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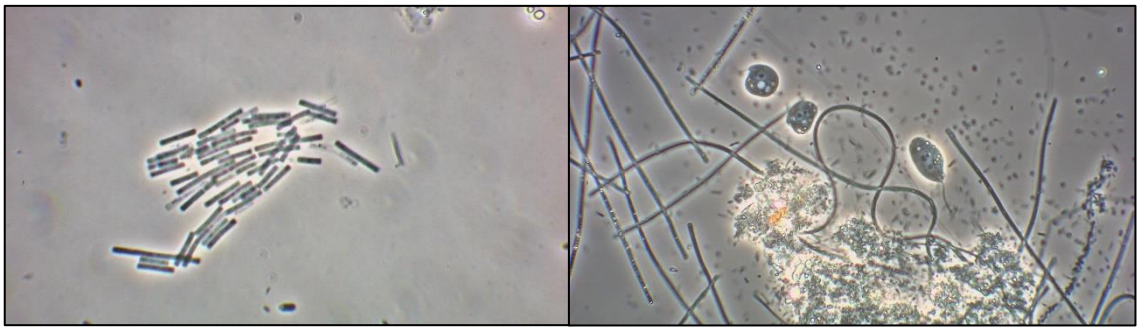

Verification and optimization of combined anaerobic-aerobic biological wastewater treatment in decentralized application

Bachelor`s thesis

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Abstract

Several measures were taken to improve the effluent quality and the digestion process of the de-centralised anaerobic-aerobic wastewater treatment plant “IWB Stöckacker Süd” with a two-chamber septic tank followed by 8 HRAR and an aerobic treatment. Structural and biological modifications have been carried out in the treatment plant to improve effluent quality and to avoid scum formation.

The structural modification of an “*InnerTube Digester*” in the septic tank did not work due to high accumulation of scum and needed to be removed. Through adding specialised microbes from *Bio-clean* the structure of the scum in the septic tank could be changed to a better digestible one but total avoidance of scum formation was not achieved. Presents of solids wastes like wet wipes and tampons supported the formation of scum. Biological modification in the anaerobic treatment showed positive results in the septic tank and first compartment of the HRAR. An increase of COD_{rem} rate from 42% to 66% was achieved. But effluent value from anaerobic treatment could not be decreased under 250mg/L COD because of hardly degradable compounds. Approaches in changing methane fermentation into dark fermentation were taken and the shift to dark fermentation could be recognized by increased VFA production.

Biological modification with *Bioclean TM* in the aerobic reactor increased the COD_{rem} rate from 50% to 65% and showed the presents of bio-flocs. An effluent COD value of 88mg/L was achieved by the combination of anaerobic and aerobic biological modification.

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Glossary

∆G°`	Gibbs Energy/ Free enthalpy
AOP	Advanced Oxidation Process
ABR	Anaerobic Baffled Reactor
AnWWTP	Anaerobic Wastewater Treatment Plant
atm	Standard atmosphere
BOD	Biological Oxygen Demand
COD	Chemical Oxygen Demand
DO	Dissolved Oxygen
FOG	Fat, Oil and Grease
HRT	Hydraulic Retention Time
LCFA	Long Chain Fatty Acids
O&M	Operations and Maintenance
PSF	Pressure Sandfilter
RT	Room Temperature
SRT	Sludge Retention Time
TSS	Total Suspended Solids
VFA	Volatile Fatty Acids
WWTP	Wastewater Treatment Plant

1 Introduction

Due to climate change, water gets to a scare resource. Not only in warm countries where draughts and low water availability are known also in countries which has good availability of water, like Switzerland can experience water scarcities. In the last past years in Switzerland due to hot and dry summers, water scarcity occurred. In some region of Switzerland water shortages occurred were agricultural fields could not be irrigated (Fuhrer, et. al., 2016).

The demand of water does not only increase in agricultural areas, also urban areas due to growing populations and need of water for irrigation of green spaces in the cities (McDonald et al., 2011). To overcome this problem the water management needs to be reconsidered. As right now for irrigation drinking water which are poor on nutrient are used and water which has been consumed are cleaned with high demand on energy so that it can be discharged into a water body. In times of increasing water scarcity this water management is not sustainable.

An option for sustainable water management in times of water scarcity is the reuse of treated wastewater for irrigation as first water is gained and second it is high on nutrients. To achieve a sustainable water circuit in the city of Bern a decentralised wastewater treatment plant was built, where the concept is to reuse the treated wastewater for irrigation.

The focus on this bachelor thesis is on this decentralised wastewater treatment plant in the settlement "Stöckacker Süd" in the city of Bern. To achieve the reuse of water from wastewater the treatment of the wastewater needs to be improved in this treatment plant. Therefore, the combination of anaerobic and aerobic treatment is verified and optimized in this bachelor thesis. The main focus in this thesis on the anaerobic treatment.

1.1 Pilot project "IWB Stöckacker Süd"

2017 in the city of Bern a new settlement called "Stöckacker Süd" was established by the property administration of city Bern (Immobilien Stadt Bern (ISB)). This settlement, which is built in the district of Bümpliz, consists of three housing blocks that includes 150 flats, a nursery and a bistro called "*Becanto"*. The concept of Stöckacker Süd is based on the "2000-watt norms" approach. As a first settlement of the city of Bern Stöckacker Süd uses renewable energy sources and technologies which are energy efficient and produce clean emissions. The proprietor, "Immobilien Stadt Bern" (ISB), took another step towards more sustainable urban living systems by building a decentralized wastewater treatment system for one of the three housing blocks. The decentralized wastewater treatment system is a pilot project, called "Integrated use of water and biomass utilisation for Stöckacker Süd" (IWB Stöckacker Süd), with the aim to verify if the system is sustainable for urban areas under real-life conditions. IWB Stöckacker Süd is the first top-down project of a decentralised wastewater treatment and reuse system for domestic wastewater in an urban site in Switzerland.

Figure 1 Settlement "Stöckacker Süd"
Source: vistadoc 2017

1.2 Description of the decentralized wastewater treatment system "IWB Stöckacker Süd"

The IWB Stöckacker Süd decentralized wastewater treatment system was designed and constructed by the company *Autark Engineering AG*. *Autark Engineering AG* is specialised in decentralised wastewater treatment and water reuse approaches, with successfully implemented projects in India, Nepal, North Korea and Papua New Guinea.

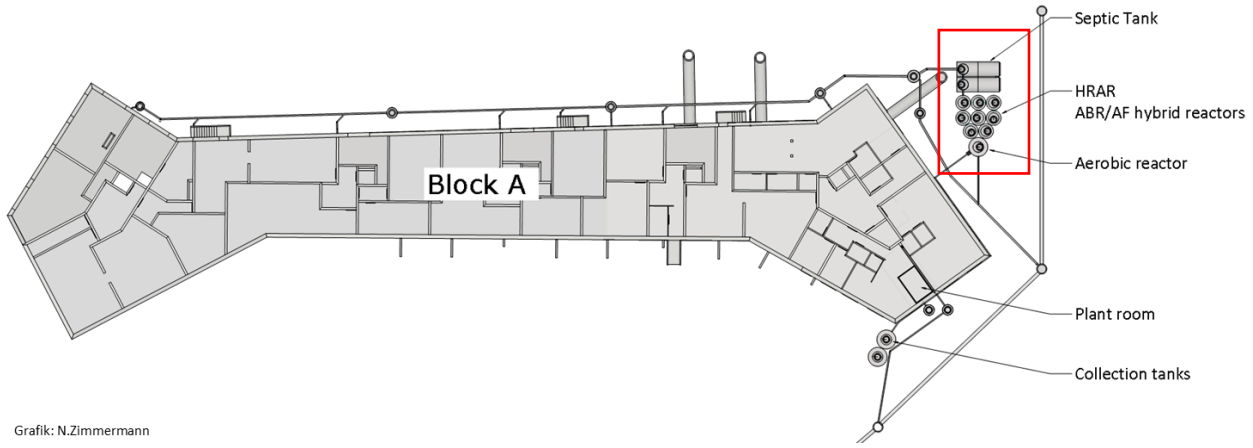


Figure 2 CAD Overview of housing block A with decentralized wastewater treatment unit. Source: Autark Engineering AG

This anaerobic wastewater treatment plant (AnWWTP) is designed for the wastewater of Block A in Stöckacker Süd (Figure 2). The AnWWTP receives the wastewater of 59 apartments, occupied by roughly 120 habitants, a bistro and a day nursery. It is estimated that mixed wastewater (greywater and blackwater) of 15m^3 is produced per day. The treatment of the AnWWTP consists of a two chamber septic tank, followed by a series of eight high rate anaerobic reactors (HRAR) and an aerobic reactor. All these biological reactors are placed as concrete tanks under the pavement next to the building A (Figure 3). After the aerobic treatment there are some polishing steps installed in the plant room in the basement of the building together with all electrical and mechanical equipment of the system. The final effluent can be stored in two underground collection tanks on the south side of the block A. All Biological reactors as well as the collection tanks have a fail-save overflow into the public sewer network. The wastewater from building Block A can be by-passed directly into the public sewer network. Tanks to this the reactor can be taken out of the line for structural changes or any kind of modification.

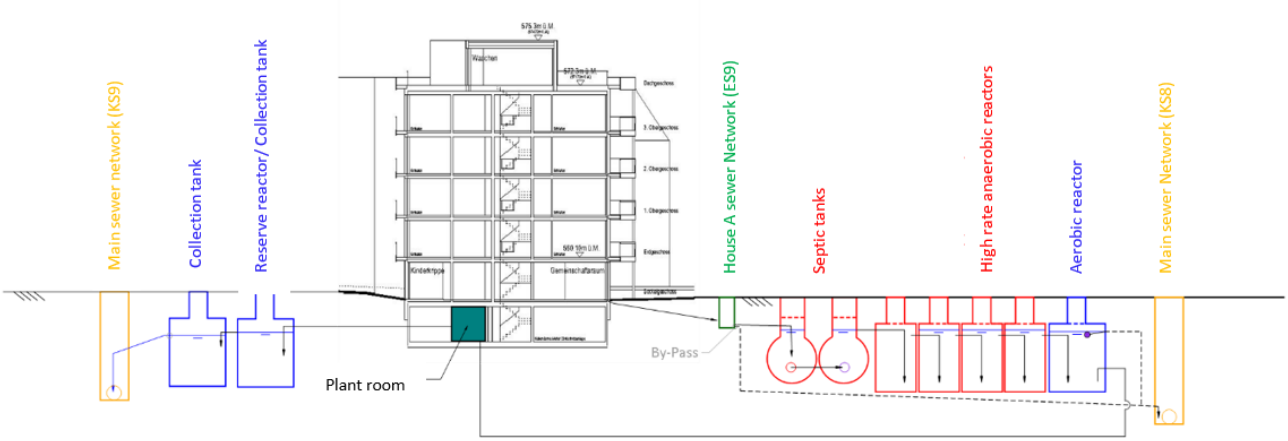


Figure 3 Side view of "Stöckacker Süd A" with WWTP
Source: Autark Engineering AG, modified

1.3 Technical layout of the treatment system

The first biological treatment step includes two different anaerobic treatment systems - Septic tank and HRAR as shown in Figure 4. The second biological treatment is an aerobic treatment system. After the biological treatment the wastewater is polished physically and chemically in the plant room and from there the water can be stored in the collection tanks.

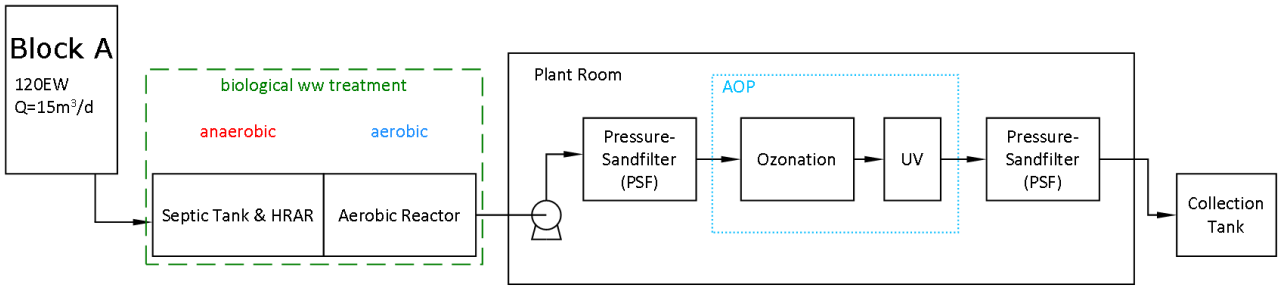


Figure 4 Technical system layout of WWTP "IWB Stöckacker Süd"
Source: Autark Engineering AG

1.3.1 Septic tank

Primary anaerobic treatment of the wastewater occurs in the two chamber septic tank (P1 and P2) (Figure 5). In this step solids or heavy particle sink to the bottom and form a sludge layer. With the time the settled organic matter in the sludge layer will be anaerobically degraded to CO_2, CH_4 and H_2S (Chernicharo, 2007). Fat, oil and grease (FOG) and other lighter material floats on the top and form a scum layer. In this way a big part of the organics is separated from the wastewater or digested, and the sewage can flow to the next treatment step. If the scum accumulates it needs to be pumped out periodically, this can vary strongly depending on how fast the scum grows. On good working conditions septic tanks are able to remove 30-50% of BOD (biological oxygen demand) and 40 to 60% of TSS (total suspended solids) (Tilley et al., 2008). This septic tank in "Stöckacker Süd" has

no freeboard as normally known for septic tanks, the whole tank is flooded. With this design forming of scum should be prevented and if scum forms then only were the inlet is (E. C. Jowett, 2009).

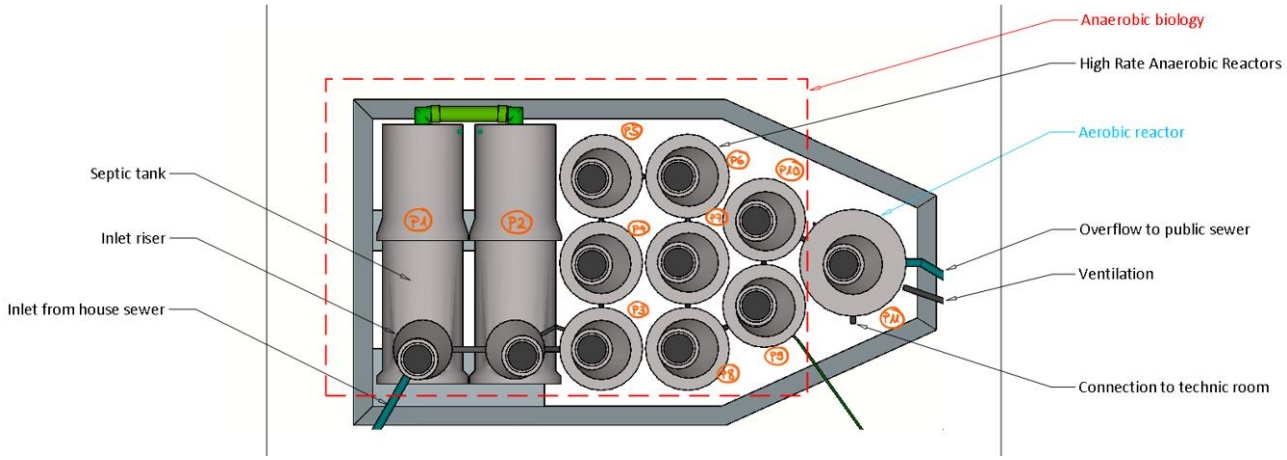


Figure 5 WWTP "IWB Stöckacker Süd" reactor plan
Source: Autark engineering AG

1.3.2 High rate anaerobic reactors (HRAR)

As a secondary anaerobic treatment step eight HRAR are installed. This HRAR are hybrids of an anaerobic baffled reactor (ABR) and an anaerobic filter (AF) (Figure 6). On this ABR/AF-hybrid system the sewage flows first through the sludge on the bottom and then up through some layer of filter material. In the sludge and in the biofilter are microbes which degrade organic compounds. As filter material are reticulated polyurethane cubes are used. Those cubes enable a big surface area where a biofilm of anaerobic bacteria can grow and digest organic matter which passes through. ABR and AF are able to reduce about 65-90% of COD (chemical oxygen demand) and 80-90% TSS, so in combination the digestion rate could be even higher (Tilley et al., 2008). After the anaerobic digestion the wastewater goes directly to the aerobic treatment.

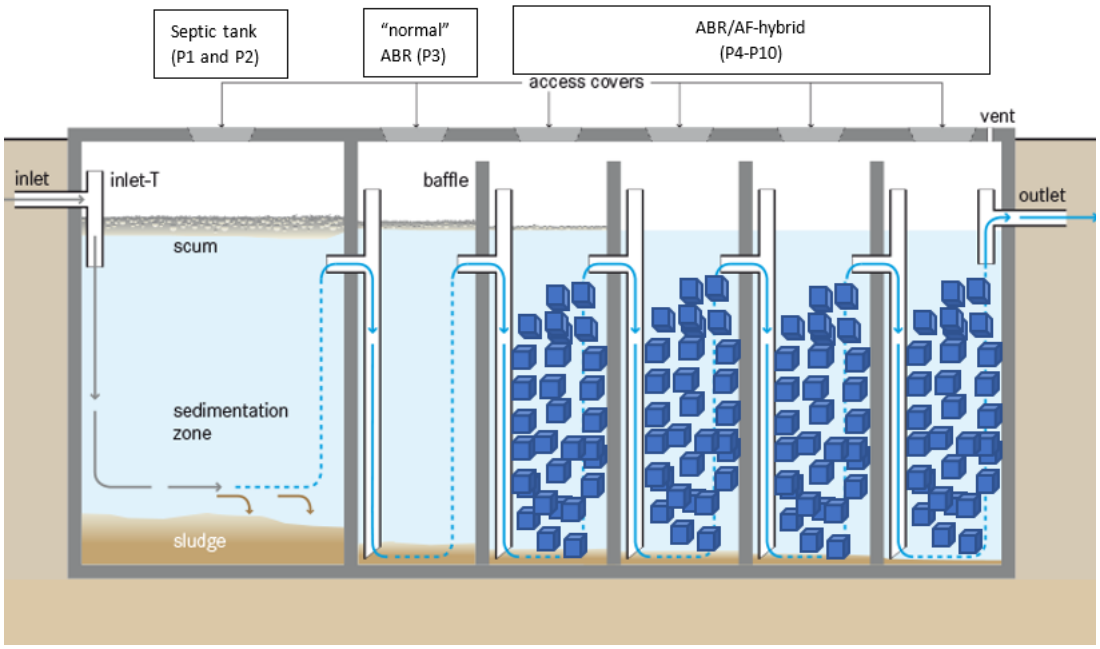


Figure 6 Septic tank and ABR/AF-hybrid reactor; Source: (SSWM, 2019) modified

1.3.3 Aeration tank

As a post treatment of the anaerobic treatment the wastewater is treated aerobically. The aerobic reactor P11 works as an integrated fixed film activated sludge (IFAS) reactor. In the reactor there are five fine bubble diffusers evenly distributed at the bottom of the tank for a constant aeration. The air is pumped from the technical room by membrane pumps with a capacity of 300mbar pressure head. The reactor is about one third filled with fixed film material (reticulated polyurethane cubes) which enables a higher surface area for the growth of biofilms in Figure 7. Another advantage of the biofilm on and in the cubes are that they combine aerobic, anaerobic and anoxic zones (Stauffer & Spuhler, 2019). Aerobic treatment was used as final stage to:

- Reduce residual organic compounds to lower the BOD, COD and TSS.
- Reduce hydrogen sulphide (H_2S). Hydrogen sulphide is produced during the anaerobic degradation process and has a strong smell like rotten eggs. To that hydrogen sulphide is poisonous for human and animal in high concentrations and is very corrosive.
- Convert ammonia to nitrate by nitrification.
- Degrade substances which are not easily degradable by anaerobic digestion like anionic surfactants or long chain fatty acids (LCFA)

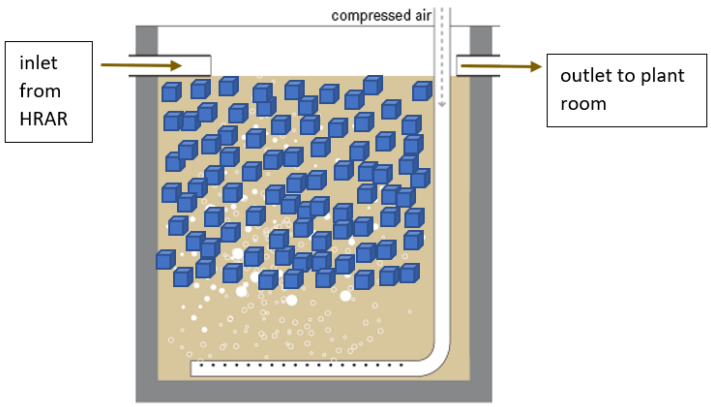


Figure 7 IFAS reactor with reticulated polyurethane cubes as filter material
Source: Tilley. et al (2014) modified

1.3.4 Polishing

After the biological treatment the water is pumped to the plant room for polishing (Figure 8). First the water flows through a pressure sand filter (PSF) for the reduction of suspended solids like bio-flocs from the aerobic treatment. After PSF the water goes through an ozonation followed by an UV-radiation. This is called an advanced oxidation process (AOP). As a final step the water is filtered through a second PSF. As the polishing step is not part of this bachelor thesis only short information are given about this step.

Figure 8 Plant room with two PSF, AOP and all electrical equipment
Source: Autark Engineering AG

1.4 Advantages and disadvantages of combined anaerobic aerobic biological treatment

This combination of anaerobic and aerobic biological treatment in a decentralized WWT with domestic wastewater as implemented in "Stöckacker Süd" is the first of this type in Switzerland. The combination of anaerobic treatment with aerobic posttreatment offers some promising advantages over "pure" aerobic treatment systems since it enables resource recovery from wastewater. In the same

time leading to substantial energy savings, compared with conventional wastewater treatment technologies (McCarty & Smith, 1985). During aerobic treatment high amount of organics are converted into new cell material which remain as sludge, in contrast with anaerobic treatment 90% of the excess sludge can be reduced as shown in Figure 9 (Van Lier, Mahmoud, & Zeeman, 2012). Another important aspect is that the through the conventional WWT only 50% of the waste is stabilised the other 50% remains as sludge and needs to be stabilised with further steps, but through anaerobic treatment 80-90% of the waste is stabilised (Lettinga, 1995). One of the key points for a decentralized WWT is that very low operation and maintenance (O&M) is needed and this is given with anaerobic WWT if they work well (Speece, 1983).

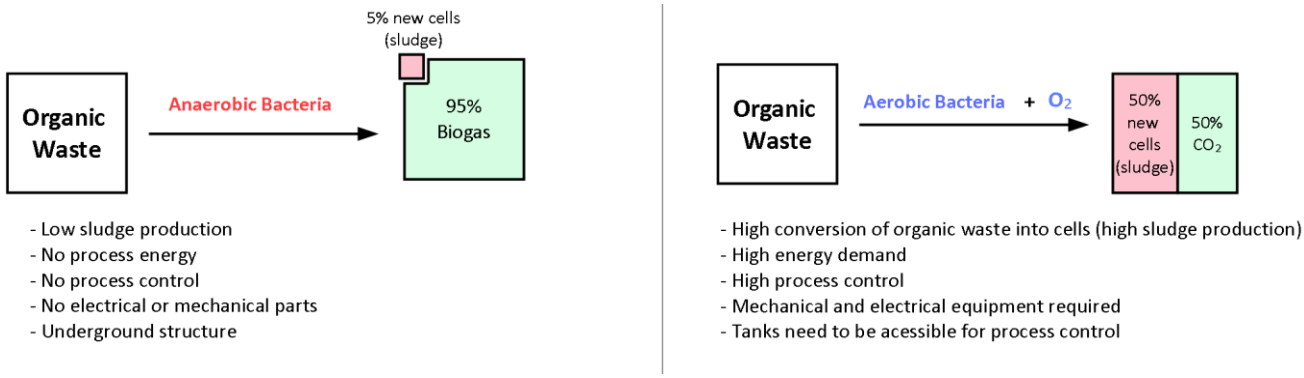


Figure 9 Adventages of anaerobic WWT in comparison to aerobic WWT
Source: Autark Engineering AG

Effluent quality of only an anaerobic treatment often does often not fulfil the national discharge norms in terms of organic pollution (TSS, COD and BOD) and nutrients (nitrogen). Therefore, posttreatment may be needed. For which anaerobic treatment seems to be a viable treatment. Aerobic treatment can reduce residuals which are produced or not digested by anaerobic treatment which are listed in chapter 1.3.3 Aeration tank. With the combination of anaerobic and aerobic biological treatment energy, O&M and biomass can be reduced and saved and still the required national discharge norms can be achieved.

Beside the advantages of anaerobic treatment there are also some drawbacks. Start-up of an anaerobic reactor does need lot of time that can take one month or even more because of the slow growth rate of methanogenic bacteria (McCarty, 1964). And because of the slow growth rate anaerobic treatment do need time after changes are taken. But if seed material are used then the start-up can be speeded up (Chernicharo, 2007). Anaerobic microorganisms are quite susceptible to a variety of xenobiotic compounds (Lettinga, 1995). And as already mentioned anaerobic treatment often requires a posttreatment to reduce odour, nutrients and organic compounds (Garuti, Dohanyos, & Tilche, 1992).

2 Background information

2.1 Anaerobic Digestion

Anaerobic digestion is a natural degradation of organic compounds in absence of oxygen. Where complex organic matter is converted into final products, like methane, carbon dioxide, hydrogen sulphide, ammonia, water and biomass (Van Lier et al., 2012). The whole degradation is caused by a complex consortium of facultative and obligate anaerobic microorganisms. This whole system can be considered as an ecosystem where several microorganisms work interactively together. The conversion product of one organism will be the substrate for another one – a syntrophy. The whole process can be divided in four parts: hydrolysis, acidogenesis, acetogenesis and methanogenesis as shown in Figure 10.

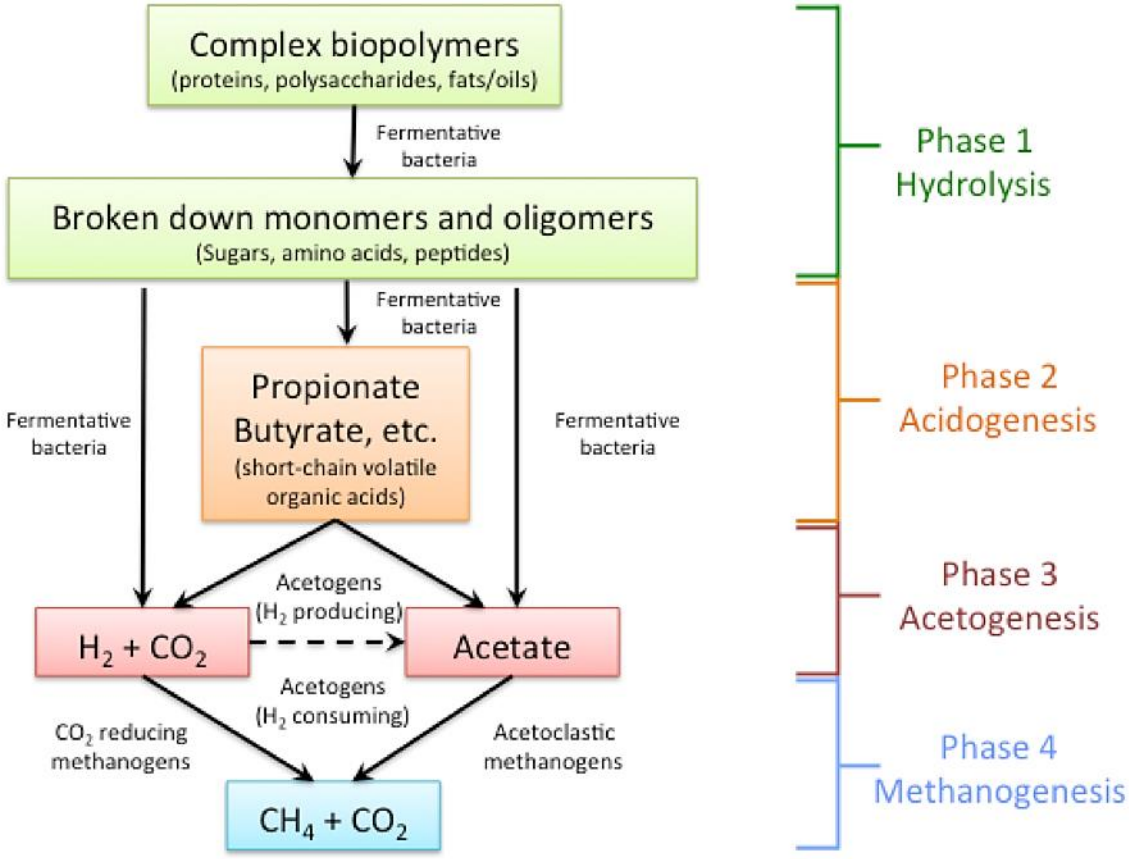


Figure 10 Scheme of anaerobic digestion
Source: https://www.e-education.psu.edu/egee439/node/727

2.1.1 Hydrolysis

Hydrolysis is the first step in the anaerobic digestion process. In this part organic polymers like carbohydrate, biopolymer, proteins and fats are fermented in smaller units (monomers). This is done by the exoenzymes produced by microbes. The small units digested by the exoenzymes are then transported into the cells of microbes where it is than further metabolized (Breure, 1986).

As said excreted enzymes from microbes are responsible for the hydrolysis of biopolymers. In the following paragraph are shown which enzymes hydrolyse which educts:

- A-glycosidic carbohydrates like starch, sucrose, glycogen and amylose are easily hydrolysed by amylases. Pectin a similar polysaccharide can also be hydrolysed by amylase or pectinase (Breure, 1986).
- Cellulose main part of plants and plant waste can not be so readily hydrolysed like the polysaccharide mentioned before, due its structure of very long chains of D-glucose units linked together through B-(1,4) bonds. But some protozoa and bacterial species like *Clostridium* are known to hydrolyse cellulose into the disaccharide cellobiose, which then can be fermented in the next process step (Breure, 1986).
- Hydrolysis of proteins are done by proteases and peptidases. These enzymes are partly cell wall-bound or free in the reactor fluid. Many enzymes degrade specific amino acids in the polypeptide chain, so the hydrolysis of proteins depends on its amino acid composition. The solubility of the proteins does have an effect on the hydrolysis, so soluble proteins can be hydrolysed faster than insoluble ones (Abdel-Halim, 2005).
- A difficult compound to digest in anaerobic digestions are fats. Again, some *Clostridium* species are known to hydrolyse glycerides by excreting lipases (Breure, 1986). The lipids are then transformed into long chain fatty acids (LCFA) and glycerine (Abdel-Halim, 2005). A problem of degradation of lipids is that they are insoluble in water, so because of their hydrophobic behaviour they attach on particles which makes it not easy for bacteria and enzymes to reach the lipids totally (Sanders, 2001).

Some very important factors in the hydrolysis are the structure of the substrate and its accessibility for the hydrolytic enzymes. Formation of complexes with other compounds for examples cellulose, which is easy to degrade but when it forms a lignocellulosic complex with lignin, the biodegradability of cellulose gets harder (Sanders, 2001).

2.1.2 Acidogenesis

The soluble products from the hydrolysis are converted inside the cells of fermentative acidogenic bacteria into much simpler compounds (Chernicharo, 2007). Sugars, amino acids and fatty acids are converted into volatile fatty acids (VFA) like acetic, propionic, formic, lactic and butyric acid and alcohol, acetate, CO_2, ammonia, H_2S, H_2 and new cell material (Abdel-Halim, 2005). For the acidogenesis a large and diverse group of fermentative bacteria are responsible (Chernicharo, 2007). In the whole anaerobic digestion process acidogenesis is the most rapid conversion step. If looked with the Gibbs Energy or free enthalpy ($\Delta G°`$) acidogenesis is the highest of all other reactions. The bacterial growth rate is ten to twentyfold higher and fivefold higher bacterial yields and conversion rates compared to methanogens. This is the reason why a reactor could get sour. If the methanogens

are inhibited and therefore do not reduce H_2 and because of that more VFA will accumulate and lead to decrease the pH (Van Lier et al., 2012).

2.1.3 Acetogenesis

The products which were produced during the acidogenesis phase are converted in this phase further to acetic acid, hydrogen and carbon dioxide by acetogenic bacteria. Most important substrates for acetogenic bacteria are propionate and butyrate, those are the key-intermediates in the anaerobic digestion process. Also, other intermediate products like lactate, ethanol, methanol and even hydrogen and carbon dioxide are converted to acetic acid during the acetogenic process. The products which acetogenic bacteria produce: acetic acid, hydrogen and carbon dioxide, are substrates for methanogenic bacterias (Van Lier et al., 2012).

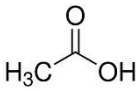


Figure 11 Structure of acetic acid Source: www.chemkits.eu

As acetogenic bacteria are obligate hydrogen producers, during the formation of acetic acid a large amount of hydrogen is produced, which leads the pH to decrease (Chernicharo, 2007). But in other hand the acetogenic metabolism is inhibited by high concentrations of hydrogen, which why the hydrogen level has to be kept low. Conversation of ethanol, butyrate, propionate and some LCFAs, do not occur under standard conditions because of positive $\Delta G°`$ whereby the bacterial energy yield is negative. But at low hydrogen partial pressure ($10^{-4} – 10^{-6}$ atm) these reactions occur favourable and will yield energy for acetogenic bacteria. In a stabilised digestion condition methanogenic bacteria and sulphate reducing bacteria effectively take up the hydrogen and do keep the hydrogen partial pressure low. That's why the syntrophic interaction between the hydrogen producing acetogenic bacteria and hydrogen consuming methanogenic bacteria is crucial (Van Lier et al., 2012).

2.1.4 Methanogenesis

Methanogenesis is the last stage of the anaerobic digestion where organic compounds are converted to methane and carbon dioxide by methanogenic archaea. This is the main stage where the influent COD is converted to methane and carbon dioxide and leaves the system in gaseous form. Methanogenic bacteria are obligate anaerobes and do use only a narrow spectrum of substrates such as acetic acid, hydrogen and carbon dioxide, methylamines, methanol, formic acid and carbon monoxide (Van Lier et al., 2012). There are two main groups of methanogenic microorganisms:

- Acetate-using microorganisms (aceticlastic methanogens)
  ➔ Produces methane form acetic acid or methanol

- Hydrogen-using microorganisms (hydrogenotrophic methanogens)
  ➔ Produces methane from hydrogen and carbon dioxide

70% of the produced methane is from acetate and about 30% form hydrogen and carbon dioxide. Acetoclastic methanogens do have a very low growth rate, doubling times of several days or even more. That is why anaerobic reactors need a long start-up time with unadapted seed material (Van Lier et al., 2012)(Abdel-Halim, 2005). There are two main genus which are known for the conversation of acetate to methane: *Methanosaeta spp.* and *Methanosarcina spp.*. *Methanosarcina spp.* uses a relative wide spectrum of substrates: acetate, hydrogen and carbon dioxide, methylamines, methanol and formate, while *Methanosaeta spp.* only uses acetate. *Methanosarcina spp.* prefers acetate concentration above 10^{-3} M while *Methanosaeta spp.* is more abundant below this concentration. *Methanosaeta spp.* is very important for the formation of granules or biofilms like in sludge bed systems or anaerobic filter systems through their filamentous characteristics they help to create these structures (Chernicharo, 2007; Van Lier et al., 2012).

Almost all well-known methanogenic species are known to use hydrogen and carbon dioxide to produce methane. Acetoclastic and hydrogenothrophic methanogenic organisms are very important for the whole anaerobic digestion, as they are consuming hydrogen and keeping so the hydrogen partial pressure low and avoiding an inhibition of the system (Chernicharo, 2007).

2.2 Inhibition and important factors of anaerobic treatment

2.2.1 Temperature

Environmental conditions do have an effect on microorganisms such as temperature. Temperature is an important factor for microbial growth. Bacteria are classified in different groups depending according to temperature (Abdel-Halim, 2005):

- Psychrophilic bacteria: <20°
- Mesophilic bacteria: 20-40°C
- Thermophilic bacteria: 45-70°C and above

The optimum range for anaerobic bacteria is in the mesophilic range 30-35°C and another in the thermophilic range 50-55°C (Chernicharo, 2007). But also at low temperature (15°C) anaerobic digestion can happen efficient but depending on the whole system and the treated wastewater (Barber & Stuckey, 1999). Important is that there are no sudden changes in temperature as hydrolysis is very sensitive to temperature fluctuation (Van Lier et al., 2012).

2.2.2 pH

Another important environmental factor is pH. Anaerobic digestion process operate at near neutral process, for methanogenic bacteria a pH range of pH 6.3 and pH 7.8 is recommended (Abdel-Halim, 2005). Important is that there are no sudden pH drops or changes as methanogenic bacteria are

very sensitive to that (Sanders, 2001). Changes in pH do have some direct effects and some indirect effects (Chernicharo, 2007):

- Direct effects: Affecting enzymes activity by changing their protein structure
- Indirect effects: Affecting the toxicity of come compounds

That is why it is important to keep the pH under control and avoid any sudden pH changes.

2.2.3 Sulfide

Sulfide can get into the treatment either through the incoming waste water or through biological production when sulfates or other sulfur containing inorganic compounds are reduced (McCarty, 1964). The inhibition or toxicity of sulfides does strongly depend on the pH and in which form the sulfides are. Inhibition depends on the concentration of non-dissociated hydrogen sulphide (H_2S) In the medium (Chernicharo, 2007). At the pH were normally anaerobic digestion happens (pH6.5-8) 50% of the sulfides are in the most toxic form (H_2S) and the other 50% in the less toxic form (HS^-) around. A sulfide concentration above 200mg/L of un-ionized H_2S in the medium are toxic for the microbes (McCarty, 1964). But it depends if the hydrogen sulfide is in the gaseous form or dissolved in the water, so the greater the methane production is the larger amount of hydrogen sulfide is in the gaseous form (Chernicharo, 2007). If the influent COD/SO_4 ratio is greater than 10, there will not be any problems with sulfide toxicity in the anaerobic reactor (Chernicharo, 2007).

2.2.4 Ammonia

Ammonia is formed during anaerobic treatment when proteins and urea are degraded (McCarty, 1964). Ammonia is either in form of ammonium ion (NH_4^+) or as free ammonia (NH_3) present in the treatment. Depending on the pH either ammonia ion concentration or free ammonia concentration becomes relevant for inhibitory(Chernicharo, 2007):

- pH ≤ 7.2 ammonia ion concentration becomes inhibitory
- pH > 7.2 free ammonia concentration becomes inhibitory

In Table 1 the effects of different ammonia nitrogen concentration on anaerobic treatment are shown.

Table 1 Effects of different ammonia nitrogen concentration on anaerobic treatment (McCarty, 1964)

Ammonia N concentration (mg/L)	Effect on anaerobic treatment
50 - 200	Beneficial
200 - 1000	No adverse effect
1500 - 3000	Inhibitory for pH >7.4 to 7.6
3000	Toxic

2.2.5 Surfactant

Surfactants are used in many products that we use in daily basis like, washing-, cleaning agents, personal care products, cosmetics and so on. Surfactants are known for their surface activity and that`s why it is used in many cleaning products. The structure of surfactants contains a hydrophobic part, that normally is out of a hydrocarbon-residues with around 10-20 C-atoms. The other part is a hydrophilic head (Pohling, 2015).

There are four different groups of surfactants, depending on the charge of the hydrophilic head the surfactants can be grouped into cationic, anionic, not ionic or amphoteric surfactant like shown in Figure 12.

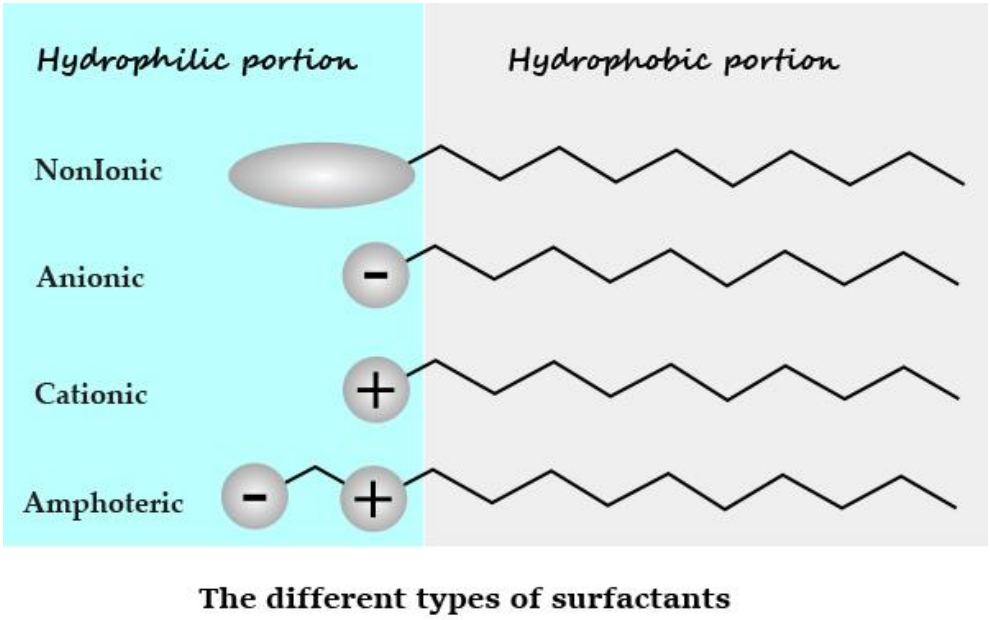


Figure 12 Different surfactant types
Source: http://hairmomentum.com/wp-content/uploads/2016/06/types-of-surfactants.jpg

The hydrophilic part is polar through this it can be solved in water or other polar fluids. In the other hand the hydrophobic part is nonpolar and can be solved in oils, grease, fats and other nonpolar fluids. Through their special structure of a polar and nonpolar compound surfactant have the ability to dissolve dirt on textiles, skin or other surfaces in water and clean the surface. Through this characteristic of lowering the surface tension fats can be dissolved in water. Because of these special characteristic's surfactants are used in many cleaning agents.

Relevant surfactants are anionic and non-ionic surfactants, 80% of the global usage are these two surfactants (Oros, Forga, & Cserha, 2002). Cationic and amphoteric surfactants are not used in big amounts. Cationic surfactants are used in disinfection and different cosmetic products and in plasti-

cizer. Amphoteric surfactants are used in dishwashing detergents, shampoos and cosmetics because of their skin compatibility. Most known and used anionic surfactants are linear alkylbenzolsulfonate (LAS). Surfactants do have a toxic effect on methanogenic bacteria and can inhibit anaerobic degradation. To that anionic surfactants are not able to be digested by anaerobic digestion (Tanaka & Ichikawa, 1994).

3 Plant status

At the beginning of this bachelor`s thesis the status of the treatment plant was checked. And following challenges where recognized.

3.1.1 Shock loads from pump sump

"Stöckacker Süd" Block A has five laundry rooms. Three of the five laundry room are connected to the pump sump where the laundry wastewater of these three laundry rooms is collected. From this pump sump the wastewater is pumped into the house sewer with a loading rate of 3.2L/s (Figure 13). This pumping causes hydraulic shock loads of wastewater with high concentration of detergents (anionic surfactant concentration around 130mg/L) and high pH (pH 9.2) (measurements from 23.04.19). These shock loads impact the hydraulic condition and the biology of the treatment plant.

Figure 13 High flow of laundry wastewater from pumping pit
Source: Autark Engineering AG

3.1.2 Scum formation

Waste products thrown down the toilette

As the treatment plant is treating wastewater from 59 households and the awareness of what can be flushed down the toilette is not around in every household. Many unwanted and problematic solids like wet wipes, tampon, pads and condoms can be found in the wastewater (Figure 14). These products are hardly degradable and accumulate in the inlet raiser of the first reactor tank (first septic tank chamber). As these products float they clump together with excreta and FOGs to a leadery scum. The non-degradable wet wipes act like barriers between the scum and the microbes, which lowers the hydrolytic efficiency, and this leads to a pile up of poorly degradable scum layer. The problem which the wet wipes cause in the system can't be solved by technical measures with reasonable effort in decentralized application, because it would not be viable to install a screen for its separation which has to be emptied on a daily basis. The only viable solution is to avoid throwing wet wipes down the toilette.

Figure 14 Waste products fished out of the first chamber of the septic tank
Source: Autark Engineering

Figure 15 Septic tank inlet filled with scum

Until to date hydrolysis did not work fast enough that a balance of incoming organic fraction from raw sewage and organics "brought-into-solution" could be reached. Scum in the first septic tank chamber piles-up over a period of time Figure 15. To lower the requirement of pumping-up the septic tank, as a periodic maintenance, it is targeted to minimize the accumulation of sludge/scum in the system.

3.1.3 Effluent quality

At the beginning of this bachelor`s thesis the effluent after the anaerobic treatment had a COD of 280mg/L with yellow colour and a smell of rotten eggs from H_2S. After the subsequent aerobic treatment, the COD was reduced to 135mg/L, without anaerobic smell but still with the yellow colour (Table 2). The anaerobic treatment achieved at this date a reduction of about 80% but still had an output COD of 280mg/L, which is high as per practical experiences of Autark Engineering AG in projects in India. The effluent quality after the aerobic post-treatment was still above national discharge norms of <60mg/L COD (Vioget, 2005). For this bachelor`s thesis the assumption is taken that the inlet has a COD of 1400mg/L based on COD analysis at inlet of septic tank and theoretical calculations based on daily COD production and water consumption per inhabitant.

Table 2 Wastewater "Stöckacker Süd A" measurement from 23.04.2019 (first measurement of project = status quo)

Reactor	O2 (mg/mL)	pH	Temp (C°)	COD (mg/L)	BOD (mg/L)	Anionic surfactants (mg/mL)
P3	0.76	7.27	22.9	810	488	
P10	<1	7.08	22.5	280	231	
P11	3.65	7.88	23.1	135	71	
After AOP and PSF2	8.24	7.75	21.9	131	58	
Water from pumping pit						132mg/L

4 Material and Method

4.1.1 Wastewater sampling

Wastewater samples for the analysis were directly taken from the reactor tanks in 500ml bottles. Only water samples for P11 are from the technical room were the water can be taken from a pipeline which is directly connected with P11. Samples were mainly taken from reactor P3, P6, P10 and P11 to get an estimate overview of the anaerobic and the aerobic digestion system. Two times (10.07.29 and 30.10.2019) water samples were taken from each ABR reactor (P3-P10) and P11.

4.1.2 Sample preparation for laboratory tests

For some measurements the wastewater sample needed to be filtered and/or centrifuged. If the sample needed to be centrifuged, then 50ml of wastewater sample were poured to a 50ml falcon tube. Sample were centrifuged at 7690xg for 10min. Supernatant were used for measurement. If filtered sample was needed, then supernatant from the centrifugation were taken and filtered through a 0.45µm filter. For which sample which preparation was used can be found in Appendix A.

4.1.3 pH, dissolved oxygen and temperature

Figure 16 On- site measurement with the Multi meter HQ40
Source: Pravin G. Moorthy

pH, dissolved oxygen (DO) and temperature were measured directly on the side with the portable *Multi Meter HQ40* from *Hach* (Figure 16)

4.1.4 Chemical Oxygen Demand (COD)

COD measurement were done with the LCK cuvette test from *Hach Lange GmbH*. The protocol of *Hach Lange* were followed. Samples which were taken in the period of 23.04.19 – 15.08.19 were measured with *LCK614 (50-300mg/L*) cuvette test. Samples which were taken in the period of 18.09.19 – 30.10.19 were measured with *LCK314 (15-150mg/L)* cuvette test. The measurement of the cuvettes was done with the *spectral photometer DR3900* from *Hach Lange GmbH*. To measure soluble COD, water samples were first filtered through a 0.45µm filter. Samples were diluted to the needed concentration with deionised water.

4.1.5 *Hach Lange* cuvette tests

Other *LCK Hach Lange* cuvette tests were also used to measure other parameters:
Which parameter was analysed on which date is shown in Appendix B.

- Ammonium (N_4) — *LCK 305 (1-12mg/L)* (NH_4-N)
- Nitrite (NO_2) — *LCK 341 (0.015-0.6mg/L)* (NO_2-N)
- Nitrate (NO_3) — *LCK 339* (0.23-13.5mg/L) (NO_3-N)
- Sulphide (S^{2-}) — *LCK 653 (0.1-2mg/L)* (S^{2-})
- Sulphate (SO_4) — *LCK 153 (40-50mg/L)* (SO_4)
- Anionic surfactants — *LCK 432 (0.1-4mg/L)*

Samples were diluted to the needed concentration with deionised water. The measurement of the cuvettes was done with the *spectral photometer DR3900* from *Hach Lange GmbH.*

4.1.6 Total Suspended Solids (TSS)

A prewashed *Whatman® glass microfiber filter (50mm)* was first dried overnight at 105°C and weighted. Then 50ml of wastewater sample were filtered through the filter. Filters were dried at 105°C overnight. After drying filters were weighted again. And calculated with following formula:

$$TSS = (W2 - W1)/V$$

TSS = Total Suspended Solids
W1 = Weight of washed filters
W2 = Weight after filtration
V = Volume taken for filtration

4.1.7 FOS/TAC

In the FOS/TAC measurement the ratio of Volatile organic acids and Total inorganic carbonate is measured. It is normally used in biogas plants to monitor the fermentation process. Over a time period it does give an overview if the biogas plant gets sour or needs more organic input. It is a good method for monitoring.

The measurement was done with the titrator *Metrohm 916 Ti-Touch* in the lab of Urs Baier from ZHAW (Figure 17). For each measurement 20ml sample were taken.

Figure 17 Titrator Metrohm 916 Ti-Touch Source: Pravin G. Moorthy

4.1.8 VFA

VFA analysis was done by Roger Fehr ZHAW. The measurement was done on a HPLC from the company *Shimadzu* with following settings:

- Collumn: *Aminex HPX-87H* 300x7.8mm
- Solvent : 2.5mMol Sulfuric acid
- Flow speed : 0.6ml/min
- Temperature : 40°C

5 Measures taken

To improve the treatment performance and reduce the O&M requirements of the WWTP "IWB Stöckacker Süd", the challenges listed in chapter 3 are tackled by the following measures. The following measures are listed chronologically

5.1 Hydraulic modification of first chamber of septic tank

To improve the hydrolytic efficiency/capacity of the first septic tank chamber it was the plan to change the inner structure of the septic tank in such a way that the hydraulic flow and pathway are increased, which should lead to a higher flow velocity with better mixing pattern of bacteria and incoming organic waste in the raw sewage, as postulated by E.C. Jowett in his paper from 2017 (C. Jowett, et. al., 2017).

The modification of the inner septic tank structure (first chamber) was done as following:

- Inlet with 2.5m' long 400mm dia. pipe (see in figure 18 red tube).
- Segmentation of tank by vertical wall out of a 3m' rubber-sheet (see in figure 18 in black wall).
- Fixing of 5.5m' long 250mm dia. pipe to change the transfer-inlet to the second septic tank chamber (see in figure 16 in purple).

The modification of the inner structure is shown in Figure 18.

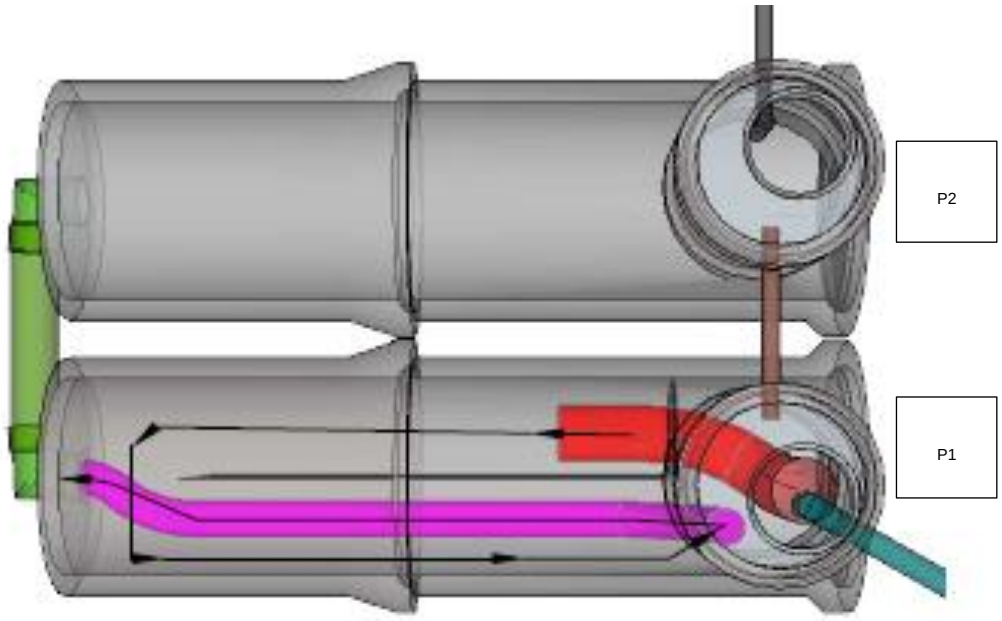


Figure 18 Modification in the first septic tank chamber
Source Autark engineering AG

5.1.1 Lowering pump volume of laundry pumping sump

On 2. April the pump volume was decreased by set-down the level controller in the pump-sump by 12cm. This action decreased the water volume which is pumped at once by 50% (94L). This measure should lower shock-loads caused by the pumping wastewater from laundry pump-sump.

5.1.2 Behaviour change of users

To prevent/reduce the input of wet wipes and other harmful solids the residents were contacted by the proprietor "Immobilien Stadt Bern (ISB)" on 20. June with a letter plus brochure about what they are allowed to throw down the toilette and what they should not dump into the toilette.

Additionally, the laundry room there were different biodegradable washing detergents provided. Residents could test different detergents and different methods to dose washing detergents and see if they do like one of them and change from conventional detergents to better biodegradable ones. If more of the residents do use better biodegradable detergents that would be less harmful and less work for the biology in the treatment plant.

5.1.3 Addition of new microbial products to improve biological degradation process

Testing of new microbial products for improvement of anaerobic and aerobic biology. For anaerobic biology *Bioclean STP* and for the aerobic reactor *Bioclean TM* from *Organica Biotech* were periodically added.

<u>Bioclean STP:</u>

Figure 19 Bioclean STP, microbial booster for the first septic tank

Bioclean STP is an all-natural product which is made by fermentation (Figure 19). *Bioclean STP* contains a complex of microbes, enzymes, micronutrients and trace elements. This product is made to optimize wastewater degradation in anaerobic reactors. By continuous input specific microbes, which hydrolyse organic compounds faster and to a greater extent could be found in the reactor. The metabolism of these microbes is faster and more effective, which gives them the ability to improve all four major steps (Hydrolysis, Acidogenesis, Acetogenesis and Methanogenesis) of anaerobic digestion. To that if these microbes are more resistance against inhibitory or toxic shocks and changes in operational setup or in the environment (MalaTech water, 2019a).

Bioclean STP was added every two or three days either by adding it directly into the septic tank, by adding through the bistro *Becanto* toilette or through the house sewer. The first time *Bioclean STP* was added on 20.06.2019 and the following inoculation protocol can be found in Appendix C.

Bioclean TM:

Bioclean TM is a powder of inactivated all-natural microbes isolated from soil and water. *Bioclean TM* contains a high number of microbial species combined with enzymatic systems and nutrients. Through its wide range of microbes, it can be used for a broad spectrum. This product is mainly used to optimize industrial and municipal WWTP. When the biology has been established it should be persistent against changes in wastewater composition, toxic compounds and temperature changes. This biology should help to decrease the COD and to speed up nitrification and denitrification in the granular sludge. It is also does control the growth of filamentous microbes which do disturb the formation of bioflocs (MalaTech water, 2019b).

As *Bioclean TM* is an inactivated powder it first needs to be activated by adding it to water and incubate it for one day at room temperature (RT). The activation of the microbes was done in a 30L barrel with an air pump in it (Figure 20). Ones a week 400g of *Bioclean TM* was added to the barrel and the water level was filled up to 30L. The activated *Bioclean TM* needed to be inoculated every day to the reactor, therefore a tube was pulled from the reactor P11 to the plant room, where the container was installed. The tube was connected to a peristaltic pump which was then connected with the container. Like this the activated culture could be dosed in daily basis into the reactor P11.

Figure 20 30L Container with peristaltic pump for activation and dosing Bioclean TM
Source: Pravin G. Moorthy

Bioclean TM was first time added by dosing it with the dosing pump on 25.06.2019. On 08.07.2019 dosing by the pump needed to be stopped because of clogging of the tube. After that the powder as directly added into the reactor for four days. The dosing protocol of *Bioclean TM* can be found in Appendix D.

5.1.4 Adjustment in the aerobic reactor

On 24. July 1m^3 of additional polyurethane cubes were added to the aerobic reactor to enhance the fixed film surface. To that the air diffusers were newly placed in the aerobic reactor to achieve a more even distribution of the air.

5.1.5 Changing anaerobic digestion pathway to dark fermentation

The microbial products from chapter 5.1.3 showed some changes but there was another biology which would have much better degradation rate with less greenhouse gases. This modification should change the whole anaerobic biology into dark fermentation. The so called "dark fermentation pathway" should inhibit methane and hydrogen sulfide formation and should have an high output of VFA, which are easily degradable in the subsequent aerobic treatment step.
To shift the anaerobic pathway from methane fermentation to dark fermentation a mix of effective microorganisms (EM) of dark-fermenting bacteria was added from 06.09.19 onwards. In this thesis this mix is called *MX_3*. The inoculation protocol of *MX_3* can be found in Appendix E..

6 Results and Discussion

6.1 Hydraulic modification of first chamber of septic tank

After two months on 6.5.19 the first chamber of the septic tank needed to be pumped out. The chamber got clogged because of increased formation of scum. The scum was bloated and clogged the whole first chamber of the septic tank. This modification should lead to a lower scum accumulation rate but in the case of WWTP "IWB Stöckacker Süd" it did not work out. Instead the scum could accumulate and clog everything. Possible reasons why this modification did not work out, is one that there was an accumulation of wet wipes which were piled layer by layer in the septic tank as shown in Figure 21) These wet wipes might have disturbed the hydraulic flow which through this modification should have be given. Another possible problem could be additionally added bacterial powder and the "*Grease Trap Guarde"* these products could have let the scum bloat through high production of gas. The combination wet wipes and additional added product might have a negative influence too. What exactly caused the high production of scum is not known but what can be said is that the design of Jowett and his team, could not solve the scum problem.

Figure 21 Pumping out of first chamber of septic tank (left), wet wipes clumbed with scum (right)
Source: Pravin G.Moorthy

6.2 Lowering pump volume of laundry pumping sump

Through lowering the level of the pump sump less shock loads of laundry wastewater were achieved. But a direct effect of these measure was not recognized.

6.3 Behaviour change of users

Figure 22 Wet wipes and tampons fished out first chamber of septic tank
Source: Pravin G. Moorthy

The letter and brochure could not change the behaviour of all the inhabitants. Still after the inhabitants were informed, in weekly basis wet wipes and tampons can be fished out of the first chamber of the septic tank as shown in Figure 22. Solid products like wet wipes are not only causing problems in this treatment plan it is an international problem. In Sydney they removed about 1 million kilograms of wet wipes from their wastewater systems and New York has spent in five years 18 million dollars to only remove wet wipes from their 14 WWTP (Mitchell, et. al., 2017). Those wet wipes clump together and clog the sewer system which causes O&M costs. To prohibit these costs and distribution, one should think of banning the wet wipes.

6.4 Addition of a microbial product to improve biological degradation

6.4.1 Bioclean STP

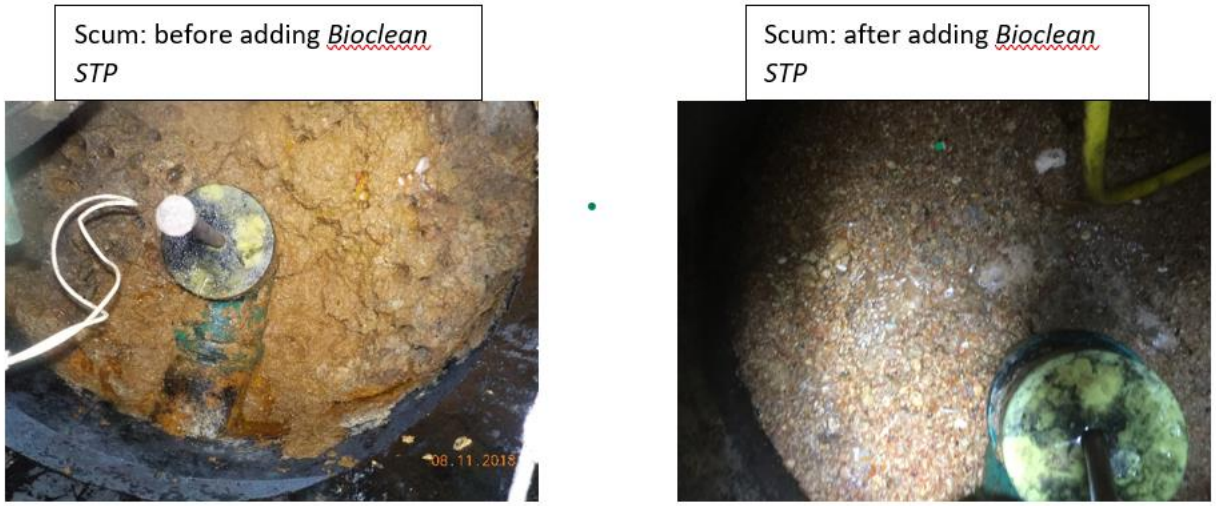


Figure 23 Comparison of scum structure. Scum structure before pump out (left) and scum structure after adding Bioclean STP

The scum before the reactor was pumped out was a thick massive bulk with a dark yellow colour and was quite fatty. Through the adding of *Bioclean STP* formation of such a thick scum could be prevented. The scum instead got more flacked and was not so dense anymore. The colour has changed to bright yellow and it got better mixed with the water. *Bioclean STP* has changed the scum but still was not able to totally prohibit scum formation.

To see how *Bioclean STP* has changed the degradation process the COD values from this measure were compared together (Table 3)

Table 3 COD results from Bioclean STP measure

	10.07.2019		24.07.2019		14.08.2019	
Reactor	COD (mg/L)	% COD removal from Inlet	COD (mg/L)	% COD removal from Inlet	COD (mg/L)	% COD removal from Inlet
Inlet effluent (Assumtion)	1400		1400		1400	
P3	1070	23.6	720	48.6	680	51.4
P6	696	50.3	NA	NA	680	51.4
P10	272	80.6	252	82.0	262	81.3
P11	85	93.9	92	93.4	88	93.7

As inlet effluent for all tests was 1400mg/L COD assumed. To that value all other reactor values were compared, to see the total COD removal in percent till to that reactor. What can be seen is that there is a change in COD removal in reactor P3. The degradation rate of the reactor P3 increases from 23.6% COD reduction to 51.4% COD reduction. There is clearly a positive influence of *Bioclean STP* in the degradation rate between the reactors P1 and P3. In the following other reactors, the COD degradation rate has not been changed.

6.4.2 Bioclean TM

After *Bioclean TM* was added in daily basis, the effluent water of the aerobic reactor showed flocs in the water, these flocs were in previous sampling not around. When checked the flocs under the microscope a consortium of bio-flocs could be seen: Bacteria, protist and algae (Figure 24). This shows that *Bioclean TM* was able to change the biology in the aerobic tank to a biology which is also used in WWTPs.

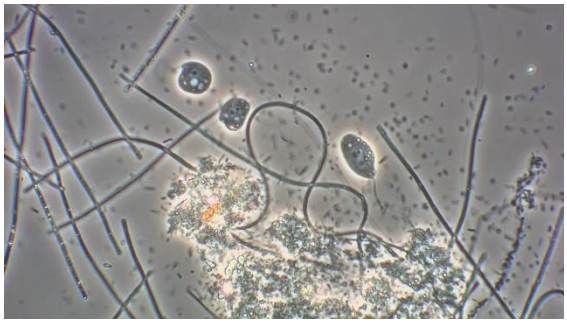


Figure 24 Bioflocs seen under microscope at a magnification of 400x
Source: Pravin G.Moorthy

Presents of bio-flocs in the aerobic reactor where pleasing recognition but the COD removal did not show any changes (Table 4). The degradation rate of reactor P11 has not changed much during these sampling points. The water from reactor P10 with an average COD of 260mg/L was degraded in average to 66% during this test period in reactor P11.

Table 4 Effect of Bioclean TM measure from reactor P10 to P11

	10.07.19		24.07.19		14.08.19	
Reactor	COD (mg/L)	% COD_{rem}	COD (mg/L)	% COD_{rem}	COD (mg/L)	% COD_{rem}
P10	272		252		262	
P11	85	68.64	92	63.33	88	66.45

6.4.3 Summary

When the final results from *Bioclean STP*/*TM* (14.08.2019) are compared with the results from "status quo" (23.04.2019) (Figure 5), it can be seen that the reduction of COD in total has been increased by 3.3% (from 90.4% to 93.7%). The influence of *Bioclean STP* can be seen in the beginning of the first reactors (P1-P3) where an increase of 10% in COD removal was achieved. The aerobic COD removal rate in P11 increased from 52% removal of COD (23.04.19) to 66% removal of COD (14.08.2019) an increase of COD removal of 14%.

Table 5 Comparison of COD values from 23.04.2019 and 14.08.2019

	23.04.2019		14.08.2019	
Reactor	COD (mg/L)	% COD removal from Inlet	COD (mg/L)	% COD removal from Inlet
Inlet	1400		1400	
P3	810.0	42.1	680	51.4
P6	NA	NA	680	51.4
P10	280.0	80.0	262	81.3
P11	135.0	90.4	88	93.7

It seems to be that through *Bioclean STP* the efficiency of the hydrolysis could be increased, which caused a better degradation of the scum and made it more flacked. To that *Bioclean STP* has shown a positive influence in degradation rate in the first two reactors but in the other anaerobic reactors there could not be seen any difference in COD removal rate. It could be that these bacteria where not able to reach and colonize the other reactors and that is why there were no change seen.

Through *Bioclean TM* the presence of bio-flocs were achieved and these bio-flocs showed an increase in COD removal in the aerobic reactor.

Overall a better effluent quality was achieved if compared with the measurements from 23.04.19. Even if the final effluent quality has been improved with an final COD value of around 90mg/L, it is still over the national discharge norms of 60mg/L COD.

6.5 Adjustment in the aerobic reactor

By reordering the diffusers in the aerobic tank a better dissolved oxygen (DO) value was achieved as it can be seen in Table 6. The measure was taken on 24.07.19 and from then on the DO value was always above 5mg/L except on 16.10.19 and 23.10.19. The reason why the DO is low on 16.10.19 could be because when arrived on that day for sampling the air pipeline from the plant room was disconnected from the diffusers and was blowing directly air into the water, which might have caused a bad distribution of the air.

Table 6 Dissolved oxygen value of reactor P11

	10.07.19	24.07.19	14.08.19	18.09.19	01.10.19	16.10.19	23.10.19	30.10.19
P11 DO (mg/L)	4.33	4.44	5.48	5.35	5.67	4.49	4.75	5.43

6.6 Changing anaerobic digestion pathway to dark fermentation

6.6.1 COD removal

The COD value of each reactor during the period of these modification can be seen in Figure 25. The COD value of reactor P3 shows some fluctuation same does reactor P10 but just vice versa. When the COD value of P3 rises the COD value of P10 declines and if the COD value of P3 declines the COD values of P10 rises. COD value of reactor P6 decreases during the whole test period from 804mg/L COD to 326mg/L COD. But it should be mentioned that during sampling of reactor P6 sometimes solids which were floating in the reactor were taken, that is why some values are almost same high as P3 or even higher like on the sampling point 18.09.19. The COD value of reactor P11 is quite constant during this test period only on 16.10.19 an increase of the COD value to 210mg/L COD occurred. This rise of COD is explained in chapter 6.5. Because of this incident the COD removal declined as less air was available.

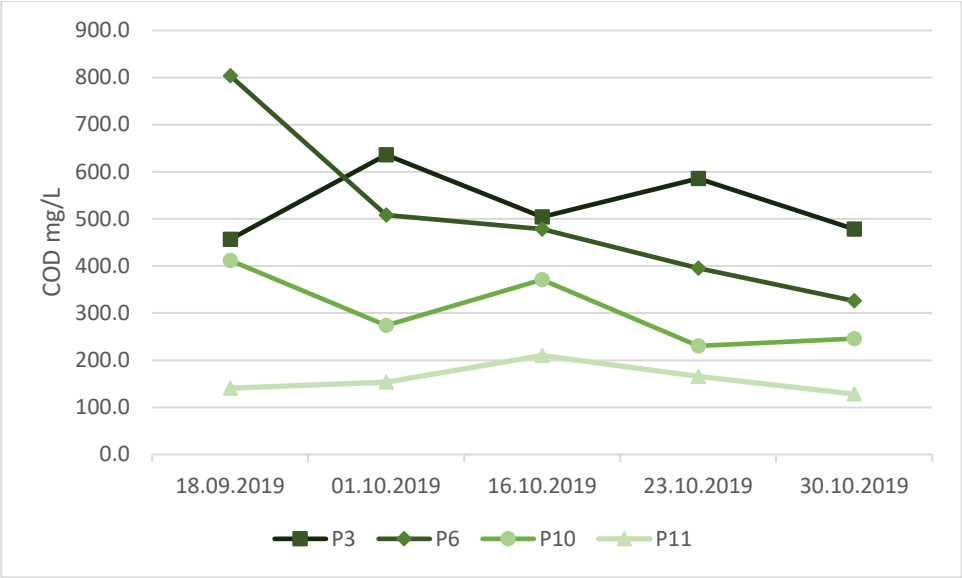


Figure 25 COD value of all reactors during MX_3 modification

Only in reactor P6 and P10 an increase of total COD removal in comparison with the inlet COD value (1400mg/L COD) from the first measurement (18.09.19) to the last measurement (30.10.19) can be seen. In case of P6 the total COD removal increased from 42.6% to 76.7% and in case of P10 an increase from 70.6% to 82.5%.

Figure 26 shows the COD development in the treatment plant from reactor P3 to P11. On 18.09.19 the COD value of reactor P6 is very high this is as already explained in chapter 6.6.1 due to sampling error. What can be seen is that it does not matter with which COD value the wastewater leaves reactor P3 in the end the COD after the aerobic treatment will be around 250mg/L and after the aerobic treatment the COD value was always around 150mg/L. Only on 16.10.19 the COD value after reactor P11 was high and this was as already explained because of an incident with the aeration pipeline (see chapter 6.5). The COD removal from reactor to reactor happens randomly, there is no synchronic removal. If the value of reactor P3 is high that does not mean that all other values from the following reactors are high too.

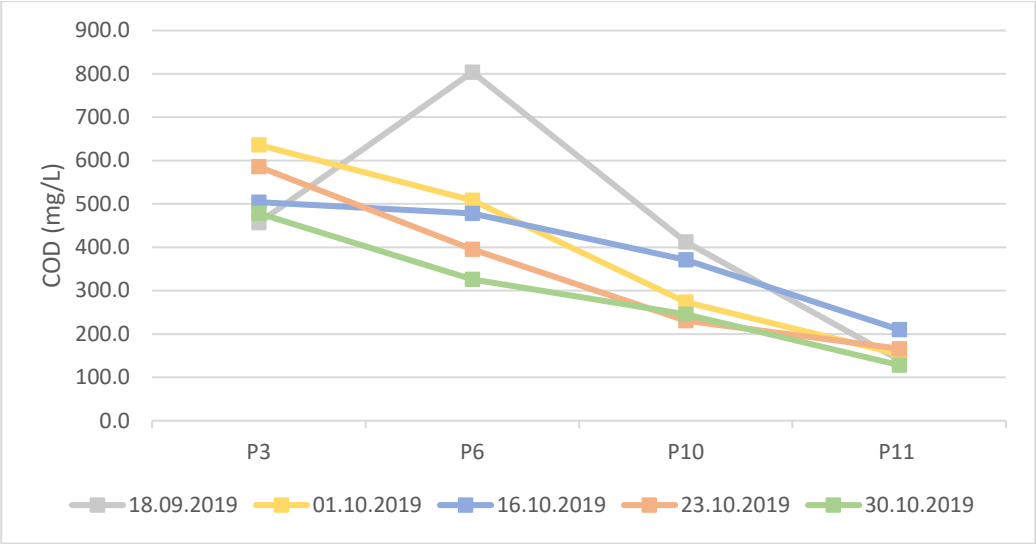


Figure 26 COD Development from reactor P3 to reactor P11 during different sampling points

An interesting development is shown in Figure 27. The COD removal rate of compartment section P4-P6 and P5-P10 do show similar pattern. When the removal rate P4-P6 increases so does the removal rate of P7-P10 rise too and vis versa. But in the other hand, compartment section P1-P3 show exactly the opposite pattern. An explanation for that could be that when the first compartment section does have a high COD removal the other compartment sections do have more of the poorly degradable organic compounds and the removal rate of these sections decreases. In the other way around when removal rate of the first compartment section decreases more of better degradable organic compounds are left, which leads to a better degradation rate of the other compartment sections. More about the hardly degradable compounds is described in 6.8 Final Evaluation.

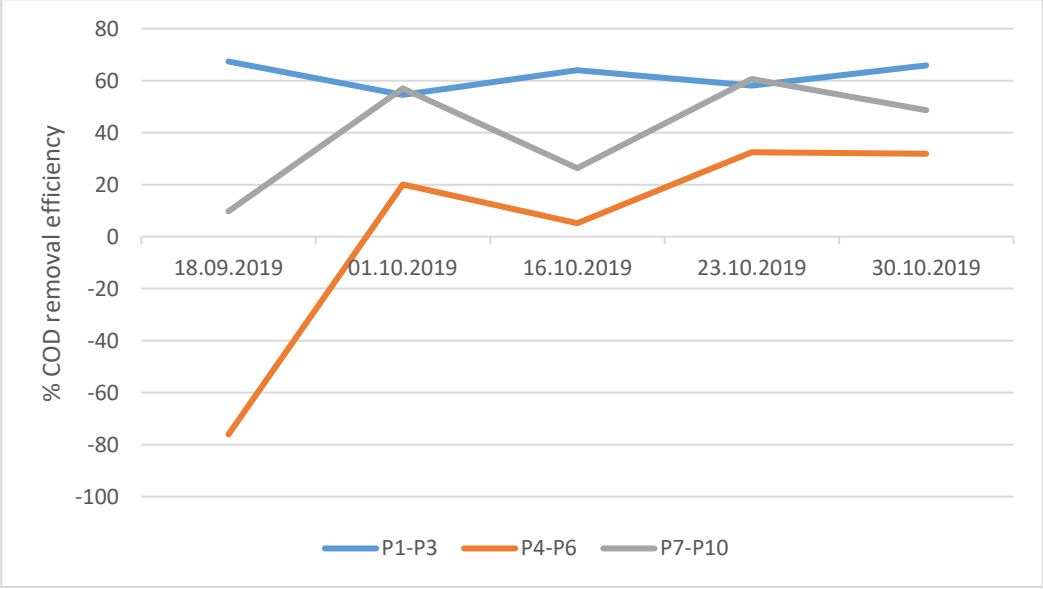


Figure 27 COD removal rate of compartment section P1-P3, P4-P6 and P7-P10

6.6.2 Volatile fatty acids

On the basis of the VFA measurement the COD value of the VFAs was calculated and put in correlation with the measured COD (Table 7). During the test period the proportion of VFA in the measured COD increases with the time. Only on 16.10.19 there is a sudden increase of VFA proportion, but this could be due to sampling errors. Anyway, when compared the VFA proportion from the beginning of the test on 1.10.19 till to the last measurement 30.10.19 it can be seen that in all three reactors the proportion of VFA COD increased. The strongest increase is in reactor P3 followed by P6 and P10, which does makes sense as the *MX_3* which should enhance VFA production by dark fermentation, is put in reactor P1 and from there on the microbes have to colonize each reactor one by one.

Table 7 Comparison of calculated COD of VFA and measured COD

		1.10.19	16.10.19	23.10.19	30.10.19
P3	CSB [mg/L]	636	504	586	478
	CSBVFAs [mg/L]	213.9	211.9	235.4	258.2
	% COD VFA	33.6	42.1	40.2	54.0
P6	CSB [mg/L]	508	478	395	326
	CSBVFAs [mg/L]	88.0	156.2	107.0	101.0
	% COD VFA	17.3	32.7	27.1	31.0
P10	CSB [mg/L]	274	371	230	246
	CSBVFAs [mg/L]	48.9	118.6	53.7	60.3
	% COD VFA	17.9	32.00	23.3	24.5

The volatile fatty acids measurement from 30.10.19 does show a profile of volatile fatty acids of all anaerobic reactors (Figure 28). In the beginning of the anaerobic treatment (P2 and P3) the VFA acetic acid and propionic acid are very high and from there on the VFA concentration decreases from reactor to reactor. Compared with the COD value the correlation between VFA and COD can be seen. Increase of VFA concentration does show an increase of COD too and vis versa.

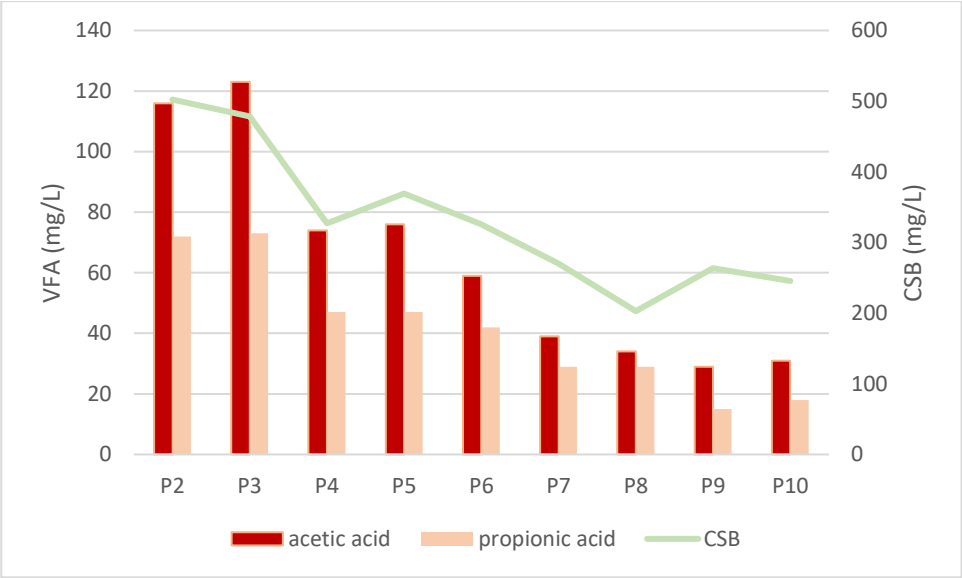


Figure 28 VFA profile of all reactor P2-P10 from 30.10.19 sampling point

What can be seen from Figure 28 is that hydrolysis and acetogenesis is very high in the P2 and P3 and decreases with each following reactor but does not disappear. This figure indicates that the microbial composition in the different trophy stage changes from P2 to P10. In the beginning acidogenic bacteria are dominant and with decreasing VFA values methanogenic bacteria are increasing (Nachaiyasit & Stuckey, 1995). So, through *MX_3* methanogenic bacteria could be outcompeted, and only dark fermentation could be achieved.

6.6.3 FOS/TAC

FOS/Tac values of reactor all three reactors P3, P6 and P10 decreases from the first measurement to the last measurement as it can be seen in Figure 29. Reactor P3 does show the strongest drop from FOS/TAC value of 0.451 to 0.111 this is a decrease of 75%. In case of reactor P6 it is a decrease from 0.320 to 0.152 – decrease of 52%. And in P10 a decrease in FOS/TAC value from 0.097 to 0.061 can be seen, this is a decrease of 37%. This shows that the volatile fatty acids are increasing as the ratio between FOS/TAC decreases. Which correlates with the results from the previous chapter. FOS/TAC values are used in biogas plants where they do monitor the process with this value. In biogas processes FOS/TAC values between 0.3 and 0.4 are recommended in which reactor P3 and P6 were in the beginning of this measure but to the end all reactors got in a range (<0.2) where they theoretically needed to be fed for a good biogas production (Lossie & Pütz, 2019). This low FOS/TAC value is a good sign as though this measure methanogenic bacteria which produce methane should be out competed.

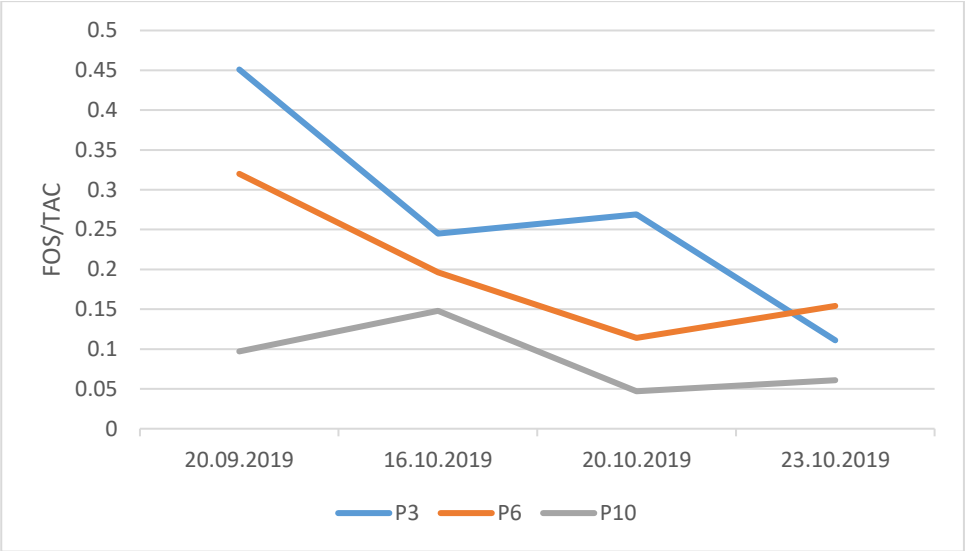


Figure 29 FOS/TAC values from reactor P3, P6 and P10 during the MX_3 test

6.6.4 Summary

The COD measurement did not show any big differences in COD removal only an increase of COD removal rate of compartment section P4-P6 and P7-P10. What could be seen is that it does not matter with which COD value the wastewater leaves compartment P3 in the end the COD value will be always around 250mg/L after anaerobic treatment and around 150mg/L after aerobic treatment. It could be that the bacteria are not able to digest some compounds in the wastewater and that is why in the end the COD values are always around 150mg/L. In the end the COD value does not matter as through dark fermentation not more COD should be removed but more organic compounds converted to much easier digestible VFA. A change in direction to dark fermentation could be recognised by the evaluation of the VFA values. It could be seen that the proportion of VFA COD is getting higher with the time. To that it could be seen that in the beginning of the reactor a much higher rate of acidogenic and hydrolysis is occurring which can be associated whit the influence of MX_3. To that the low FOS/TAC value in the end of these measurements do confirm the trend to dark fermentation. The treatment into dark fermentation is going the right way.

6.7 Side tests for WWT process evaluation

6.7.1 Temperature

Temperature in the reactors were always around 22°C and 23°C degree. These temperatures are not in the optimum range for anaerobic bacteria (Chernicharo, 2007). But the temperature is still in the range for mesophilic bacteria and above 20°C, as temperature under 20°C can be inhibitory for anaerobic digestion (Van Lier et al., 2012). There are ABRs working with temperature around 15°C, so temperature should not be a limiting factor (Barber & Stuckey, 1999).

6.7.2 pH

From the beginning till to the end of this bachelor`s thesis the pH in the anaerobic reactor was in the optimum range for anaerobic bacteria between pH 6.6 and pH7.4 (Chernicharo, 2007). No sudden pH changes where measured as it can be seen in Figure 30. The highest pH value in the anaerobic reactor was in reactor P3 on the 16.10.19 with a pH of 6.99. The lowest pH value was also on 16.10.19 in reactor P10 with a pH of 6.75. But all these values are still in the range for anaerobic bacteria. The pH in P11 was constantly around pH 7.6 and 7.8.

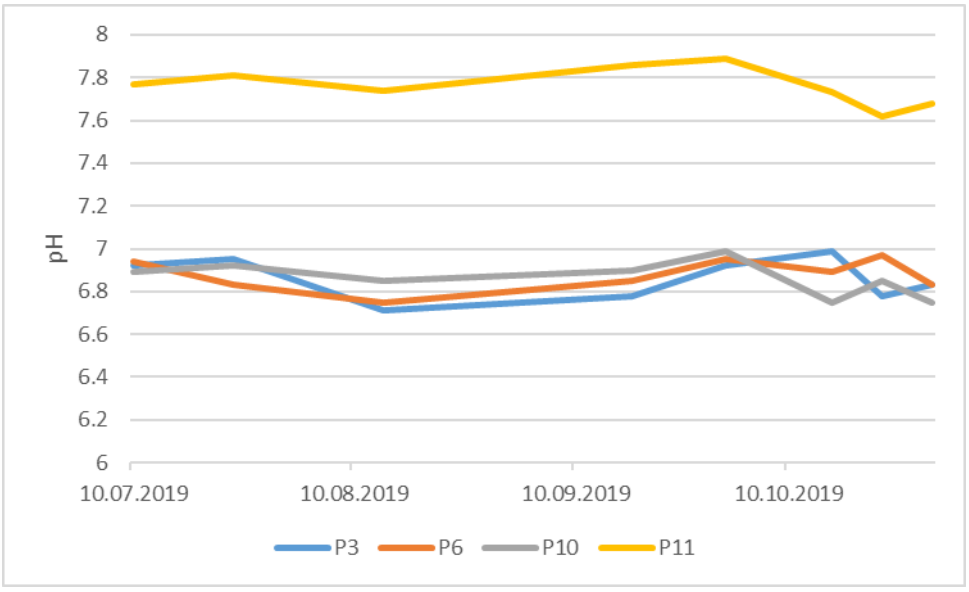


Figure 30 pH values from the beginning till to the end of the thesis

6.7.3 Anionic surfactants

Removal of anionic surfactants are shown in Table 8. By anaerobic treatment around 40% of the surfactants are removed. About 88% of the anionic surfactants from P10 which were not degraded by anaerobic treatment are removed by aerobic treatment. In total around 93% of anionic surfactants were removed.

Table 8 Removal of anionic surfactants

	10.07.2019		14.08.2019	
Reactor	Anionic surfactant (mg/ml)	% total removal	Anionic surfactant (mg/ml)	% total removal
P3	11.5		9.3	
P10	6.8	40.9	5.3	43.0
P11	1.2	82.4	0.323	93.9

In the literature it can be found that anionic surfactants are hardly digestible by anaerobic treatment or that only 30% of anionic surfactants can be degraded by anaerobic treatment (De Wolf & Feijtel, 1998) (Tanaka & Ichikawa, 1994). The results from these measurements show that around 40% of anionic surfactants can be degraded by anaerobic treatment. A possible way of degradation of anionic surfactants like linear alkylbenzolsulfonate (LAS) by anaerobic treatment is that anaerobic bacteria break the LAS to use sulphate for their growth (Denger & Cook, 1999).

6.7.4 Nitrogen

Ammonia:

The measured ammonia values were in anaerobic and aerobic reactors between 70mg/L and 80mg/L. Slight increase from reactor P3 to reactor P10 can be seen on all dates except on 16.10.19. Also, on 16.10.19 ammonia increased in reactor P11 from 71.7mg/L to 81.6mg/L. On the 16.10.19 the aeration pipeline from the plant room was disconnected from the air diffusers, because of that the reactor P11 was not properly aerated and this led to an increase of ammonia possibly because of microorganism died as not enough oxygen was available. The ammonia values are in the range where it is beneficial for anaerobic bacteria (McCarty, 1964).

Table 9 Ammonia values from 18.09.19 to 23.10.19

	18.09.2019	01.10.2019	16.10.2019	23.10.2019
	NH_4-N (mg/L)	NH_4-N (mg/L)	NH_4-N (mg/L)	NH_4-N (mg/L)
P3	74.7	72.9	77.6	73.1
P6	73.3	79.1	76	72.1
P10	78.95	80.6	71.7	77
P11	74.6	77.8	81.6	74.6

Nitrification:

One of the tasks of the aerobic reactor is converting ammonia to nitrate by nitrification. In Table 10 can be seen that there is an increase of nitrite in the reactor P11 compared to reactor P10. Interesting is that on the 16.10.19 the highest amount of nitrite was measured although the aeration was not applied well.

Table 10 Nitrite values from reactor P10 and P11

	18.09.2019	01.10.2019	16.10.2019	23.10.2019
	NO_2-N (mg/L)	NO_2-N (mg/L)	NO_2-N (mg/L)	NO_2-N (mg/L)
P10	0.019	0.021	0.027	0.028
P11	0.139	0.074	0.153	0.074

In Table 11 shows that there is a decrease of nitrogen on 18.09.19 and 01.10.19 and only a slight decrease of nitrate on 16.10.19 and 23.10.19. Nitrification has not been achieved yet in the aerobic reactor. And this might be because of sulfide which can inhibit nitrification at a certain concentration (look chapter 6.7.5). To that nitrate measurement where done after adding *Bioclean TM* was stopped and as discussed in chapter 6.4.2 through *Bioclean TM* formation of bio-flocs were achieved in the aerobic reactor but after stopping *Bioclean TM* those Bbioflocs might got reduced, which why no nitrification could not be achieved.

Table 11 Nitrate values from reactor P10 and P11

	18.09.2019	01.10.2019	16.10.2019	23.10.2019
	NO3-N (mg/L)	NO3-N (mg/L)	NO3-N (mg/L)	NO3-N (mg/L)
P10	0.485	0.459	0.775	0.471
P11	0.463	0.419	0.828	0.473

6.7.5 Sulfide

Sulfide can be inhibitory for anaerobic digestion. To check how much sulfur compounds are in the wastewater and could it be inhibitory sulphate and sulfide were tested on 01.10.19 (Table 12). The results show that there is no sulfide (S^{2-}) in the wastewater which does make sense as in the pH range of pH6-7 sulfide is in form of H_2S or HS^- around (McCarty, 1964). To check possible inhibitory of sulphate, COD and sulphate values of P3 were taken as inflow wastewater values to calculate the COD/sulphate ratio which is an indicator for sulphate inhibition. At that time point the COD/sulphate ratio of reactor P3 was 24.9 which is much higher than 10. So it can be assumed that the anaerobic treatment system is not inhibited by sulphur compounds (Chernicharo, 2007).

Table 12 Sulphate and sulfide measurements from 01.10.19

	01.10.2019	
	SO_4 (mg/L)	S^{2-} (mg/L)
P3	25.5	0
P6	23.1	0
P10	20.8	0
P11	69.8	0

There might be an inhibition of nitrification by sulfide compounds. If assumed that the increase of sulphate value from P10 to P11 is by oxidation of all HS^- which were in the outflow water of P10, then out of the difference of the sulphate values from P10 and P11 the HS^- can be calculated: 16mg/L HS^-. HS^- concentrations above 13mg/L can be inhibitory for nitrification, so it can be assumed that nitrification is inhibited by sulfide (Ortiz, et. al. , 2013). Sulfides oxidize much faster as it is a chemical

oxidation process and not a biological one, so in 2h sulfide can be oxidized to sulphate (Joye & Hollibaugh, 1995). Thereby the oxygen is taken for by sulfides instead by nitrifiers. To give a clear statement about inhibition by sulfide more tests need to be done as this is just an interpretation from one measurement.

6.7.6 TSS removal

Figure 31 shows the TSS amount at each reactor point. There is an increase of TSS in reactor P6 this is due to sampling errors where solids were taken during sampling. After reactor P10 there is an increase of TSS in reactor P11 and this is due to bio-flocs which are not filtered out of the water. Through anaerobic digestion between P3 and P10 about 70% of TSS are removed. As the TSS value from the effluent is not known the total TSS removal cannot be calculated.

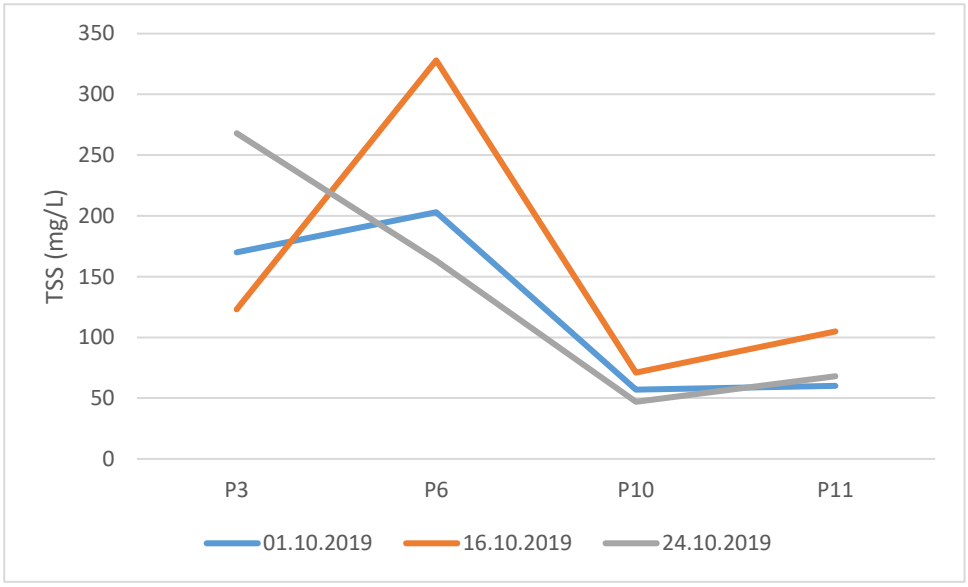


Figure 31 TSS value in mg/L

6.8 Final Evaluation

To get an overview from all changes in the treatment plant from the beginning of the thesis till to the end the results from the first sampling point (23.04.2019), from the last sampling point of the *Bioclean* measure and the last sampling point from the *MX_3* measure were compared together in Table 13.

Table 13 Comparison of the whole process change during the bachelor`s thesis

	23.04.2019 (status quo)		14.08.2019		30.10.2019	
Reactor	COD (mg/L)	% COD_{rem} from Inlet	COD (mg/L)	% COD_{rem} from Inlet	COD (mg/L)	% COD_{rem} from Inlet
Inlet	1400		1400		1400	
P3	810.0	42.1	680	51.4	478	65.8
P10	280.0	80.0	262	81.3	246	82.5
P11	135.0	90.4	88	93.7	128	90.8

What can be seen is that through these actions which where taken the COD removal rate of reactors P1 - P3 has increased from 42.1% to 65.8% COD removal, an increase of 20% COD removal rate. The total COD removal rate after reactor P10 increased from 80% to 82.5%. A little increase can be seen but this is mainly thank to the good COD removal of the first three reactors because when compared with Table 14 it can be clearly seen that the COD removal rate of compartment section P4-P10 has been decreased during the whole thesis. The total COD removal rate after P11 shows an increase after the *Bioclean TM* was added (from 90% to 93%) but then when adding of *Bioclean TM* was stopped and only *MX_3* was added to the treatment plant the total COD removal rate went back to 90%. This scheme can be also seen when only the efficiency of P11 during the thesis is compared (Table 14). With the combination of *Bioclean STP* and *TM* a final effluent COD of 85mg/L was achieved so low as never before in this thesis.

In Table 14 Comparison of COD-removal efficiency during the main timepoint of the bachelor`s thesis shows the efficiency of COD removal from reactor compartments in the main timepoint of the bachelor thesis – "status quo", after *Bioclean STP/TM adding* and after *MX_3 adding.* As already described the COD-removal efficiency of the reactors P1-P3 increased during this whole bachelor`s thesis. The COD removal efficiency of the reactors P4-P10 decreased from 65.4% removal to 48.6% removal rate, a decrease of 17%. *MX_3* does show positive influence in the first three reactors. The aerobic reactor COD-removal rate can be correlated with the measures which were taken on reactor P11. On "status quo" the efficiency was at 52% after adding *Bioclean TM* the efficiency rate increased to 66.5% but when the *Bioclean TM* was stopped the efficiency of the reactor P11 dropped to 48%.

Table 14 Comparison of COD-removal efficiency during the main timepoint of the bachelor`s thesis

	23.04.2019	14.08.2019	30.10.2019
Reactor	% COD_{rem} Efficiency	% COD_{rem} Efficiency	% COD_{rem} Efficiency
P1-P3	42.1	51.4	65.8
P4-P10	65.4	61.5	48.6
P11	51.8	66.5	47.8

What is the very interesting it does not matter which measure was taken the COD after the aerobic treatment was always around 250mg/L and if no special measure is taken in P11 the COD value was around 150mg/L. It does not matter how the COD degradation is in between in the end these values are reached (Figure 32)

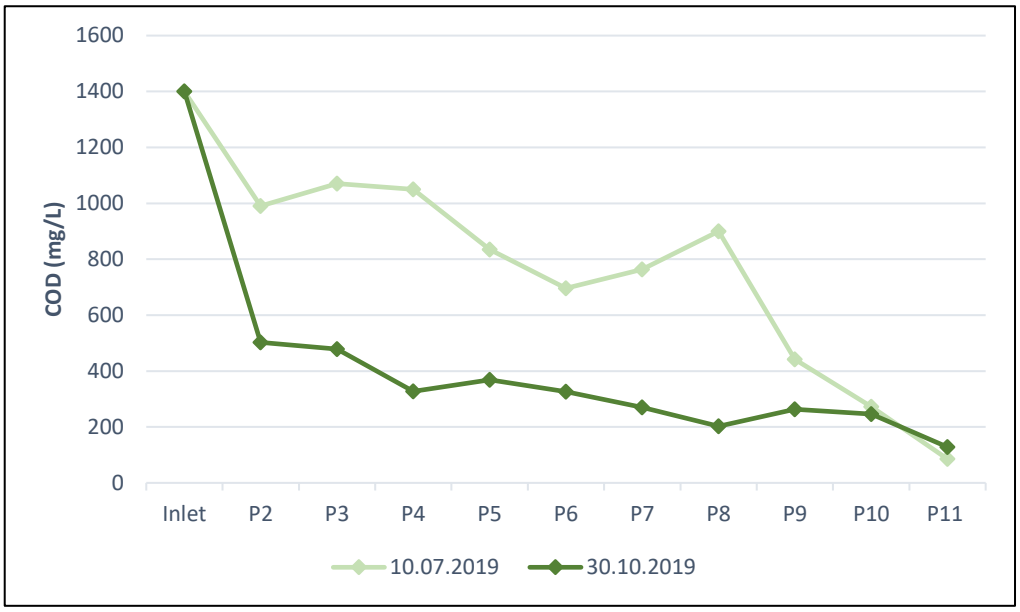
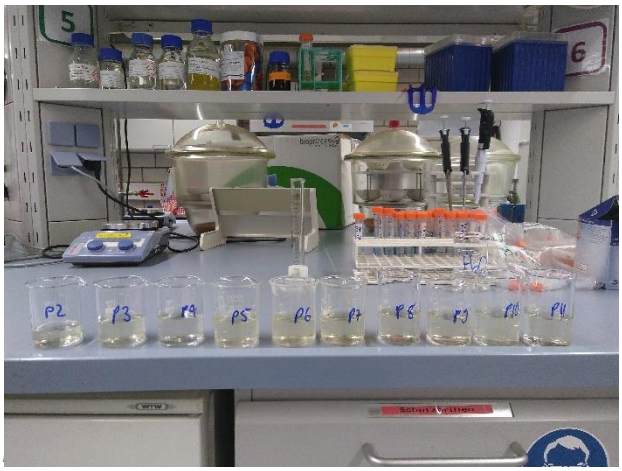


Figure 32 COD values of first (10.07.19) and last (30.10.19) sampling point of the bachelor thesis



the sampling point 30.10.19
Source: Pravin G.Moorthy

In the wastewater there must be some compounds which are very hard to degrade. Another point is that the effluent always has a yellowish colour as it can be seen in Figure 33.

A possible assumption what these compounds could be is that these are humic substances. Humic substances are produced during anaerobic digestion when organic compounds are digested and in high concentration they do colour the water yellow till to brown (Fettig & Steinert, 2000). Humic

substances are close to being non-biodegradable and are the end-point of biodegradation (Ødegaard, et. al., 1999). These are all possible evidences that the substance which is not degradable in wastewater could be humic substances.

If these undegradable compounds are humic substances and the water should be used ones for irrigation, it could even be then favourable as humic substances have a positive influence on plant growth (Vanitha & Mohandass, 2014). Humic substances do not have a direct negative influence but indirect they to help pathogens during disinfection treatment like ozonation or UV-radiation (Koparal, et. al. , 2008). That is why before this water is used for irrigation pathogenic tests needs to be done.

7 Conclusion and recommendations for future research

In this bachelor thesis several modifications were taken on the WWTP "IWB Stöckacker Süd" and many interesting outcomes were achieved. Not only about wastewater treatment systems also about problems which do have an impact on such a system.

First modification of changing the hydraulic flow regime might have worked if there were not such a huge amount of solid wastes around. This shows the complexity of this topic, in some cases this measure does work like in case of E.C Jowett but in the case of WWTP "IWB Stöckacker Süd" it did not work as many other factors do have an influence and the composition of wastewater does matter too.

It could be recognised how important the behaviour of the people is if such a treatment plant is built. The impact of solid waste could be seen in this project and the difficulty of handling these products. It also confirms the quote in the paper of Zeeman et al., 1996*:*

"As mentioned, hydrolysis is generally considered to be the rate-limiting step during the anaerobic digestion of complex substrates. However, usually this is not due to a lack of enzyme activity but to the availability of free accessible surface area of the particles and the overall structure of the solid substrate"

Even if the digestion is disrupted by solid products the digestion rate which has been achieved in this project are comparable with other projects like from Gopala and Bodkhe which have reached similar COD_{rem} rate even if they had screened wastewater (Gopala et al. , 2009)(Bodkhe, 2009).

Through adding new microbes better results in all three biological measures has been achieved and that shows how important the microbes are. A wastewater treatment plant is not only about civil engineering which considers only reactor design, it has a lot to do with ecological engineering. If the right consortia of microbes are found, then the degradation of wastewater can be achieved with a high degradation rate.

This project also showed how important time is when working with anaerobic treatment systems till a change can be seen and that this change has established itself. Lot of patience and time is needed when biological changes are taken. In case of the changing the degradation pathway into dark fermentation it has been showed that the system is going in the right way, but it still has not been established at all and this process needs to be monitored for a longer period.

As still the effluent quality is under the national discharge norms further research and measures needs to be done in the future on this treatment plant. Following measures are recommended:

- *Bioclean TM* should be added again in the aerobic reactor as it has shown some very promising results
- To get better effluent quality recirculation of the wastewater through the treatment system should be considered
- To get the non-degradable components which are quite possible humic substances could be reduced by a recirculation, first through an ozonation and then added back to the anaerobic/aerobic treatment. As through the ozonation the structures of the humic substances get broken and are more easily degradable (Ødegaard et al., 1999).
- If the humic substance want to be kept in the water for irrigation as it has a positive influence on plant growth, pathogenic test needs to be done of the wastewater to see if humic substance help pathogen to survive through AOP treatment.
- Inhabitants needs to be informed again about the problems of solid wastes as the weekly fishing of solid wastes is not a solution.

A very important point to conclude is that this decentralised WWTP "IWB Stöckacker Süd" gives perfect opportunity for research of decentralised wastewater treatment in urban area with approach of reusing the water for irrigation under real life conditions. More research projects should be implemented with this treatment plant.

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Appendix

Appendix A Sample preparation

Test	no preparation	centrifuged	0.45 µm filtration
COD	x		
NO_2-N		x	x
NO_3-N		x	x
NH_4-N		x	x
SO_4		x	x
S^{2-}		x	x
Anionic surfactant	x		
TSS	x		
FOS / TAC		x	
HPLC		x	x

Appendix B Dates on which parameter was measured

Table 15 Dates on which parameter was analysed

	10.07.	24.07.	14.08.	18.09.	01.10.	16.10.	23.10.	30.10.
pH	x	x	x	x	x	x	x	x
DO	x	x	x	x	x	x	x	x
Temp	x	x	x	x	x	x	x	x
CSB	x	x	x	x	x	x	x	x
Anionic surfactant	x		x					
NH4				x	x	x	x	
NO2				x	x			
NO3				x	x	x		
SO4					x			
S2-				x	x			
TSS					x	x	x	
FOS/TAC				x	x	x	x	
VFA					x	x	x	x

Appendix C Inoculation protocol of *Bioclean STP*

Table 16 Inoculation protocol of Bioclean STP

	Bioclean STP	
Date	Where added	Amount [g]
20.6.	ES8	50
25.6.	Inlet	50
27.6.	WC Becanto	50
30.6.	WC Becanto	50
3.7.	WC Becanto	50
5.7.	Inlet	50
7.7.	WC Becanto	50
10.7.	Inlet	50
14.7.	WC Becanto	50
17.7.	Inlet	50
20.7.	Inlet	50
24.7.	house sewer	50
27.7.	house sewer	75
29.7.	house sewer	75
31.7.	house sewer	75
2.8.	house sewer	75
9.8.	house sewer	75
27.8.	ES8	75
1.9.	house sewer	100

Appendix D Inoculaation protocol of *Bioclean TM*

Table 17 Inoculation protocol of Bioclean TM

	Bioclean TM		
Date	Where added	Dosing	Amount [g]
25.6.	Dosing 2h/d @ 1.3L/h		
26.6.	Dosing 2h/d @ 1.3L/h		
27.6.	Dosing 2h/d @ 1.3L/h		
28.6.	Dosing 2h/d @ 1.3L/h		
29.6.	Dosing 2h/d @ 1.3L/h		
30.6.	Dosing 2h/d @ 1.3L/h		
1.7.	Dosing 3h/d @ 1.3L/h		
2.7.	Dosing 3h/d @ 1.3L/h		
3.7.	Dosing 3h/d @ 1.3L/h		
4.7.	Dosing 3h/d @ 1.3L/h		
5.7.	Dosing 3h/d @ 1.3L/h		
6.7.	Dosing 3h/d @ 1.3L/h		
7.7.	Dosing 3h/d @ 1.3L/h		
8.7.	Dosing 3h/d @ 1.3L/h		
9.7.	inlet P11		200
24.7.	reactor P11		200
29.7.	reactor P11		200
31.7.	reactor P11		300

Appendix E Inoculation protocol of MX_3

Table 18 Inoculation protocol of MX_3

	MX_3	
Date	Where added	Amount [L]
6.9.	P1	25
11.9.	P1	25
18.9.	P1	25
24.9.	P1	175
10.10.	P1	250
16.10.	P1	250
23.10.	P1	150

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