	288.84	11.5	75	0
42	21/04/2014	12	18.5	291.65	11.15	299.99	11.5	75	0
43	22/04/2014	7	18.6	291.75	6.50	306.49	11	79	0
44	23/04/2014	8	20.4	293.55	7.47	313.96	10	78	0
45	24/04/2014	12	20.8	293.95	11.19	325.15	10	76	0
46	25/04/2014	13	20.2	293.35	12.10	337.26	11	74	0
47	26/04/2014	16	19.9	293.05	14.94	352.19	11.5	75.5	0
48	27/04/2014	20	19.9	293.05	18.63	370.83	11.5	75.5	0
49	28/04/2014	12	19.7	292.85	11.16	381.99	12	77	0
50	29/04/2014	13	19.8	292.95	12.10	394.08	13	76	0
51	30/04/2014	12	19.7	292.85	11.17	405.25	14	76	0
52	01/05/2014	16	20.3	293.45	14.92	420.18	13	65	0
53	02/05/2014	14	20.9	294.05	13.00	433.18	12	54	0
54	03/05/2014	10	18.8	291.95	9.45	442.63	12	64.5	0
55	04/05/2014	14	18.4	291.55	13.25	455.88	12	64.5	0
56	05/05/2014	14	18	291.15	13.17	469.05	12	64.5	0
57	06/05/2014	8	18	291.15	7.46	476.51	12	64.5	0
58	07/05/2014	16	18	291.15	15.05	491.56	13	64.5	0
59	08/05/2014	21	19.4	292.55	19.66	511.21	14	78	0
60	09/05/2014	16	19.7	292.85	14.95	526.17	14	71	0
61	10/05/2014	22	19.15	292.3	20.60	546.77	14.5	74	0
62	11/05/2014	19	19.15	292.3	17.96	564.72	14.5	74	0
63	12/05/2014	17	18.6	291.75	15.88	15.88	15	77	0
64	13/05/2014	14	17.9	291.05	13.19	29.08	15	73	0
65	14/05/2014	21	18	291.15	20.05	49.13	16	77	0
66	15/05/2014	15	18	291.15	14.42	63.55	15	76	0
67	16/05/2014	16	18.4	291.55	15.32	78.86	14	77	0
68	17/05/2014	21	20.4	293.55	20.12	98.98	15	75.5	0
69	18/05/2014	20	20.4	293.55	18.92	117.90	15	75.5	0
70	19/05/2014	19	22.4	295.55	18.02	135.92	16	77	0
71	20/05/2014	16	22.7	295.85	14.77	150.70	16	75	0
72	21/05/2014	14	19.7	292.85	13.06	163.75	20	74	0
73	22/05/2014	12	23.8	296.95	11.02	174.77	20	71	0
74	23/05/2014	14	20.7	293.85	13.00	187.77	20	73	0
75	24/05/2014	16	21	294.15	14.95	202.72	19	74.5	0
76	25/05/2014	10	21	294.15	9.31	212.03	19	74.5	0

Beginning of phase 2

Measurement	Date	REACTOR 1 – Gas parameters. Table 3/4							
		Volume measured	Gas tank temp.	Gas tank temp.	Volume normal conditions	Summ n-volume	CO_2	CH_4	H_2S
		L	°C	K	L	L	%	%	%
77	26/05/2014	14	21	294.15	13.00	225.03	18	76	0
78	27/05/2014	18	21	294.15	16.75	241.78	18	77.5	0
79	28/05/2014	22	18	291.15	20.60	262.38	18	79	0
80	29/05/2014	14	18	291.15	13.16	275.54	18.5	80.5	0
81	30/05/2014	14	18	291.15	13.23	288.76	19	82	0
82	31/05/2014	11	19	292.15	10.39	299.15	19.5	83	0
83	01/06/2014	15	19	292.15	14.15	313.30	19.5	83	0
84	02/06/2014	14	21	294.15	13.09	326.39	19.5	83	0
85	03/06/2014	14	22.3	295.45	12.92	339.31	20	84	0
86	04/06/2014	16	23	296.15	14.80	354.11	18	75	0
87	05/06/2014	16	23	296.15	14.76	368.87	17	75	0
88	06/06/2014	13	22.7	295.85	11.99	380.86	18	78	0
89	07/06/2014	17	25	298.15	15.64	396.49	17	78	0
90	08/06/2014	13	25	298.15	11.95	408.44	17	78	0
91	09/06/2014	12	25	298.15	11.03	419.46	17	78	0
92	10/06/2014	14	27.6	300.75	12.78	432.24	16	78	0
93	11/06/2014	10	23.6	296.75	9.34	441.58	17	79	0
94	12/06/2014	14	24.8	297.95	13.04	454.62	18	76	0
95	13/06/2014	12	22.9	296.05	11.20	465.82	16	76	0
96	14/06/2014	14	20.8	293.95	13.14	478.96	16	79.5	0
97	15/06/2014	14	20.8	293.95	13.16	492.13	16	79.5	0
98	16/06/2014	14	20.2	293.35	13.19	505.32	16	83	0
99	17/06/2014	4	21.5	294.65	3.74	509.06	16	81.5	0
100	18/06/2014	15	22.6	295.75	13.99	523.05	16	80	0
101	19/06/2014	10	20.9	294.05	9.36	532.41	16	81.5	0
102	20/06/2014	12	21.5	294.65	11.19	543.60	16	83	0
103	21/06/2014	16	22.6	295.75	14.84	558.44	15	84	0
104	22/06/2014	16	21.9	295.05	14.90	573.34	15	84	0
105	23/06/2014	20	23.1	296.25	18.66	591.99	15	84	0
106	24/06/2014	13	22.5	295.65	12.08	604.08	15	84	0
107	25/06/2014	10	22.6	295.75	9.27	9.27	15	84	0
108	26/06/2014	12	22.6	295.75	11.10	20.38	15	84	0
109	27/06/2014	19	22.8	295.95	17.64	38.02	14	85	0
110	28/06/2014	17	23	296.15	15.73	53.74	15	84.5	0
111	29/06/2014	9	23	296.15	8.27	62.01	15	84.5	0
112	30/06/2014	14	23	296.15	12.96	74.98	15	84.5	0
113	01/07/2014	11	23	296.15	10.22	85.19	16	84	0
114	02/07/2014	10	23	296.15	9.33	94.52	15.5	83	0

Beginning of phase 3

Measurement	Date	REACTOR 1 – Gas parameters. Table 4/4							
		Volume measured	Gas tank temp.	Gas tank temp.	Volume normal conditions	Summ n-volume	CO_2	CH_4	H_2S
		L	°C	K	L	L	%	%	%
115	03/07/2014	10	23	296.15	9.34	103.87	15.5	83	0
116	04/07/2014	12	24	297.15	11.05	114.92	15.5	83	0
117	05/07/2014	8	24	297.15	7.33	122.25	15.5	83	0
118	06/07/2014	14	24	297.15	12.83	135.08	15.5	83	0
119	07/07/2014	12	24.7	297.85	11.05	146.14	15	82	0
120	08/07/2014	12	23.6	296.75	11.04	157.18	14.5	82	0
121	09/07/2014	10	22.5	295.65	9.22	166.39	14	82	0
122	10/07/2014	10	21.7	294.85	9.25	175.65	15	79	0
123	11/07/2014	8	21	294.15	7.45	183.10	16	76	0
124	12/07/2014	10	21.8	294.95	9.29	192.39	15.75	78.5	0
125	13/07/2014	16	21.8	294.95	14.79	207.17	15.75	78.5	0
126	14/07/2014	13	21.8	294.95	12.06	219.24	15.5	81	0
127	15/07/2014	10	22.6	295.75	9.29	228.53	15	86	0
128	16/07/2014	12	21.5	294.65	11.24	239.77	12.5	84.5	0
129	17/07/2014	12	22.3	295.45	11.20	250.97	10	83	0
130	18/07/2014	12	22.9	296.05	11.14	262.11	12	82	0
131	19/07/2014	16	23.5	296.65	14.81	276.91	12	82.5	0
132	20/07/2014	12	24.1	297.25	10.99	287.91	12	82.5	0
133	21/07/2014	12	24.8	297.95	10.99	298.90	12	83	0
134	22/07/2014	13	25.3	298.45	11.96	310.85	12.5	83	0
135	23/07/2014	15	25.8	298.95	13.79	324.64	13	83	0
136	24/07/2014	10	26.3	299.45	9.16	333.80	14	82	0
137	25/07/2014	12	25.8	298.95	11.03	344.83	14	82	0
138	26/07/2014	15	26.2	299.35	13.75	358.58	14	82	0
139	27/07/2014	13	25.4	298.55	11.93	370.51	14	82	0
140	28/07/2014	12	27.8	300.95	10.89	381.40	14	82	0
141	29/07/2014	16	26.9	300.05	14.59	396.00	14	82	0

Measurement	Date	REACTOR 1 – Sludge parameters. Table 1/4					
		Organic Acids					
		A	A´	B	Lime reserve	Organic acids	pH
		ml	ml	ml	mg C_aCO_3/l	Mg Hac/l	-
1	07/03/2014						
2	10/03/2014						
3	11/03/2014						
4	12/03/2014						
5	13/03/2014	8.89	9.19	0.23	2297.5	115.9	
6	14/03/2014	9.77	10.25	0.29	2562.5	165.7	
7	17/03/2014	10.26	10.51	0.38	2627.5	240.4	
8	18/03/2014	9.02	9.65	0.33	2412.5	198.9	
9	19/03/2014	11.13	11.31	0.41	2827.5	265.3	
10	20/03/2014	11.45	11.56	0.62	2890	439.6	
11	21/03/2014	12.26	12.33	0.83	3082.5	613.9	
12	22/03/2014	12.045	12.29	0.685	3072.5	493.55	
13	23/03/2014	12.045	12.29	0.685	3072.5	493.55	
14	24/03/2014	11.83	12.25	0.54	3062.5	373.2	
15	25/03/2014	11.82	12.22	0.56	3055	389.8	
16	26/03/2014	12.31	12.75	0.6	3187.5	423	
17	27/03/2014	10.68	11.14	0.55	2785	381.5	
18	28/03/2014	12.39	12.92	0.84	3230	622.2	
19	29/03/2014	12.16	12.73	1.03	3181.25	775.5	
20	30/03/2014	12.16	12.73	1.03	3181.25	775.5	
21	31/03/2014	11.93	12.53	1.21	3132.5	929.3	
22	01/04/2014	12.53	12.92	1.52	3230	1186.6	
23	02/04/2014	12.01	12.52	1.23	3130	945.9	7.40
24	03/04/2014	12.69	13.24	1.1	3310	838	7.38
25	04/04/2014	11.26	11.77	0.86	2942.5	638.8	7.40
26	05/04/2014	12.47	13.05	0.73	3263.75	530.9	7.45
27	06/04/2014	12.47	13.05	0.73	3263.75	530.9	7.45
28	07/04/2014	13.68	14.34	0.6	3585	423	7.50
29	08/04/2014	13.68	14.27	0.79	3567.5	580.7	7.38
30	09/04/2014	14.06	14.63	1.02	3657.5	771.6	7.35
31	10/04/2014	12.63	13.27	1.13	3317.5	862.9	7.20
32	11/04/2014	13.05	13.63	1.13	3407.5	862.9	7.35
33	12/04/2014	13.145	13.685	1.04	3421.25	788.2	7.39
34	13/04/2014	13.145	13.685	1.04	3421.25	788.2	7.39
35	14/04/2014	13.24	13.74	0.95	3435	713.5	7.42
36	15/04/2014	14.17	14.6	1.32	3650	1020.6	7.54
37	16/04/2014	13.5	14.03	1.08	3507.5	821.4	7.35
38	17/04/2014	14.24	14.56	1.29	3640	995.7	7.31

Measurement	Date	REACTOR 1 – Sludge parameters. Table 2/4					
		Organic Acids					
		A	A´	B	Lime reserve	Organic acids	pH
		ml	ml	ml	mg C_aCO_3/l	Mg Hac/l	-
39	18/04/2014	14.36	14.8	0.86	3700	638.8	7.43
40	19/04/2014	14.36	14.8	0.86	3700	638.8	7.43
41	20/04/2014	14.36	14.8	0.86	3700	638.8	7.43
42	21/04/2014	14.36	14.8	0.86	3700	638.8	7.43
43	22/04/2014	14.48	15.04	0.43	3760	281.9	7.54
44	23/04/2014	14.36	14.89	0.47	3722.5	315.1	7.56
45	24/04/2014	13.57	14.09	0.5	3522.5	340	7.63
46	25/04/2014	14.08	14.63	0.58	3657.5	406.4	7.52
47	26/04/2014	13.63	14.205	0.52	3551.25	356.6	7.62
48	27/04/2014	13.63	14.205	0.52	3551.25	356.6	7.62
49	28/04/2014	13.18	13.78	0.46	3445	306.8	7.71
50	29/04/2014	13.82	14.36	0.43	3590	281.9	7.47
51	30/04/2014	12.9	13.39	0.46	3347.5	306.8	7.43
52	01/05/2014	13.52	14.08	0.54	3347.5	373.2	7.52
53	02/05/2014	14.14	13.39	0.62	3347.5	439.6	7.60
54	03/05/2014	12.525	12.37	0.71	3092.5	514.3	7.51
55	04/05/2014	12.525	12.37	0.71	3092.5	514.3	7.51
56	05/05/2014	10.91	11.35	0.8	2837.5	589	7.42
57	06/05/2014	12.66	12.92	0.88	3230	655.4	7.47
58	07/05/2014	13.17	13.53	0.59	3382.5	414.7	7.48
59	08/05/2014	14.85	15.57	0.25	3892.5	132.5	7.50
60	09/05/2014	14.84	15.43	0.22	3857.5	107.6	7.49
61	10/05/2014	15.17	15.75	0.24	3937.5	124.2	7.58
62	11/05/2014	15.17	15.75	0.24	3937.5	124.2	7.58
63	12/05/2014	15.5	16.07	0.26	4017.5	140.8	7.66
64	13/05/2014	14.9	15.33	0.22	3832.5	107.6	7.53
65	14/05/2014	15.15	15.62	0.23	3905	115.9	7.58
66	15/05/2014	14.21	14.76	0.23	3690	115.9	7.73
67	16/05/2014	14.79	15.42	0.34	3855	207.2	7.60
68	17/05/2014	14.59	15.19	0.39	3797.5	248.7	7.72
69	18/05/2014	14.59	15.19	0.39	3797.5	248.7	7.72
70	19/05/2014	14.39	14.96	0.44	3740	290.2	7.83
71	20/05/2014	15.23	15.69	0.21	3922.5	99.3	7.85
72	21/05/2014	15.03	15.66	0.32	3915	190.6	7.75
73	22/05/2014	13.35	14.06	0.3	3515	174	7.59
74	23/05/2014	14.01	14.65	0.21	3662.5	99.3	7.60
75	24/05/2014	13.61	14.18	0.295	3545	169.85	7.60
76	25/05/2014	13.61	14.18	0.295	3545	169.85	7.60

Annex 5. SLUDGE PARAMETERS - Reactor 1.

Beginning of phase 1.2

Measurement	Date	REACTOR 1 – Sludge parameters. Table 3/4					
		Organic Acids					
		A	A´	B	Lime reserve	Organic acids	pH
		ml	ml	ml	mg C_aCO_3/l	Mg Hac/l	-
77	26/05/2014	13.21	13.71	0.38	3427.5	240.4	7.60
78	27/05/2014	14.65	15.2	0.22	3800	107.6	7.60
79	28/05/2014	14.97	15.44	0.28	3860	157.4	7.60
80	29/05/2014	14.695	15.35	0.23	3837.5	115.9	7.60
81	30/05/2014	14.695	15.35	0.23	3837.5	115.9	7.60
82	31/05/2014	14.695	15.35	0.23	3837.5	115.9	7.60
83	01/06/2014	14.695	15.35	0.23	3837.5	115.9	7.60
84	02/06/2014	14.42	15.26	0.18	3815	74.4	7.60
85	03/06/2014	15.26	15.75	0.12	3937.5	24.6	7.70
86	04/06/2014	15.29	15.92	0.18	3980	74.4	7.70
87	05/06/2014	15.69	16.3	0.19	4075	82.7	7.50
88	06/06/2014	15.96	16.47	0.14	4117.5	41.2	7.70
89	07/06/2014	16.18	16.585	0.17	4146.25	66.1	7.70
90	08/06/2014	16.18	16.585	0.17	4146.25	66.1	7.70
91	09/06/2014	16.18	16.585	0.17	4146.25	66.1	7.70
92	10/06/2014	16.4	16.7	0.2	4175	91	7.70
93	11/06/2014	14.43	15.08	0.15	3770	49.5	7.60
94	12/06/2014	14.585	15.23	0.16	3807.5	57.8	7.70
95	13/06/2014	14.74	15.38	0.17	3845	66.1	7.60
96	14/06/2014	15.18	15.71	0.165	3927.5	61.95	7.60
97	15/06/2014	15.18	15.71	0.165	3927.5	61.95	7.60
98	16/06/2014	15.62	16.04	0.16	4010	57.8	7.60
99	17/06/2014	14.52	15.15	0.88	3788	655.4	7.50
100	18/06/2014	14.69	15.22	0.91	3805	680.3	7.50
101	19/06/2014	14.95	15.52	0.91	3880	680.3	7.50
102	20/06/2014	15.21	15.82	0.91	3955	680.3	7.50
103	21/06/2014	15.12	15.685	0.6	3921.25	423	7.50
104	22/06/2014	15.12	15.685	0.6	3921.25	423	7.50
105	23/06/2014	15.03	15.55	0.29	3887.5	165.7	7.50
106	24/06/2014	14.22	14.87	0.25	3717.5	132.5	7.50
107	25/06/2014	15.01	15.62	0.77	3905	564.1	7.51
108	26/06/2014	15.05	15.52	0.81	3880	597.3	7.52
109	27/06/2014	14.55	14.85	0.78	3712.5	572.4	7.53
110	28/06/2014	14.275	14.615	0.63	3653.75	447.9	7.53
111	29/06/2014	14.275	14.615	0.63	3653.75	447.9	7.53
112	30/06/2014	14	14.38	0.48	3595	323.4	7.54
113	01/07/2014	16.29	16.88	0.39	4220	248.7	7.74
114	02/07/2014	15.515	16.03	0.405	4007.5	261.15	7.70

Beginning of phase 2

Measurement	Date	REACTOR 1 – Sludge parameters. Table 4/4					
		Organic Acids					
		A	A´	B	Lime reserve	Organic acids	pH
		ml	ml	ml	mg C_aCO_3/l	Mg Hac/l	-
115	03/07/2014	14.74	15.18	0.42	3795	273.6	7.62
116	04/07/2014	13.94	14.39	0.59	3597.5	414.7	7.55
117	05/07/2014	14.08	14.68	0.405	3670	261.15	7.68
118	06/07/2014	14.08	14.68	0.405	3670	261.15	7.68
119	07/07/2014	14.22	14.97	0.22	3742.5	107.6	7.80
120	08/07/2014	16.69	17.6	0.18	4400	74.4	7.72
121	09/07/2014	16.92	17.61	0.33	4402.5	198.9	7.60
122	10/07/2014	15.575	16.13	0.25	4075	132.5	7.70
123	11/07/2014	14.23	14.99	0.17	3747.5	66.1	7.68
124	12/07/2014	14.395	15.065	0.175	3766.25	70.25	7.60
125	13/07/2014	14.395	15.065	0.175	3766.25	70.25	7.60
126	14/07/2014	14.56	15.14	0.18	3785	74.4	7.52
127	15/07/2014	14.52	15.25	0.21	3812.5	99.3	7.56
128	16/07/2014	14.08	14.5	0.5	3625	340	7.65
129	17/07/2014	16.04	16.73	0.25	4182.5	132.5	7.65
130	18/07/2014	14.845	15.58	0.275	3895	153.25	7.68
131	19/07/2014	14.845	15.58	0.275	3895	163.625	7.68
132	20/07/2014	14.845	15.58	0.275	3895	163.625	7.68
133	21/07/2014	13.65	14.43	0.3	3607.5	174	7.71
134	22/07/2014	13.51	14.27	0.23	3567.5	115.9	7.77
135	23/07/2014	14.5	15.18	0.47	3795	315.1	7.67
136	24/07/2014	14.46	15.11	0.25	3777.5	132.5	7.54
137	25/07/2014	15.54	16.17	0.5	4042.5	340	7.54
138	26/07/2014	15.88	16.43	0.56	4107.5	389.8	7.54
139	27/07/2014	15.88	16.43	0.56	4107.5	389.8	7.54
140	28/07/2014	16.22	16.69	0.62	4172.5	439.6	7.41
141	29/07/2014	16.6	17.34	0.28	4335	157.4	7.60

Beginning of phase 3

Annex 6. SOLIDS DATA - Reactor 2.

Measurement	Date	REACTOR 2 - Solids. Table 1/4							
		Total extracted sludge	Dry solids	Organic content	Inorganic content	Dry solids	Dry solids summ	Solids in the reactor	Organic content
		L/d	%	%	%	g/d	g	g	g/d
1	07/03/2014	2	2.93	55.33	44.67	58.60	58.60	3.39	32.42
2	10/03/2014	2	2.16	47.20	52.88	40.10	98.70	24.69	18.93
3	11/03/2014	2	1.07	55.48	44.19	21.45	120.15	84.24	12.04
4	12/03/2014	2	0.86	50.67	48.04	16.01	136.16	124.23	8.03
5	13/03/2014	2	1.08	27.17	72.83	21.50	157.66	174.43	5.84
6	14/03/2014	2	0.43	34.09	65.91	8.58	166.24	239.25	2.92
7	17/03/2014	2	0.51	40.00	60.00	10.27	176.50	306.41	4.11
8	18/03/2014	2	0.40	39.06	60.94	8.04	184.54	377.60	3.14
9	19/03/2014		0.67	32.24	67.76	13.40	184.54	377.60	4.32
10	20/03/2014	2	0.93	25.42	74.58	18.64	203.18	427.94	4.74
11	21/03/2014	2	1.17	50.18	49.82	23.40	226.58	471.82	11.74
12	22/03/2014	2	1.07	53.59	46.41	21.40	247.98	522.42	11.47
13	23/03/2014	2	1.07	53.59	46.41	21.40	269.38	573.02	11.47
14	24/03/2014		1.22	55.29	44.71	24.40	269.38	573.02	13.49
15	25/03/2014	2	1.37	56.99	43.01	27.38	296.76	621.64	15.60
16	26/03/2014	2	1.64	44.81	55.19	32.80	329.56	668.46	14.70
17	27/03/2014	2	0.99	48.95	51.05	19.80	349.36	722.66	9.69
18	28/03/2014	2	0.91	50.00	50.00	18.29	367.65	795.90	9.15
19	29/03/2014	2	0.91	50.00	50.00	18.29	385.94	870.41	9.15
20	30/03/2014	2	0.91	50.00	50.00	18.29	404.24	944.92	9.15
21	31/03/2014	2	0.91	50.00	50.00	18.29	422.53	1020.78	9.15
22	01/04/2014		1.02	48.74	51.26	20.40	422.53	1020.78	9.94
23	02/04/2014		1.02	48.74	51.26	20.40	422.53	1020.78	9.94
24	03/04/2014		1.02	48.74	51.26	20.40	422.53	1020.78	9.94
25	04/04/2014		1.02	48.74	51.26	20.40	442.93	1020.78	9.94
26	05/04/2014		1.02	48.74	51.26	20.40	422.53	1020.78	9.94
27	06/04/2014		1.02	48.74	51.26	20.40	422.53	1020.78	9.94
28	07/04/2014	2	1.12	47.49	52.51	22.40	444.93	1573.58	10.64
29	08/04/2014	2	1.20	55.03	44.97	23.96	468.89	1619.40	13.18
30	09/04/2014	2	1.17	50.23	49.77	23.38	492.27	1663.50	11.74
31	10/04/2014		1.33	52.49	47.51	26.60	492.27	1663.50	13.96
32	11/04/2014		1.33	52.49	47.51	26.60	492.27	1663.50	13.96
33	12/04/2014		1.33	52.49	47.51	26.60	492.27	1663.50	13.96
34	13/04/2014		1.33	52.49	47.51	26.60	492.27	1663.50	13.96
35	14/04/2014	2	1.50	54.74	45.26	30.00	522.27	2016.26	16.42
36	15/04/2014	2	0.85	46.37	53.63	17.00	539.27	2074.06	7.88
37	16/04/2014	2	0.94	49.76	50.24	18.76	558.03	2140.90	9.33

Measurement	Date	REACTOR 2 - Solids. Table 2/4							
		Total extracted sludge	Dry solids	Organic content	Inorganic content	Dry solids	Dry solids summ	Solids in the reactor	Organic content
		L/d	%	%	%	g/d	g	g	g/d
38	17/04/2014	2	2.22	52.33	47.67	44.32	602.35	2179.98	23.19
39	18/04/2014		2.17	52.71	47.29	43.40	602.35	2179.98	22.88
40	19/04/2014		2.17	52.71	47.29	43.40	602.35	2179.98	22.88
41	20/04/2014		2.17	52.71	47.29	43.40	602.35	2179.98	22.88
42	21/04/2014		2.17	52.71	47.29	43.40	602.35	2179.98	22.88
43	22/04/2014	2	2.13	53.08	46.92	42.60	644.95	2548.14	22.61
44	23/04/2014	2	2.50	52.30	47.71	50.00	694.95	2581.54	26.15
45	24/04/2014	2	2.33	52.15	47.85	46.60	741.55	2624.54	24.30
46	25/04/2014	2	2.29	51.89	48.11	45.72	787.27	2663.12	23.72
47	26/04/2014	2	2.41	52.72	47.28	48.20	835.47	2694.92	25.41
48	27/04/2014	2	2.41	52.72	47.28	48.20	883.67	2726.72	25.41
49	28/04/2014	2	2.53	53.55	46.45	50.60	934.27	2754.30	27.10
50	29/04/2014	2	2.39	53.88	46.12	47.80	982.07	2783.02	25.75
51	30/04/2014	2	2.77	50.44	49.56	55.38	1037.45	2804.08	27.93
52	01/05/2014	2	1.85	51.38	48.62	37.00	1074.45	2842.08	19.01
53	02/05/2014	2	0.93	52.33	47.67	18.58	1093.03	2896.92	9.72
54	03/05/2014	2	0.99	50.31	49.69	19.80	1112.83	2950.12	9.96
55	04/05/2014	2	0.99	50.31	49.69	19.80	1132.63	3003.32	9.96
56	05/05/2014	2	1.05	48.29	51.71	20.90	1153.53	3055.42	10.09
57	06/05/2014	2	1.07	26.67	73.33	21.40	1174.93	3106.72	5.71
58	07/05/2014	2	3.12	49.60	50.41	62.40	1237.33	3116.44	30.95
59	08/05/2014	2	3.02	53.34	46.66	60.41	1297.74	3124.09	32.22
60	09/05/2014	2	2.04	53.96	46.04	40.75	1338.49	3169.44	21.99
61	10/05/2014	2	1.60	54.91	45.09	32.00	1370.49	3219.44	17.57
62	11/05/2014	2	1.60	54.91	45.09	32.00	1402.49	3269.44	17.57
63	12/05/2014	2	1.17	55.86	44.14	23.40	1425.89	3326.00	13.07
64	13/05/2014	2	1.04	53.72	46.28	20.80	1446.69	3377.20	11.17
65	14/05/2014	2	1.02	53.82	46.18	20.30	1466.99	3442.40	10.93
66	15/05/2014	2	1.05	57.08	42.92	21.00	1487.99	3495.80	11.99
67	16/05/2014	2	0.98	56.33	43.67	19.50	1507.49	3556.90	10.98
68	17/05/2014	2	0.94	55.69	44.31	18.80	1526.29	3627.30	10.47
69	18/05/2014	2	0.94	55.69	44.31	18.80	1545.09	3697.70	10.47
70	19/05/2014	2	0.90	55.05	44.95	17.96	1563.05	3777.34	9.89
71	20/05/2014	2	1.00	58.27	41.73	19.90	1582.95	3824.44	11.60
72	21/05/2014	2	1.16	55.94	44.06	23.19	1606.14	3873.60	12.98
73	22/05/2014	2	1.12	59.41	40.59	22.38	1628.52	3920.02	13.30
74	23/05/2014	2	1.17	55.00	45.00	23.30	1651.82	3966.02	12.82
75	24/05/2014	2	1.12	56.09	43.91	22.40	1674.22	4012.22	12.56
76	25/05/2014	2	1.12	56.09	43.91	22.40	1696.62	4058.42	12.56

Measurement	Date	REACTOR 2 - Solids. Table 3/4							
		Total extracted sludge	Dry solids	Organic content	Inorganic content	Dry solids	Dry solids summ	Solids in the reactor	Organic content
		L/d	%	%	%	g/d	g	g	g/d
77	26/05/2014	2	1.07	57.19	42.81	21.46	1718.08	4104.96	12.27
78	27/05/2014	2	3.51	53.45	46.55	70.28	1788.36	4098.91	37.56
79	28/05/2014	2	3.62	56.30	43.70	72.48	1860.84	4093.15	40.81
80	29/05/2014	2	3.60	53.90	46.10	72.00	1932.84	4088.15	38.81
81	30/05/2014	2	3.60	53.90	46.10	72.00	2004.84	4083.15	38.81
82	31/05/2014	2	3.60	53.90	46.10	72.00	2076.84	4078.15	38.81
83	01/06/2014	2	3.60	53.90	46.10	72.00	2148.84	4073.15	38.81
84	02/06/2014	2	3.57	51.50	48.50	71.40	2220.24	4069.09	36.77
85	03/06/2014	2	3.49	51.97	48.04	69.85	2290.09	4071.06	36.30
86	04/06/2014	2	2.97	51.59	48.41	59.40	2349.49	4084.22	30.64
87	05/06/2014	2	3.37	51.14	48.86	67.41	2416.91	4089.71	34.48
88	06/06/2014	2	2.91	51.77	48.23	58.10	2475.01	4115.23	30.08
89	07/06/2014	2	3.00	51.93	48.07	60.00	2535.01	4132.23	31.16
90	08/06/2014	2	3.00	51.93	48.07	60.00	2595.01	4149.23	31.16
91	09/06/2014	2	3.00	51.93	48.07	60.00	2655.01	4166.23	31.16
92	10/06/2014	2	3.28	52.09	47.91	65.60	2720.61	4171.03	34.17
93	11/06/2014	2	2.85	53.11	46.89	57.00	2777.61	4191.03	30.27
94	12/06/2014	2	3.01	52.65	47.35	60.20	2837.81	4210.43	31.70
95	13/06/2014	2	3.01	52.65	47.35	60.20	2898.01	4229.83	31.70
96	14/06/2014	2	3.01	52.65	47.35	60.20	2958.21	4249.23	31.70
97	15/06/2014	2	3.01	52.65	47.35	60.20	3018.41	4268.63	31.70
98	16/06/2014	2	3.18	52.19	47.81	63.59	3081.99	4287.32	33.19
99	17/06/2014	2	2.94	48.67	51.33	58.78	3140.77	4307.54	28.61
100	18/06/2014	2	2.46	44.76	55.24	49.21	3189.98	4334.01	22.03
101	19/06/2014	2	2.88	44.76	55.24	57.60	3247.58	4352.81	25.78
102	20/06/2014	2	3.31	40.85	59.15	66.15	3313.73	4363.61	27.02
103	21/06/2014	2	3.35	42.34	57.66	67.00	3380.73	4368.21	28.37
104	22/06/2014	2	3.35	42.34	57.66	67.00	3447.73	4372.81	28.37
105	23/06/2014	2	3.39	43.83	56.17	67.71	3515.43	4371.17	29.67
106	24/06/2014	2	3.07	51.01	48.99	61.40	3576.83	4387.33	31.32
107	25/06/2014	2	2.85	46.09	53.91	57.00	3633.83	4410.83	26.27
108	26/06/2014	2	2.87	48.53	51.47	57.40	3691.23	4410.93	27.86
109	27/06/2014	2	2.93	49.00	51.01	58.64	3749.87	4424.25	28.73
110	28/06/2014	2	2.92	49.77	50.23	58.40	3808.27	4437.45	29.07
111	29/06/2014	2	2.92	49.77	50.23	58.40	3866.67	4450.65	29.07
112	30/06/2014	2	2.92	49.77	50.23	58.40	3925.07	4463.65	29.07
113	01/07/2014	2	2.92	49.00	51.00	58.40	3983.47	4477.05	28.62
114	02/07/2014	2	2.92	49.77	50.23	58.40	4041.87	4490.45	29.07
115	03/07/2014	2	2.91	50.55	49.45	58.28	4100.15	4503.97	29.46
116	04/07/2014	2	2.53	50.56	49.45	50.58	4150.73	4525.75	25.57
117	05/07/2014	2	2.75	50.50	49.50	55.00	4205.73	4549.75	27.78

Measurement	Date	REACTOR 2 - Solids. Table 4/4							
		Total extracted sludge	Dry solids	Organic content	Inorganic content	Dry solids	Dry solids summ	Solids in the reactor	Organic content
		L/d	%	%	%	g/d	g	g	g/d
118	06/07/2014	2	2.75	50.50	49.50	55.00	4260.73	4573.75	27.78
119	07/07/2014	2	2.97	50.45	49.55	59.37	4320.10	4599.85	29.95
120	08/07/2014	2	2.47	52.02	47.98	49.32	4369.42	4625.53	25.65
121	09/07/2014	2	2.72	51.23	48.77	54.34	4423.77	4651.43	27.84
122	10/07/2014	2	2.72	51.23	48.77	54.34	4478.11	4667.08	27.84
123	11/07/2014	2	2.44	51.96	48.04	48.72	4526.83	4695.62	25.32
124	12/07/2014	2	2.34	52.54	47.46	46.80	4573.63	4724.82	24.59
125	13/07/2014	2	2.34	52.54	47.46	46.80	4620.43	4754.02	24.59
126	14/07/2014	2	2.24	53.13	46.87	44.83	4665.26	4784.12	23.81
127	15/07/2014	2	2.95	51.27	48.73	59.00	4724.25	4798.58	30.25
128	16/07/2014	2	2.89	50.77	49.23	57.79	4782.04	4812.44	29.34
129	17/07/2014	2	2.93	50.79	49.21	58.55	4840.59	4820.85	29.74
130	18/07/2014	2	2.89	51.65	48.35	57.80	4898.39	4829.85	29.85
131	19/07/2014	2	2.89	51.65	48.35	57.80	4956.19	4838.85	29.85
132	20/07/2014	2	2.89	51.65	48.35	57.80	5013.99	4847.85	29.85
133	21/07/2014	2	2.86	52.50	47.50	57.18	5071.17	4857.48	30.02
134	22/07/2014	2	2.62	51.13	48.87	52.31	5123.48	4873.00	26.74
135	23/07/2014	2	2.90	53.16	46.84	57.92	5181.40	4900.15	30.79
136	24/07/2014	2	2.72	49.78	50.22	54.34	5235.74	4912.77	27.05
137	25/07/2014	2	2.42	51.90	48.11	48.33	5284.07	4936.38	25.08
138	26/07/2014	2	2.50	52.03	47.97	50.00	5334.07	4965.18	26.02
139	27/07/2014	2	2.50	52.03	47.97	50.00	5384.07	4993.98	26.02
140	28/07/2014	2	2.59	52.16	47.84	51.81	5435.89	5027.66	27.02
141	29/07/2014	2	2.50	50.21	49.79	50.00	5485.89	5057.66	25.11

Annex 7. REACTOR PARAMETERS - Reactor 2.

Measurement	Date	REACTOR 2 – Reactor parameters. Table 1/4			
		Temperature	Manometric pressure	Atmospheric pressure	Absolute pressure
		°C	mbar	mbar	mbar
1	07/03/2014			1018	1018.0
2	10/03/2014	37.8		1017	1017.0
3	11/03/2014	31.25	4	1020	1024.0
4	12/03/2014	36.56	7	1023	1030.0
5	13/03/2014	36.37	7	1020	1027.0
6	14/03/2014	36.12	8	1017	1025.0
7	17/03/2014	32.95	10	1012	1022.0
8	18/03/2014	36.2	2.5	1005	1007.5
9	19/03/2014	36.52	10	1013	1023.0
10	20/03/2014	36.81	5	1007	1012.0
11	21/03/2014	36.42	7	1000	1007.0
12	22/03/2014	36.32	7	996	1003.0
13	23/03/2014	36.27	15	998	1013.0
14	24/03/2014	35.83	19	1003	1022.0
15	25/03/2014	35.15	12	1003	1015.0
16	26/03/2014	36.22	12	1004	1016.0
17	27/03/2014	35.83	11	1003	1014.0
18	28/03/2014	37.41	13.5	1006	1019.5
19	29/03/2014	37.43	13	1011	1024.0
20	30/03/2014	37.06	22	1006	1028.0
21	31/03/2014	37.43	30.5	1005	1035.5
22	01/04/2014	36.8	13	1001	1014.0
23	02/04/2014	38.1	8	999	1007.0
24	03/04/2014	37.8	6	996	1002.0
25	04/04/2014	36.5	5	1000	1005.0
26	05/04/2014	36.5	7.5	1003	1010.5
27	06/04/2014	36.5	7.5	1003	1010.5
28	07/04/2014	36.5	10	1006	1016.0
29	08/04/2014	37.3	8	1006	1014.0
30	09/04/2014	37.6	10	1016	1026.0
31	10/04/2014	37.7	10	1013	1023.0
32	11/04/2014	37.8	8	1010	1018.0
33	12/04/2014	36.38	5	1008	1013.0
34	13/04/2014	36.22	9	1009	1018.0
35	14/04/2014	36.5	10	1006	1016.0
36	15/04/2014	37	8	1015	1023.0
37	16/04/2014	36.5	5	1020	1025.0
38	17/04/2014	38	15	1011	1026.0
39	18/04/2014	38.27	13.5	1002	1015.5

Measurement	Date	REACTOR 2 – Reactor parameters. Table 2/4			
		Temperature	Manometric pressure	Atmospheric pressure	Absolute pressure
		°C	mbar	mbar	mbar
40	19/04/2014	37.83	4.5	1002	1006.5
41	20/04/2014	37.88	4	999	1003.0
42	21/04/2014	37.69	3.5	997	1000.5
43	22/04/2014	37.4	1.5	1002	1003.5
44	23/04/2014	36.9	8	1008	1016.0
45	24/04/2014	37.4	12	1008	1020.0
46	25/04/2014	36.5	12	1003	1015.0
47	26/04/2014	37.3	13	1003	1016.0
48	27/04/2014	36.96	11	1000	1011.0
49	28/04/2014	37.1	11	1002	1013.0
50	29/04/2014	36.9	12	1002	1014.0
51	30/04/2014	37.8	10	1003	1013.0
52	01/05/2014	36.92	7	1002	1009.0
53	02/05/2014	37.9	10	1003	1013.0
54	03/05/2014	38.85	10	1014	1024.0
55	04/05/2014	38.47	7	1014	1021.0
56	05/05/2014	37.85	12	1007	1019.0
57	06/05/2014	38.03	4	1001	1005.0
58	07/05/2014	37.05	13.5	1002	1015.5
59	08/05/2014	36.5	13.5	1003	1016.5
60	09/05/2014	37.9	10	1003	1013.0
61	10/05/2014	37.25	15	1000	1015.0
62	11/05/2014	37.2	13	997	1010.0
63	12/05/2014	37.86	10	1001	1011.0
64	13/05/2014	37	12	1005	1017.0
65	14/05/2014	38	14	1017	1031.0
66	15/05/2014	36.6	11	1026	1037.0
67	16/05/2014	38.1	11	1023	1034.0
68	17/05/2014	38.67	29	1015	1044.0
69	18/05/2014	38.62	27	1004	1031.0
70	19/05/2014	39.1	38	1001	1039.0
71	20/05/2014	37.3	7	1003	1010.0
72	21/05/2014	37.5	12	1003	1015.0
73	22/05/2014	37.4	12	1001	1013.0
74	23/05/2014	37	11	1002	1013.0
75	24/05/2014	37.7	15	1005	1020.0
76	25/05/2014	38.3	9	1010	1019.0
77	26/05/2014	38.1	10	1004	1014.0
78	27/05/2014	37.8	14	1002	1016.0
79	28/05/2014	36.9	8	1002	1010.0
80	29/05/2014	36.1	11	1005	1016.0

Measurement	Date	REACTOR 2 – Reactor parameters. Table 3/4			
		Temperature	Manometric pressure	Atmospheric pressure	Absolute pressure
		°C	mbar	mbar	mbar
81	30/05/2014	37.9	9	1012	1021.0
82	31/05/2014	37.9	9	1014	1023.0
83	01/06/2014	36.9	11	1012	1023.0
84	02/06/2014	36.4	12	1011	1023.0
85	03/06/2014	37.7	12	1003	1015.0
86	04/06/2014	38	15	1001	1016.0
87	05/06/2014	36.4	14	1002	1016.0
88	06/06/2014	37.3	10	1002	1012.0
89	07/06/2014	38.5	15	1006	1021.0
90	08/06/2014	38.63	9	1008	1017.0
91	09/06/2014	37.69	10	1008	1018.0
92	10/06/2014	37	10	1010	1020.0
93	11/06/2014	37.5	13	1016	1029.0
94	12/06/2014	37.6	12	1019	1031.0
95	13/06/2014	37.4	12	1015	1027.0
96	14/06/2014	37.2	10	1013	1023.0
97	15/06/2014	37.2	10	1015	1025.0
98	16/06/2014	37.1	10	1015	1025.0
99	17/06/2014	37.8	2	1014	1016.0
100	18/06/2014	37.6	8	1014	1022.0
101	19/06/2014	37.1	8	1013	1021.0
102	20/06/2014	36.8	10	1012	1022.0
103	21/06/2014	37.7	9	1012	1021.0
104	22/06/2014	38.6	5	1013	1018.0
105	23/06/2014	37.5	12	1015	1027.0
106	24/06/2014	37.6	8	1010	1018.0
107	25/06/2014	36.38	8.5	1009	1017.5
108	26/06/2014	36.81	8.5	1008	1016.5
109	27/06/2014	37.3	5	1007	1012.0
110	28/06/2014	37.4	11	1004	1015.0
111	29/06/2014	35.2	8	1001	1009.0
112	30/06/2014	36.42	8	1008	1016.0
113	01/07/2014	37.8	8	1012	1020.0
114	02/07/2014	37.4	8	1013	1021.0
115	03/07/2014	38.1	9	1015	1024.0
116	04/07/2014	36.7	8	1006	1014.0
117	05/07/2014	37.8	8	1001	1009.0
118	06/07/2014	38.1	9	1002	1011.0
119	07/07/2014	38.5	8	1009	1017.0
120	08/07/2014	37.1	10.5	1002	1012.5
121	09/07/2014	36.12	11.5	1002	1013.5

Measurement	Date	REACTOR 2 – Reactor parameters. Table 4/4			
		Temperature	Manometric pressure	Atmospheric pressure	Absolute pressure
		°C	mbar	mbar	mbar
122	10/07/2014	37.1	13	1002	1015.0
123	11/07/2014	37	8	1007	1015.0
124	12/07/2014	36.12	9	1006	1015.0
125	13/07/2014	36.43	10.5	1002	1012.5
126	14/07/2014	37.87	9.5	1006	1015.5
127	15/07/2014	36.61	8	1013	1021.0
128	16/07/2014	37.69	7	1015	1022.0
129	17/07/2014	37.3	9	1014	1023.0
130	18/07/2014	36.91	7	1010	1017.0
131	19/07/2014	38.13	10	1006	1016.0
132	20/07/2014	38.91	6.5	1003	1009.5
133	21/07/2014	37.05	8	1005	1013.0
134	22/07/2014	37.44	7	1009	1016.0
135	23/07/2014	38.37	10	1010	1020.0
136	24/07/2014	39.35	7	1008	1015.0
137	25/07/2014	36.52	8	1007	1015.0
138	26/07/2014	37.24	10	1007	1017.0
139	27/07/2014	38.13	8	1008	1016.0
140	28/07/2014	37.75	10	1005	1015.0
141	29/07/2014	36.9	9	1004	1013.0

Annex 8. GAS PARAMETERS - Reactor 2.

Measurement	Date	REACTOR 1 – Gas parameters. Table 1/4							
		Volume measured	Gas tank temp.	Gas tank temp.	Volume normal conditions	Summ n-volume	CO_2	CH_4	H_2S
		L	°C	K	L	L	%	%	%
1	07/03/2014					0.00			
2	10/03/2014			273.15		0.00			
3	11/03/2014	2	22	295.15		0.00			
4	12/03/2014	5	19.4	292.55	4.75	4.75			
5	13/03/2014	9	19.1	292.25	8.53	13.27	2	40.5	0
6	14/03/2014	11	18.6	291.75	10.42	23.70	4	52	0
7	17/03/2014	12	15.7	288.85	11.45	35.14	4	72	0
8	18/03/2014	2	17	290.15	1.87	37.02	5	73.5	0
9	19/03/2014	12	17.6	290.75	11.38	48.40	6	75	0
10	20/03/2014	4	18.5	291.65	3.74	52.14	6	80	0
11	21/03/2014	9	19.6	292.75	8.35	60.49	6	80	0
12	22/03/2014	8	18.45	291.6	7.42	67.91	9	77.5	0
13	23/03/2014	12	18.45	291.6	11.24	79.15	9	77.5	0
14	24/03/2014	14	17.3	290.45	13.28	92.44	12	75	0
15	25/03/2014	13	16.6	289.75	12.28	104.71	12	82	0
16	26/03/2014	14	16.3	289.45	13.25	117.97	13	80	0
17	27/03/2014	12.6	16.9	290.05	11.88	129.84	12	76	0
18	28/03/2014	16	18.3	291.45	15.09	144.93	12	75	0
19	29/03/2014	18	19.65	292.8	16.97	161.91	13	73	0
20	30/03/2014	15	19.65	292.8	14.20	176.11	13	73	0
21	31/03/2014	11	21	294.15	10.44	186.55	14	71	0
22	01/04/2014	16	22.4	295.55	14.80	201.35	14	71	0
23	02/04/2014	8	22.4	295.55	7.35	208.70	12	74	0
24	03/04/2014	5	21.8	294.95	4.58	213.28	6	78	0
25	04/04/2014	4	22.3	295.45	3.67	216.95	4	79	0
26	05/04/2014	4	22.2	295.35	3.69	220.64	4	80.5	0
27	06/04/2014	4	22.1	295.25	3.69	224.33	4	80.5	0
28	07/04/2014	4	22	295.15	3.71	228.05	4	82	0
29	08/04/2014	8	21.2	294.35	7.43	235.48	8	84	0
30	09/04/2014	12	20.9	294.05	11.29	246.77	10	78	0
31	10/04/2014	12	20.6	293.75	11.27	258.04	10	74	0
32	11/04/2014	8	20.7	293.85	7.47	265.51	7	79	0
33	12/04/2014	2	20.1	293.25	1.86	267.37	5.5	80.5	0
34	13/04/2014	2.5	20.1	293.25	2.34	269.71	5.5	80.5	0
35	14/04/2014	3	19.4	292.55	2.81	272.52	4	82	0
36	15/04/2014	9	18.5	291.65	8.51	281.03	8	81	0
37	16/04/2014	3	16.7	289.85	2.86	283.90	2	54	0
38	17/04/2014	19	18.2	291.35	18.04	301.94	13	71	0

Measurement	Date	REACTOR 2 – Gas parameters. Table 2/4							
		Volume measured	Gas tank temp.	Gas tank temp.	Volume normal conditions	Summ n-volume	CO_2	CH_4	H_2S
		L	°C	K	L	L	%	%	%
39	18/04/2014	18	18	291.15	16.93	318.87	9.5	75.5	0
40	19/04/2014	6	18	291.15	5.59	324.46	9.5	75.5	0
41	20/04/2014	6	18	291.15	5.57	330.03	9.5	75.5	0
42	21/04/2014	6	18	291.15	5.56	335.59	13	75.5	0
43	22/04/2014	3	18.3	291.45	2.79	338.38	6	80	0
44	23/04/2014	9	20.6	293.75	8.39	346.77	10	78	0
45	24/04/2014	14	20.8	293.95	13.10	359.87	11	76	0
46	25/04/2014	15	19.9	293.05	14.01	373.88	11	76	0
47	26/04/2014	18	19.5	292.65	16.85	390.73	12.5	77	0
48	27/04/2014	16	19.5	292.65	14.90	405.63	12.5	77	0
49	28/04/2014	10	19.3	292.45	9.34	414.97	14	78	0
50	29/04/2014	15	19.5	292.65	14.01	428.99	12	77	0
51	30/04/2014	14	19.4	292.55	13.07	442.06	12	79	0
52	01/05/2014	8	20.1	293.25	7.42	449.48	12	79.5	0
53	02/05/2014	14	20.7	293.85	13.01	462.50	12	80	0
54	03/05/2014	14	18	291.15	13.28	475.77	11.5	79	0
55	04/05/2014	14	18	291.15	13.24	489.01	11.5	79	0
56	05/05/2014	14	18	291.15	13.21	502.22	11.5	79	0
57	06/05/2014	6	18	291.15	5.58	507.81	11	78	0
58	07/05/2014	18	18	291.15	16.93	524.74	12.5	80	0
59	08/05/2014	21	18.6	291.75	19.73	544.47	14	82	0
60	09/05/2014	13	19.6	292.75	12.13	556.60	12	77	0
61	10/05/2014	22	19.1	292.25	20.60	577.20	13	76.5	0
62	11/05/2014	19	19.1	292.25	17.71	594.90	13	76.5	0
63	12/05/2014	15	18.9	292.05	14.00	14.00	14	76	0
64	13/05/2014	17	17.7	290.85	16.03	30.03	14	75	0
65	14/05/2014	18	18.2	291.35	17.18	47.21	14	77	0
66	15/05/2014	15	18	291.15	14.41	61.61	14	75	0
67	16/05/2014	16	18.6	291.75	15.29	76.90	14	77	0
68	17/05/2014	22	20.4	293.55	21.10	98.00	14	76	0
69	18/05/2014	18	20.4	293.55	17.05	115.05	14	76	0
70	19/05/2014	16	22.2	295.35	15.18	130.22	14	75	0
71	20/05/2014	16	22.6	295.75	14.73	144.96	14	76	0
72	21/05/2014	15	19.3	292.45	14.04	158.99	20	74	0
73	22/05/2014	16	23.8	296.95	14.72	173.71	20	73	0
74	23/05/2014	15	20.7	293.85	13.94	187.66	20	74	0
75	24/05/2014	20	20	293.15	18.76	206.42	19	75.5	0
76	25/05/2014	16	20	293.15	15.00	221.42	19	75.5	0

Measurement	Date	REACTOR 2 – Gas parameters. Table 3/4							
		Volume measured	Gas tank temp.	Gas tank temp.	Volume normal conditions	Summ n-volume	CO_2	CH_4	H_2S
		L	°C	K	L	L	%	%	%
77	26/05/2014	14	21	294.15	13.01	234.43	18	77	0
78	27/05/2014	20	18	291.15	18.82	253.25	20	77	0
79	28/05/2014	16	18	291.15	14.97	268.22	21	78	0
80	29/05/2014	14	19	292.15	13.13	281.34	20.5	80	0
81	30/05/2014	16	20	293.15	15.03	296.37	20	82	0
82	31/05/2014	12	20	293.15	11.29	307.66	20	82	0
83	01/06/2014	17	21	294.15	15.94	323.60	20	82	0
84	02/06/2014	21	20	293.15	19.76	343.36	20	82	0
85	03/06/2014	15	22.1	295.25	13.90	357.27	20	84	0
86	04/06/2014	12	22.8	295.95	11.11	368.38	16	76	0
87	05/06/2014	20	23	296.15	18.50	386.88	20	74	0
88	06/06/2014	10	22.8	295.95	9.22	396.10	20	80	0
89	07/06/2014	21	25	298.15	19.39	415.49	20	79	0
90	08/06/2014	15	25	298.15	13.80	429.29	20	79	0
91	09/06/2014	14	25	298.15	12.89	442.18	20	79	0
92	10/06/2014	15	26.8	299.95	13.75	455.93	20	78	0
93	11/06/2014	10	23.6	296.75	9.35	465.28	18	78	0
94	12/06/2014	12	24	297.15	11.23	476.51	18	77	0
95	13/06/2014	12	23.7	296.85	11.19	487.70	16	73	0
96	14/06/2014	14	22.1	295.25	13.08	500.78	17	76.5	0
97	15/06/2014	14	22.1	295.25	13.11	513.89	17	76.5	0
98	16/06/2014	15	20.5	293.65	14.12	528.01	18	80	0
99	17/06/2014	2	20.9	294.05	1.86	529.87	17	80	0
100	18/06/2014	11	21.9	295.05	10.27	540.14	16	80	0
101	19/06/2014	16	20.5	293.65	15.00	555.14	17	81	0
102	20/06/2014	20	21.2	294.35	18.72	573.87	18	82	0
103	21/06/2014	18	21.9	295.05	16.80	590.66	17.25	82.5	0
104	22/06/2014	2	22.3	295.45	1.86	592.52	17.25	82.5	0
105	23/06/2014	18	23.2	296.35	16.82	609.34	16.5	83	0
106	24/06/2014	13	22.8	295.95	12.06	621.40	16.5	83	0
107	25/06/2014	12	22.7	295.85	11.13	11.13	16.5	83	0
108	26/06/2014	12	22.7	295.85	11.12	22.25	16.5	83	0
109	27/06/2014	7	22.6	295.75	6.46	28.70	15	84	0
110	28/06/2014	10	23.45	296.6	9.23	37.93	15.25	84	0
111	29/06/2014	19	23.45	296.6	17.43	55.36	15.25	84	0
112	30/06/2014	10	23.45	296.6	9.24	64.60	15.5	84	0
113	01/07/2014	13	23.45	296.6	12.05	76.65	16	84	0
114	02/07/2014	10	23.45	296.6	9.28	85.93	15.5	83	0

Measurement	Date	REACTOR 2 – Gas parameters. Table 4/4							
		Volume measured	Gas tank temp.	Gas tank temp.	Volume normal conditions	Summ n-volume	CO_2	CH_4	H_2S
		L	°C	K	L	L	%	%	%
115	03/07/2014	12	23.45	296.6	11.17	97.11	15.5	83	0
116	04/07/2014	12	23.45	296.6	11.06	108.17	15.5	83	0
117	05/07/2014	10	23.45	296.6	9.17	117.34	15.25	82.5	0
118	06/07/2014	14	23.45	296.6	12.87	130.21	15.25	82.5	0
119	07/07/2014	13	24.3	297.45	11.99	142.19	15	82	0
120	08/07/2014	12	23.25	296.4	11.05	153.25	14.5	80.5	0
121	09/07/2014	14	22.2	295.35	12.95	166.20	14	79	0
122	10/07/2014	12	21.6	294.75	11.14	177.34	15	78	0
123	11/07/2014	12	21	294.15	11.17	188.51	16	77	0
124	12/07/2014	14	21.7	294.85	13.00	201.50	16	78.25	0
125	13/07/2014	15	21.7	294.85	13.89	215.39	16	78.25	0
126	14/07/2014	13	21.7	294.85	12.07	227.47	16	79.5	0
127	15/07/2014	12	22.4	295.55	11.18	238.64	16	82	0
128	16/07/2014	11	23.15	296.3	10.23	248.88	14	84.5	0
129	17/07/2014	13	23.9	297.05	12.07	260.95	12	87	0
130	18/07/2014	8	23.9	297.05	7.39	268.33	12.5	84	0
131	19/07/2014	12	24.2	297.35	11.06	279.39	12.5	84	0
132	20/07/2014	8	24.5	297.65	7.32	286.70	12.5	84	0
133	21/07/2014	8	25.1	298.25	7.33	294.03	13	81	0
134	22/07/2014	12	25.6	298.75	11.00	305.04	12.5	82	0
135	23/07/2014	14	25.9	299.05	12.88	317.91	12	83	0
136	24/07/2014	8	26.3	299.45	7.31	325.22	12	87	0
137	25/07/2014	10	26.8	299.95	9.12	334.35	13.5	82.5	0
138	26/07/2014	13	26.2	299.35	11.91	346.26	13.5	82.5	0
139	27/07/2014	12	25.9	299.05	10.99	357.25	13.5	82.5	0
140	28/07/2014	15	26.3	299.45	13.71	370.96	15	78	0
141	29/07/2014	15	26	299.15	13.70	384.66	15	78	0

Measurement	Date	REACTOR 2 – Sludge parameters. Table 1/4					
		Organic Acids					
		A	A´	B	Lime reserve	Organic acids	pH
		ml	ml	ml	mg C_aCO_3/l	Mg Hac/l	-
1	07/03/2014						
2	10/03/2014						
3	11/03/2014						
4	12/03/2014						
5	13/03/2014	7.2	7.48	0.17	1870	66.1	
6	14/03/2014	8.09	8.39	0.27	2097.5	149.1	
7	17/03/2014	8.6	8.82	0.36	2205	223.8	
8	18/03/2014	8.75	9.5	0.3	2375	174	
9	19/03/2014	9.16	9.31	0.29	2327.5	165.7	
10	20/03/2014	9.61	9.71	0.62	2427.5	439.6	
11	21/03/2014	10.06	10.11	0.9	2527.5	672	
12	22/03/2014	9.875	10.065	0.585	2516.25	410.55	
13	23/03/2014	9.875	10.065	0.585	2516.25	410.55	
14	24/03/2014	9.69	10.02	0.27	2505	149.1	
15	25/03/2014	10.17	10.62	0.26	2655	140.8	
16	26/03/2014	10.06	10.43	0.28	2607.5	157.4	
17	27/03/2014	10.19	10.71	0.24	2677.5	124.2	
18	28/03/2014	10.42	10.87	0.21	2717.5	99.3	
19	29/03/2014	10.585	11.085	0.275	2771.25	153.25	
20	30/03/2014	10.585	11.085	0.275	2771.25	153.25	
21	31/03/2014	10.75	11.3	0.34	2825	207.2	
22	01/04/2014	11.17	11.77	0.33	2942.5	198.9	
23	02/04/2014	11.37	11.79	0.31	2947.5	182.3	7.40
24	03/04/2014	11.73	12.16	0.3	3040	174	7.35
25	04/04/2014	11.63	12.17	0.19	3042.5	82.7	7.32
26	05/04/2014	11.775	12.38	0.225	3095	111.75	7.35
27	06/04/2014	11.775	12.38	0.225	3095	111.75	7.35
28	07/04/2014	11.92	12.59	0.26	3147.5	140.8	7.37
29	08/04/2014	12.25	12.75	0.25	3187.5	132.5	7.37
30	09/04/2014	12.2	12.74	0.24	3185	124.2	7.40
31	10/04/2014	12.16	12.8	0.26	3200	140.8	7.30
32	11/04/2014	12.4	13.1	0.18	3275	74.4	7.45
33	12/04/2014	12.55	13.225	0.195	3306.25	86.85	7.43
34	13/04/2014	12.55	13.225	0.195	3306.25	86.85	7.43
35	14/04/2014	12.71	13.35	0.21	3337.5	99.3	7.41
36	15/04/2014	13.08	13.5	0.43	3375	281.9	4.76
37	16/04/2014	12.15	12.62	0.31	3155	182.3	7.45
38	17/04/2014	11.77	12.26	0.18	3065	74.4	7.45

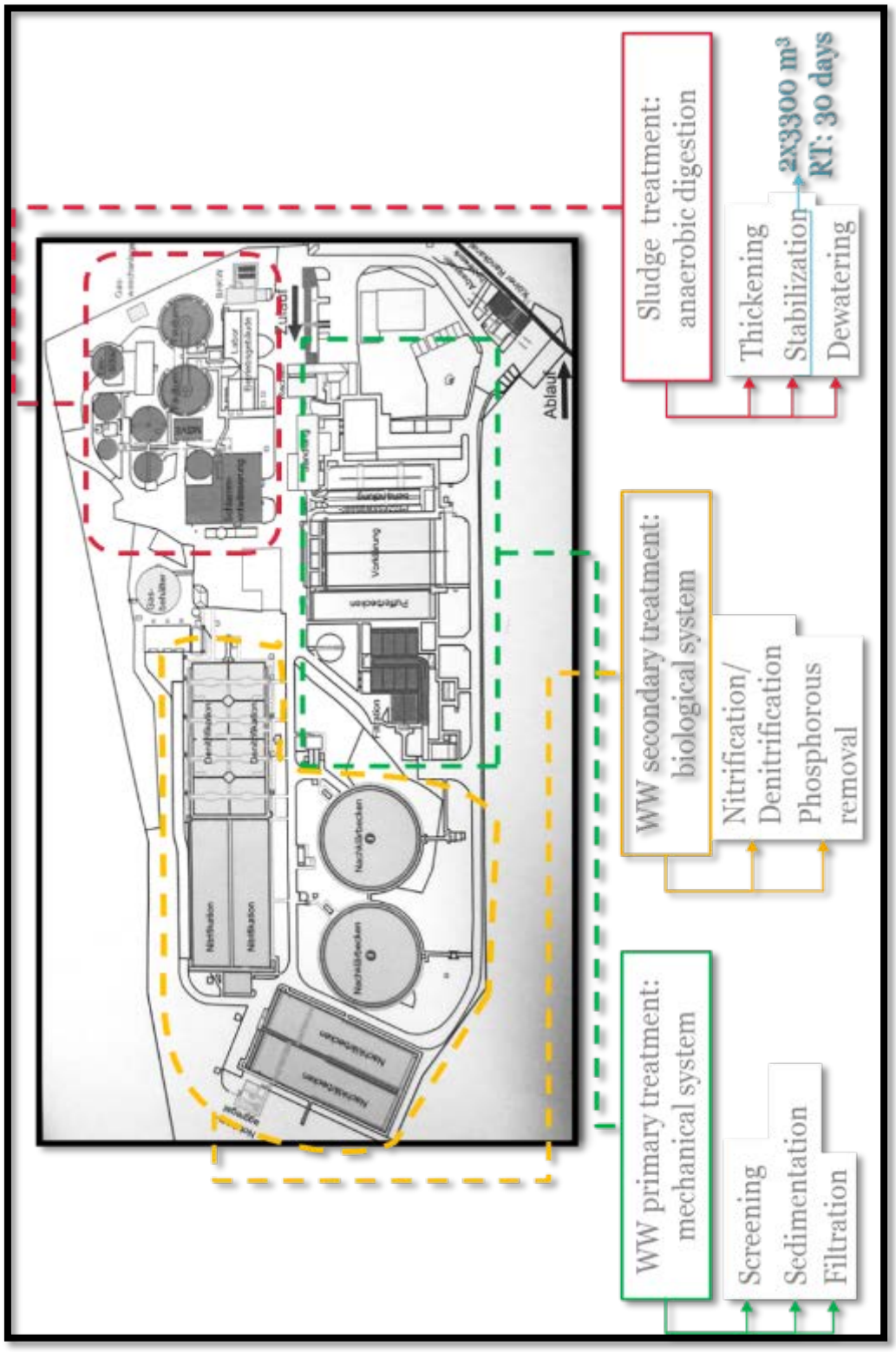
Measurement	Date	REACTOR 2 – Sludge parameters. Table 2/4					
		Organic Acids					
		A	A´	B	Lime reserve	Organic acids	pH
		ml	ml	ml	mg C_aCO_3/l	Mg Hac/l	-
39	18/04/2014	12.7	13.18	0.17	3295	66.1	7.42
40	19/04/2014	12.7	13.18	0.17	3295	66.1	7.42
41	20/04/2014	12.7	13.18	0.17	3295	66.1	7.42
42	21/04/2014	12.7	13.18	0.17	3295	66.1	7.42
43	22/04/2014	13.63	14.1	0.16	3525	57.8	7.39
44	23/04/2014	13.67	14.22	0.18	3555	74.4	7.50
45	24/04/2014	13.66	14.08	0.14	3520	41.2	7.59
46	25/04/2014	12.5	13.12	0.13	3280	32.9	7.46
47	26/04/2014	12.98	13.57	0.125	3392.5	28.75	7.47
48	27/04/2014	12.98	13.57	0.125	3392.5	28.75	7.47
49	28/04/2014	13.46	14.02	0.12	3505	24.6	7.48
50	29/04/2014	13.48	14.03	0.15	3507.5	49.5	7.46
51	30/04/2014	13.76	14.33	0.15	3582.5	49.5	7.46
52	01/05/2014	13.51	14.11	0.215	3527.5	103.45	7.55
53	02/05/2014	13.26	13.89	0.28	3472.5	157.4	7.64
54	03/05/2014	12.655	13.145	0.335	3286.25	203.05	7.53
55	04/05/2014	12.655	13.145	0.335	3286.25	203.05	7.53
56	05/05/2014	12.05	12.4	0.39	3100	248.7	7.41
57	06/05/2014	11.85	12.24	0.44	3060	290.2	7.40
58	07/05/2014	14	14.53	0.32	3632.5	190.6	7.43
59	08/05/2014	13.6	14.27	0.19	3567.5	82.7	7.46
60	09/05/2014	13.18	13.83	0.27	3457.5	149.1	7.49
61	10/05/2014	13.66	14.245	0.24	3561.25	124.2	7.57
62	11/05/2014	13.66	14.245	0.24	3561.25	124.2	7.57
63	12/05/2014	14.14	14.66	0.21	3665	99.3	7.64
64	13/05/2014	14.99	15.59	0.3	3897.5	174	7.53
65	14/05/2014	13.5	14.01	0.25	3502.5	132.5	7.66
66	15/05/2014	14.19	14.67	0.49	3667.5	331.7	7.72
67	16/05/2014	14.12	14.6	0.35	3650	215.5	7.60
68	17/05/2014	14.24	14.75	0.315	3687.5	186.45	7.70
69	18/05/2014	14.24	14.75	0.315	3687.5	186.45	7.70
70	19/05/2014	14.36	14.9	0.28	3725	157.4	7.79
71	20/05/2014	14.61	15.29	0.39	3822.5	248.7	7.76
72	21/05/2014	14.95	15.55	0.23	3887.5	115.9	7.75
73	22/05/2014	13.87	14.55	0.28	3637.5	157.4	7.75
74	23/05/2014	15.08	15.73	0.23	3932.5	115.9	7.80
75	24/05/2014	14.325	14.815	0.29	3703.75	165.7	7.70
76	25/05/2014	14.325	14.815	0.29	3703.75	165.7	7.70

Annex 9. SLUDGE PARAMETERS - Reactor 2.

Measurement	Date	REACTOR 2 – Sludge parameters. Table 3/4					
		Organic Acids					
		A	A´	B	Lime reserve	Organic acids	pH
		ml	ml	ml	mg C_aCO_3/l	Mg Hac/l	-
77	26/05/2014	13.57	13.9	0.35	3475	215.5	7.60
78	27/05/2014	15.06	15.67	0.22	3917.5	107.6	7.60
79	28/05/2014	14.78	15.26	0.28	3815	157.4	7.60
80	29/05/2014	14.56	14.985	0.27	3746.25	149.1	7.60
81	30/05/2014	14.56	14.985	0.27	3746.25	149.1	7.60
82	31/05/2014	14.56	14.985	0.27	3746.25	149.1	7.60
83	01/06/2014	14.56	14.985	0.27	3746.25	149.1	7.60
84	02/06/2014	14.34	14.71	0.26	3677.5	140.8	7.60
85	03/06/2014	13.87	14.44	0.15	3610	49.5	7.70
86	04/06/2014	16	16.69	0.19	4172.5	82.7	7.70
87	05/06/2014	15.15	15.83	0.16	3957.5	57.8	7.60
88	06/06/2014	15.85	16.43	0.18	4107.5	74.4	7.50
89	07/06/2014	15.925	16.565	0.19	4141.25	82.7	7.55
90	08/06/2014	15.925	16.565	0.19	4141.25	82.7	7.55
91	09/06/2014	15.925	16.565	0.19	4141.25	82.7	7.55
92	10/06/2014	16	16.7	0.2	4175	91	7.60
93	11/06/2014	14.02	14.68	0.17	3670	66.1	7.60
94	12/06/2014	14.66	15.16	0.18	3790	74.4	7.65
95	13/06/2014	14.74	15.28	0.17	3820	66.1	7.65
96	14/06/2014	15.035	15.625	0.19	3906.25	82.7	7.65
97	15/06/2014	15.035	15.625	0.19	3906.25	82.7	7.65
98	16/06/2014	15.33	15.97	0.21	3992.5	99.3	7.70
99	17/06/2014	14.77	15.3	0.78	3825	572.4	7.50
100	18/06/2014	14.05	14.87	1.05	3717.5	796.5	7.50
101	19/06/2014	15.505	15.275	0.68	3818.75	489.4	7.55
102	20/06/2014	14.96	15.68	0.31	3920	182.3	7.55
103	21/06/2014	14.665	15.265	0.25	3816.25	132.5	7.55
104	22/06/2014	14.665	15.265	0.25	3816.25	132.5	7.55
105	23/06/2014	14.37	14.85	0.19	3712.5	82.7	7.60
106	24/06/2014	13.95	14.47	0.73	3617.5	530.9	7.50
107	25/06/2014	14.61	15.21	0.35	3802.5	215.5	7.54
108	26/06/2014	14.45	14.93	0.38	3732.5	240.4	7.54
109	27/06/2014	14.985	15.565	0.335	3891.25	203.05	7.55
110	28/06/2014	14.985	15.565	0.335	3891.25	203.05	7.55
111	29/06/2014	14.985	15.565	0.335	3891.25	203.05	7.55
112	30/06/2014	14.985	15.565	0.335	3891.25	203.05	7.56
113	01/07/2014	15.52	16.2	0.29	4050	165.7	7.73
114	02/07/2014	15.295	15.875	0.42	3968.75	273.6	7.68

Measurement	Date	REACTOR 2 – Sludge parameters. Table 4/4					
		Organic Acids					
		A	A´	B	Lime reserve	Organic acids	pH
		ml	ml	ml	mg C_aCO_3/l	Mg Hac/l	-
115	03/07/2014	15.07	15.55	0.55	3887.5	381.5	7.63
116	04/07/2014	11.94	12.3	0.46	3075	306.8	7.51
117	05/07/2014	13.325	13.64	0.44	3410	290.2	7.66
118	06/07/2014	13.325	13.64	0.44	3410	290.2	7.66
119	07/07/2014	14.53	14.98	0.42	3745	273.6	7.81
120	08/07/2014	13.31	14.2	0.15	3550	49.5	7.74
121	09/07/2014	16.37	17.12	0.49	4280	331.7	7.74
122	10/07/2014	15.735	16.425	0.31	4106.25	182.3	7.74
123	11/07/2014	15.1	15.73	0.13	3932.5	32.9	7.73
124	12/07/2014	15.575	15.225	0.15	3806.25	49.5	7.64
125	13/07/2014	15.575	15.225	0.15	3806.25	49.5	7.64
126	14/07/2014	14.05	14.72	0.17	3680	66.1	7.55
127	15/07/2014	14.62	15.12	0.18	3780	74.4	7.59
128	16/07/2014	13.71	14.35	0.6	3587.5	423	7.62
129	17/07/2014	15.78	16.55	0.31	4137.5	182.3	7.63
130	18/07/2014	14.76	15.48	0.32	3870	190.6	7.64
131	19/07/2014	14.76	15.48	0.32	3870	190.6	7.64
132	20/07/2014	14.76	15.48	0.32	3870	190.6	7.64
133	21/07/2014	13.74	14.41	0.33	3602.5	198.9	7.65
134	22/07/2014	15.17	15.97	0.16	3992.5	57.8	7.69
135	23/07/2014	13.36	13.81	0.45	3452.5	298.5	7.57
136	24/07/2014	14.19	14.77	0.46	3692.5	306.8	7.57
137	25/07/2014	15.62	16.41	0.32	4102.5	190.6	7.57
138	26/07/2014	15.1	15.685	0.455	3921.25	302.65	7.57
139	27/07/2014	15.1	15.685	0.455	3921.25	302.65	7.57
140	28/07/2014	14.58	16.41	0.59	4102.5	414.7	7.44
141	29/07/2014	16.2	16.82	0.48	4205	323.4	7.60

Annex 10. Plant view of the treatment plant in Bergisch Gladbach.



Annex 11. Gas production for R1 and R2 during the first 30 days of phases 1, 2 and 3.

Days	R1 nVolume (l)			R2 nVolume (l)		
	Phase 1	Phase 2	Phase 3	Phase 1	Phase 2	Phase 3
1	0	15.88	9.27	0.00	14.00	11.13
2	1.86	29.08	20.38	0.00	30.03	22.25
3	4.89	49.13	38.02	0.00	47.21	28.70
4	9.14	63.55	53.74	4.75	61.61	37.93
5	21.39	78.86	62.01	13.27	76.90	55.36
6	34.55	98.98	74.98	23.70	98.00	64.60
7	38.33	117.90	85.19	35.14	115.05	76.65
8	40.48	135.92	94.52	37.02	130.22	85.93
9	45.66	150.70	103.87	48.40	144.96	97.11
10	46.59	163.75	114.92	52.14	158.99	108.17
11	56.75	174.77	122.25	60.49	173.71	117.34
12	69.67	187.77	135.08	67.91	187.66	130.21
13	84.48	202.72	146.14	79.15	206.42	142.19
14	94.02	212.03	157.18	92.44	221.42	153.25
15	101.57	225.03	166.39	104.71	234.43	166.20
16	112.92	241.78	175.65	117.97	253.25	177.34
17	123.67	262.38	183.10	129.84	268.22	188.51
18	135.90	275.54	192.39	144.93	281.34	201.50
19	152.89	288.76	207.17	161.91	296.37	215.39
20	167.11	299.15	219.24	176.11	307.66	227.47
21	175.66	313.30	228.53	186.55	323.60	238.64
22	184.90	326.39	239.77	201.35	343.36	248.88
23	193.19	339.31	250.97	208.70	357.27	260.95
24	198.70	354.11	262.11	213.28	368.38	268.33
25	202.38	368.87	276.91	216.95	386.88	279.39
26	206.08	380.86	287.91	220.64	396.10	286.70
27	210.71	396.49	298.90	224.33	415.49	294.03
28	215.37	408.44	310.85	228.05	429.29	305.04
29	218.15	419.46	324.64	235.48	442.18	317.91
30	222.37	432.24	333.80	246.77	455.93	325.22

Annex 12. Energy values given as an input to the sludge during phase 2.

Time (s)	Energy (W)			
	Measurement 1	**Measurement 2**	**Measurement 3**	**Average**
0	440.3	397.25	415	**417.5**
15	367.08	295.1	361.6	**341.3**
30	310.99	258.08	302.84	**290.6**
45	281.48	227.8	281.86	**263.7**
60	192.8	223.74	253.72	**223.4**
75	282.72	235.94	268.5	**262.4**
90	292.8	244	272.25	**269.7**
105	291.8	246.34	270	**269.4**
120	291.5	244.08	274.5	**270.0**
Average	**305.72**	**263.59**	**300.03**	**289.8**

Annex 13. Energy values given as an input to the sludge during phase 3.

Time (s)	Energy (W)			
	Measurement 1	**Measurement 2**	**Measurement 3**	**Average**
0	614.72	597.01	606.09	**605.9**
15	569.52	560.69	571.7	**567.3**
30	560.5	542.53	567.26	**556.8**
45	549	528.84	562.75	**546.9**
60	569.25	551.44	567.26	**562.7**
75	560.48	567.5	562.74	**563.6**
90	574.05	560.69	560.48	**565.1**
105	574.04	562.5	558	**564.8**
120	567.5	558.22	562.74	**562.8**
Average	**571.01**	**558.82**	**568.78**	**566.2**

Annex 14. Example calculation of different parameters.

Volatile solids consumed in the reactor.

$$\text{Volatile solids consumed}_{\text{Reactor}}(\text{g/d}) = \text{Volatile solids}_{\text{inflow}}(\text{g/d}) - \text{Volatile solids content}_{\text{Reactor}}\ (\text{g/d})$$

If,

Volatile solids inflow = 50.92 (g/d)

Volatile solids content from the Reactor = 7.81 (g/d)

Then,

$$\text{Volatile solids consumed}_{\text{Reactor}}\ (\text{g/d}) = 50.92 - 7.81 = 43.11\ (\text{g/d})$$

Conversion of volatile solids in the inflow into biogas.

$$\text{Conversion of volatile solids into biogas (Lgas/Kg volatile solids inf)} = \frac{\text{nVolume (l/d)}}{\frac{\text{Volatile solids inf. (g/d)}}{1000}}$$

If,

nVolume: 13.17 (l/d)

Volatile solids inflow = 50.92 (g/d)

Then,

$$\text{(Lgas/Kg volatile solids inf)} = \frac{13.17\ (\text{l/d})}{\frac{50.92(\text{g/d})}{1000}} = 258.62\frac{\text{Lgas}}{\text{Kg volatile solids inf}}$$

The same calculation applies for the conversion of volatile solids consumed in the reactor.

Conversion of volatile solids in the inflow into energy.

$$\left(\frac{(\mathrm{Wh/l})}{\mathrm{Kg\ volatile\ solids\ inf}}\right) = \frac{\mathrm{Lgas}}{\mathrm{Kg\ volatile\ solids\ inf}} * 10\frac{\mathrm{Wh}}{\mathrm{l}} * \frac{\%\mathrm{CH_4}}{100}$$

If,

Lgas/Kg volatile solids in the inflow: 258.62 (l/kg)

% CH_4: 53%

Then,

$$\left(\frac{(\mathrm{Wh/l})}{\mathrm{Kg\ volatile\ solids\ inf}}\right) = 258.62\frac{\mathrm{Lgas}}{\mathrm{Kg\ volatile\ solids\ inf}} * 10\frac{\mathrm{Wh}}{\mathrm{l}} * \frac{53}{100}$$

$$= 1370.68\ \frac{(\mathrm{Wh/l})}{\mathrm{Kg\ Volatile\ solids\ inf}}$$

The same calculation applies for the conversion of volatile solids consumed in the reactor.