TAMPERE UNIVERSITY OF APPLIED SCIENCES

SIMULATION OF AN ANAEROBIC SLUDGE STABILIZATION IN WASTEWATER TREATMENT PLANT

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Bachelor's Thesis
August 2018
Degree Program in Bio and Environmental Engineering

DECLARATION OF AUTHORSHIP

I, Yauheni Karavai, hereby certify that this thesis has been composed by me, that it is the record of work carried out by me and that it has not been submitted in any previous application for a bachelor's degree. This project was conducted by me at the Ostfalia University of Applied Sciences from 06/2018 to 08/2018 towards fulfillment of requirements of Ostfalia University of Applied Sciences and Tampere University of Applied Sciences for the degrees of B. Eng. In Environmental Engineering and Bio and Environmental Engineering under the supervision of Professor Dr.-Ing. Jens Wagner and Professor Dr. Corinna Klapproth and practical supervisor Stefan Kielmeier.

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ABSTRACT

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Nowadays cleaning water becoming more and more popular around the world and with this issue Waste Water Treatment Plants are dealing with. In order to get water clean, there are a lot of steps it needs to go through. The aim of this work was to simulate an existing sewage treatment plant, which is called "Schladen", located in Lower Saxony, Germany with a simulation program Simba# with the data provided by the company. Next step, to model a new sludge stabilization system inside the plant and show the outcome of different possible installations with the same program. 3 simulations were done in order to show that. 1st was the current situation of the plant, 2nd was the new system with primary clarification tank and digesters connected in series and parallelly and the last one was with fine screen instead of primary clarification tank.

The simulations were done, and the results were obtained for all of them. The measured values in the outflow from the plant did not exceed the limits almost for the whole time-period, which was analyzed, and cannot be compared to the real life, due to lack of data provided. Simulation 2 with primary clarification tank was satisfying and showed positive outcome, which cannot be said for the Simulation 3 with fine screen, which was modeled to the program, where the outflow showed high concentrations of total nitrogen, which was up to 4 times higher than the limit as we as the other analyzed parameters.

The amounts of gas outflow from the Simulation 2 was around 513 kg/d of CH_4 and around 590 kg/d of CH_4 for the Simulation 3.

Key words: Simulation, Optimization, WWTP, Simba#, Sludge, Anaerobic, Digester, ASM

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Yauheni Karavai

CONTENTS

ABBREVIATIONS AND TERMS

Fe	Iron
PO_4	Phosphate
NH_4	Ammonium
NO_3	Nitrate
PAO	Phosphate accumulating organisms
O_2	Oxygen
TS	Total solids
COD	Chemical Oxygen Demand
Bio-P Tank	Biological Phosphate Tank
CH_4	Methane
WWTP	Waste Water Treatment Plant
CH_3OH	Methanol
N_2	Nitrogen
CO_2	Carbon dioxide
NO_2	Nitrite
H_2O	Water
OH^-	Hydroxide
H_2S	Hydrogen sulfide
CH_3COOH	Acetic acid
ASM	Activated sludge model
HRT	Hydraulic retention time

1 INTRODUCTION

That is true that long time ago people have faced a problem with waste water and were trying to find solutions to this issue. The reason for that was in chemicals that contains that waste water. Some of them can be dangerous in even small concentrations and can badly affect an environment or living organisms.

Nowadays waste water is coming from different places such as homes, industries, businesses or even from storm runoff. For the term wastewater can be taken all used water. Human waste, oils, soaps, chemicals and food scraps can be included inside such water. As it was mentioned before about the ways the wastewater is coming from, homes, for instance, the origin of it comes from sinks, bathtubs, washing machines, dishwashers or showers. Also, that is true that some people think that water from rain, which goes down the street is totally clean. However, this is not true as it contains all the chemicals and stuff that was washed off roads, parking lots and rooftops. (Perlman, 2016)

One of the most common elements in wastewater are nutrients (phosphorus and nitrogen), hydrocarbons, heavy metals and microbes. (Akporand et al, 2014)

Before the treatment, nitrogen is usually in a form of ammonium (NH_4) and organic nitrogen and at the same time, phosphorus, is in the form of soluble orthophosphate ion, organically-bound phosphate or some other phosphorus/oxygen form (Akporand and Muchie, 2011). Water clarity level is decreased due to the presents of algal blooms in water. And it leads to the depletion of dissolved oxygen in receiving water bodies. And low dissolved oxygen in water bodies is the reason for the death of aquatic life. As well, excessive nutrient proliferation in water can be the reason to the growth of some microbes. And those microbes can be harmful for our bodies. For instance, *Pfisteria.* It can cause eye and respiratory irritation, gastrointestinal complaints or headache. (Akpor. et al, 2008)

Moreover, hydrocarbon pollutants are known to lead to several health and environmental problems. They are threat to fishery, marine habitats of wildlife, human health and that is true that in order to return of ecological balance it might take a lot of time. (Zhag et al, 2011)

Heavy metals, such as zinc, copper and iron can be presented in high concentrations and can became detrimental (Samir and Ibrahim, 2008). And that is obvious that the composition of heavy metals in water can lead to problems with aquatic organisms as those metals are becoming a part of food chain and later on can be affecting human bodies trough fishes for instance. (Dhokpande and Kaware, 2013)

From the research of Kris (2007) it can be said that a lot of microorganisms, which were born in water and can cause some disease are from fecal wastes, which are from humans or animals that contain these diseases. Untreated water can be a vehicle for some water-related diseases, such as cholera, shigellosis, salmonellosis, giardiasis or typhoid fever etc.

Due to all those problems, mentioned above, there is a need to deal with waste water and clean it. Nowadays a lot of countries are using Sewage treatment plants for that purpose and in this report mostly the talk would go about them.

Sewage treatment plant is the place, where the waste water is coming from different sources and with different steps, which would be explained further, cleaned as much as possible and returned to the user. And the wastes from it can be used for some other purposes, such as composting for instance.

Next topics of this report are modelling and simulation, where an already existing abject, in this case the plant is created in a program, all needed elements are added and it is ready for simulation, which is showing the results as the outcome. In the model it is possible to do the changes fast and start it over and over again, till the point, when the needed result would be achieved. That is the main advantage and important part before making any changes or constructing a plant, where it can be seen what is working and what is not.

During the process of the sewage treatment plant, parallel to the cleaned water, one more outflow can be seen. That is a sludge. Nowadays, there are a couple of ways in order to process the sludge. That can be also a combination of methods. For instance, thickening, digestion and dewatering processes. Thickening is usually the first step in a sludge treatment. That is because it is hard to handle a sludge, which is thin and with this process the sludge volume can be decreased even half from the original sludge volume. That is usually happening with a help of gravity in a tank, which is called gravity thickener. (Encyclopaedia Britannica, 2018)

For the digestion, it can be said that it is a biological process, which is widely used in Germany nowadays. Organic solids are decomposed into stable substances. Digestion destroys pathogens and total mass of solids. There are different types of digestion systems, which would be explained later. (Unep.or.jp, 2018)

Next one was dewatering, where water is taken out from it. Besides it can still contain a lot of water, up to 70 %, it is not any more behaving as a liquid and can be handled as a solid material. It is usually happening before disposal. (Unep.or.jp, 2018)

Furthermore, based on Encyclopaedia Britannica (2018), it is also true that there are alternatives to the most common possibilities and they are centrifuge, rotary drum vacuum filter and the belt filter press. These mechanical systems require less space than do sludge-drying beds, and they offer a greater degree of operational control.

The final step of the treated sludge usually is the land. It can be buried underground in a land field or used in the agriculture to make use of its value as a soil conditioner and fertilizer. And that is true that sludge can contain toxic chemicals and that is why it is not spread in land, where crops are grown for human consumption. (Encyclopaedia Britannica, 2018)

2 THEORY

2.1 Constituent of a sewage treatment plant

The constituent of a sewage treatment plant can vary from the plant itself and here, the main parts of it would be explained and showed.

The Figure 1 below illustrates the main parts of the sewage treatment plant. The numbers from 1 to 6 was used in order to mark the main parts.

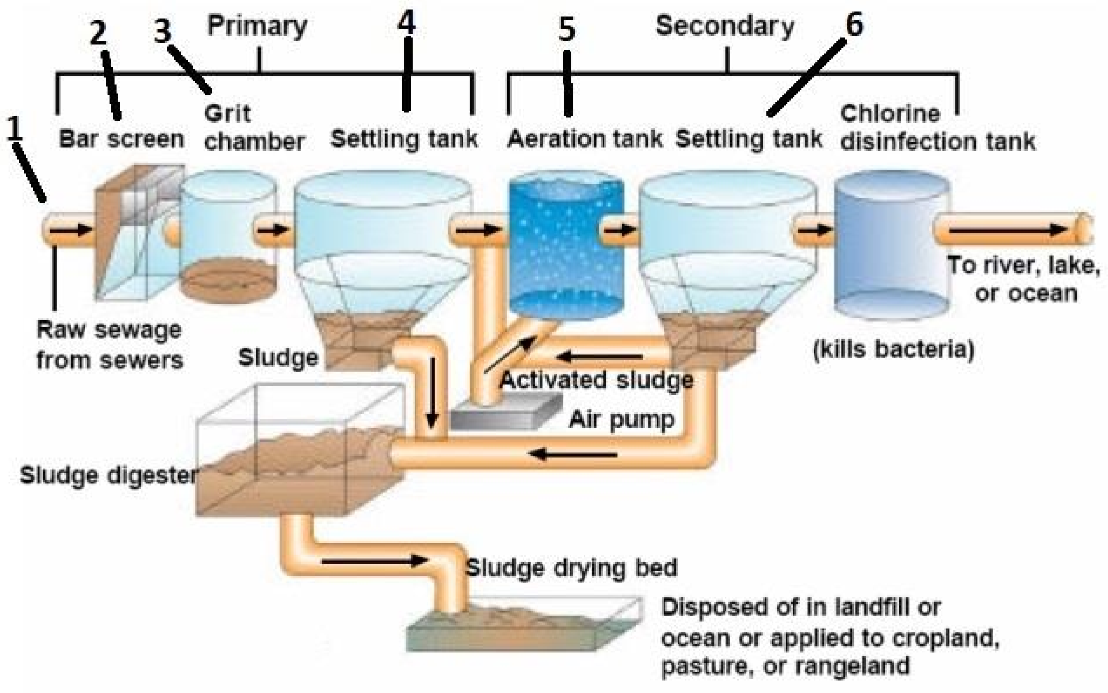

Figure 1 Scheme of a sewage treatment plant. Lesson C1: Operation and Management of wastewater treatment plant (2006)

First marks 1 and 2 are sewer system and preliminary treatment, which were not used in modelling this project. That is why we are going further to primary treatment.

2.1.1 Primary treatment

In here, primary settling tank (Figure 2) can be found. Waste water is driven towards the hopper in the base of the tank. Hopper arm is moving around the edge of the tank at small velocity. Particles, with high sedimentation velocity then the flow velocity settle on the bottom of the tank and treated water heads toward edges (Figure 1[3]).

Figure 2 Primary settling tank (Tankonyvtar.hu, 2018)

It is also called primary clarification tank. In this tank the primary sludge is separated from the wastewater. From here the sludge is going for next treatment process and separated water is going for secondary treatment. (Tankonyvtar.hu, 2018)

2.1.2 Secondary/Biological treatment

Secondary treatment of sewage is designed to substantially degrade the biological content of the sewage. That is happening usually with a help of biological processes.

One of the first steps in secondary treatment is Aeration tank (Figure 3), which is based on pumping air into tank and that is the reason, why the microbes are growing in the wastewater (Figure 1[4]). Those microbes are growing due to the fact that they are using organic material, forming flocks and they can easily settle out. Then, bacteria are settling in a separate settling tank and forming activated sludge (Figure 1[5]). Which, at the same time recirculated back to the aeration basin to increase the rate of decomposition. Activated sludge is aerated sewage, which contain aerobic microorganisms. (Byrne, 2018)

Figure 3. Aeration tank (Curriculum, 2018)

In the aeration tanks main process of water cleaning is happening. There are two main steps there, such as nitrification and denitrification.

Nitrification is the sequential conversion of ammonia to nitrite and ultimately nitrate. The formulas can be seen below. Formula 1 represents the process from ammonia to nitrite and formula 2 from nitrite to nitrate. (ECOS, 2018)

$$NH_4^+ + 1.5O_2 \rightarrow NO_2^- + 2H^+ \quad (1)$$

$$NO_2^- + 0.5O_2 \rightarrow NO_3^- \quad (2)$$

Ammonia in wastewater can be from variety of sources such as proteins, urea, raw materials, cleaning chemicals, amino acid products, casein etc.

Nitrification happening under aerobic conditions in an activated sludge system or other biological treatment systems. It is a bio-chemical reaction and occurs inside bacteria. For this process two types of bacteria are used *Nitrosomonas* and *Nitrobacter*. They are autotrophic bacteria and that means that they are getting their carbon source from inorganic carbon or carbon dioxide. (ECOS, 2018)

And denitrification is the process by which nitrates are reduced t gaseous nitrogen by facultative anaerobes. The formula 3 below shows the denitrification process.

$$6NO_3^- + 5CH_3OH \rightarrow 5CO_2 + 3N_2 + 7H_2O + 6OH^- \qquad (3)$$

The organisms carrying out this process are called denitrifies. In general, they are heterotrophic bacteria that metabolize readily biodegradable substrate under anoxic conditions using nitrate as the electron acceptor. If oxygen is available, these bacteria use it for metabolism before they use the nitrate. Therefore, dissolved oxygen concentrations must be minimized for the denitrification process to function properly. (Sewage Treatment - Reverse Osmosis - Waste Water Treatment, 2018)

After, comes secondary clarifiers. The primary purpose of them is to separate and remove solids, biomass, which was produced in biological process. It is also thickening solids for recalculation. The Figure 4 shows secondary clarification tank.

Figure 4. Secondary clarification tank (Indiamart, 2018)

The difference between primary and secondary clarification tanks is that the sludge from the primary clarification tank is a result of the capture of suspended solids and organic. Meanwhile, the sludge from the secondary clarification tank is the biomass from the microorganisms, which were feed with organic material from wastewater.

2.2 Sludge stabilization

Ones sludge was thickened, the process of sludge stabilization is taking part. Coarse primary solids and secondary sludge should be treated before disposal because they are often indivertibly contaminated with toxic organic and inorganic compounds and is nutrient rich.

There are 3 main sources/places in the plant, where the sludge is coming from. First is the primary sludge, which is produced by settleable solids removed from raw wastewater in primary clarification tank. It has a good dewaterability when compared to biologic sludge. TS content is in a range between 2 and 7 percent (Turovskiy and Mathai, 2006). Secondary sludge is the next one. It is produced by biologic processes such as activate sludge systems. It contains microorganisms grown on biodegradable matter. TS content in this case is about 1 percent. And the last is chemical sludge, which is produced by precipitation of specific substances (phosphorus) or suspended solids. (Publications, 2018)

There is a term, called sludge age, which is measure of the length of time a particle of suspended solids has been under aeration. That is expressed in days. Sludge age is used to maintain the proper amount of activated sludge in the aeration tanks. To calculate the sludge age, it is necessary to know the amount of suspended solids (kg) that are in the aeration tank and the amount of suspended solids (kg) that enter the aeration tanks daily. (KY OCP, 2018)

The main goals of sludge stabilization are: to reduce pathogens, elimination of odour, reduction of organic matter and preventing or inhibiting future decomposition. There are biological and chemical sludge stabilization. Biological treatment is most common in Germany nowadays. Chemical is done with adding lime to the sludge to alter the value of pH to a high level (more then 11). Microorganisms cannot survive in a such environment. On the other hand, there is a biological stabilization, which utilizes biological/microbiological agents to reduce organic matter in the sludge. There are many digestion technics known nowadays, such as anaerobic digestion, aerobic digestion and composting. Two first would be further described in this report. (Progressivegardening.com, 2018)

2.2.1 Aerobic

Aerobic digestion is a process, which is treating the secondary sludge from the biological waste water treatment process. That is true that secondary sludge is mostly insoluble, and it is the biomass of microorganisms. And the purpose of aerobic digestion is to degrade insoluble solids in an aerobic environment. For this purpose, aerobic digesters are used. They are continuous stirred tank reactors, which are bubbling and mixing oxygen into the liquid in the tank. With an oxygen supply, the process can be significantly accelerated. (Progressivegardening.com, 2018)

With constant feeding the raw secondary sludge into the tank punctuated with supernatant and sludge withdrawals, the aerobic digester is operating. Those digesters are aerated continuously, while the tank is filling and after filling as well. After stopping the aeration, the solids are allowed to settle. That is happening because of gravity. (Progressivegardening.com, 2018)

Aerobic digestion of municipal wastewater sludges is based on the principle that, when there is inadequate external substrate available, microorganisms metabolize their own cellular mass. In actual operation, aerobic digestion involves the direct oxidation of any biodegradable matter and the oxidation of microbial cellular material by organisms. Formulas 4 and 5 shows the process.

$$Organic\ matter + O_2 \rightarrow Cellular\ material + CO_2 + H_2O \quad (4)$$

$$Cellular\ material + O_2 \rightarrow Digested\ sludge + CO_2 + H_2O \quad (5)$$

Formula 5 describes the endogenous respiration, which is normally the predominant reaction on aerobic digestion. (Shammas et al, 2007)

Based to study of Shammas et al (2007), the advantages of aerobic digestion can be seen below:

1. Costs are lower compared to anaerobic systems
2. Easy to operate compared to anaerobic systems
3. Do not generate nuisance odour
4. Will produce a supernatant low in BOD, suspended solids and ammonia nitrogen
5. Stable humus in end product is produced
6. Reduce the quantity of grease in the sludge mass
7. Reduce the number of pathogens to a low level

Disadvantages are listed below (Shammas et al, 2007):

1. Production a digested sludge with very poor mechanical dewatering characteristics.
2. Have high power costs to supply oxygen, even for small plants.

Aerobic sludge digestion can be used to reduce both the organic content and the volume of the sludge. As was described above with formulas 4 and 5, that under aerobic conditions, a large portion of the organic matter can be oxidized to carbon dioxide and water. Aerobic sludge digestion can be design for batch and continuous flow operations. In batch operation, sludge is added to a reaction tank and meanwhile the contents are continuously aerated. After the tank is filled, the sludges are aerated from 2 to 3 weeks. It depends on the sludge type. After, aeration stopped, and solids and liquids are separated. In continuous flow system, an aeration tank is utilized, followed by a settling tank. (Encyclopedia.com, 2018)

Aerobic sludge digestion is usually used only for biological sludges from secondary treatment and with no sludge from primary treatment units. The most commonly used application is for the treatment of sludges wasted from extended aeration systems (which is a modification of the activated sludge system). (Encyclopedia.com, 2018)

2.2.2 Anaerobic

On the other hand, there is an anaerobic digestion, which is carrying out without oxygen supply. It can be thermophilic digestion, where sludge is fermented in tanks at 55 degrees Celsius or mesophilic at 36 degrees Celsius. That is true that thermophilic digestion is more expensive, because of energy consumption in order to heat the sludge. (Progressive-gardening.com, 2018)

Anaerobic digestion has been used for a long time already. Mostly, for the managing animal wastes. It is simple process, which can reduce organic matter. As well, it can be mentioned here that almost any organic material can be processed with anaerobic digestion, starting from waste paper, food, sewage and ending with animal waste. (Progressivegardening.com, 2018)

Anaerobic digesters generate biogas, which can be used in different ways, either to heat the tanks and run some engines or, it can be sold out to get profit. On the other hand, there are some disadvantages in this process, such as costs and as well time. In order to get biogas out of this process, it can be up to 30 days that you need to wait. (Progressive-gardening.com, 2018)

The overall conversion process of complex organic matter into carbon dioxide and methane can be divided in four steps, which are Hydrolysis, Acidogenesis, Acetogenesis and Methanogenesis. (Publish.extension.org, 2018)

The first step of anaerobic digestion is hydrolysis. Usually biomass comprised of very large organic polymers and with this first step, those polymers, namely proteins, fats and carbohydrates are broken down into smaller molecules such as fatty acids, amino acids and sugars. (Publish.extension.org, 2018)

Next one is acidogenesis. It is also called fermentation. These fermentative bacteria, which is located there produce an acidic environment in the digester, while creating ammonia, H_2, CO_2 and H_2S, carbonic acids, alcohols and trace amounts of other by-products. During this process again, the organic matter breaks down, however, to produce methane, organic matter is still too large. (Publish.extension.org, 2018)

Further step is Acetogenesis. In there, there is an acetate creating as well as derivative of acetic acid from carbon and energy sources by acetogens. Acetogens catabolize many of the products created in acidogenesis into acetic acid, CO_2 and H_2, which are used by methanogens to create methane. (Publish.extension.org, 2018)

The last step is Methanogenesis, where methanogens create methane from the final products of acetogenesis as well as from some trace elements from all the stages. There are two main paths in order to crate methane in methanogenesis. See formulas 6 and 7.

$$CO_2 + 4H_2 \rightarrow CH_4 + 2H_2O \quad (6)$$

$$CH_3COOH \rightarrow CH_4 + CO_2 \quad (7)$$

While CO_2 can be converted into methane and water through the reaction, the main mechanism in order to create methane in methanogenesis is the path involving acetic acid. This path creates methane and CO_2, the two main products of anaerobic digestion. (Publish.extension.org, 2018)

The advantages of anaerobic digestion can be seen below (The Anaerobic Digestion Biofuels Blog, 2018):

1. It is an energy producing process which produces renewable energy in the form of biogas
2. It produces a liquid and a fibrous fertilizer
3. It reduces odour below unprocessed waste odour levels
4. The effect of the fertilizer is loner lasting than for untreated organic waste
5. Less luckily to cause environmental pollution than spreading organic waste on land.
6. Low biological solids yield which means less wasting than seen in aerobic treatment

And disadvantages of such system can be seen below (Biological Waste Treatment Expert, 2018):

1. High investments
2. If run inefficiently AD can cause an odour nuisance.
3. Methanogenic archaea are slow growing microbes
4. Does not remove ammonia-nitrogen
5. Temperature should be controlled the whole year

6. Not all materials can be processed with such system and some of them are better with aerobic digestion.

2.3 The Schladen treatment plant

In this report, the Schladen sewage treatment plant is analysed. It is based in Lower Saxony in a town, which is called Schladen. The Figure 5 shows the map, taken from the google maps with a view of Shladen treatment plant.

Figure 5. Schladen sewage treatment plant. Google satellite

The Schladen treatment plant is a sewage treatment plant with 14,000 population equivalents, which is operated as a wastewater treatment plant with aerobic sludge stabilization.

Below, it can be also seen the Figure 6 with schematic illustration of the Schladen sewage treatment plant with markings. As it can be noticed form the Figure 6, plant has Grid (1), sedimentation tank (2), Bio-P tank (3), which is 615 m^3, 2 Aeration tanks (4), each 2230 m^3, 2 Secondary clarification tanks (5), each 1300 m^3, measurement point (6), Sludge tank (7), soil humification field (8), pond (9).

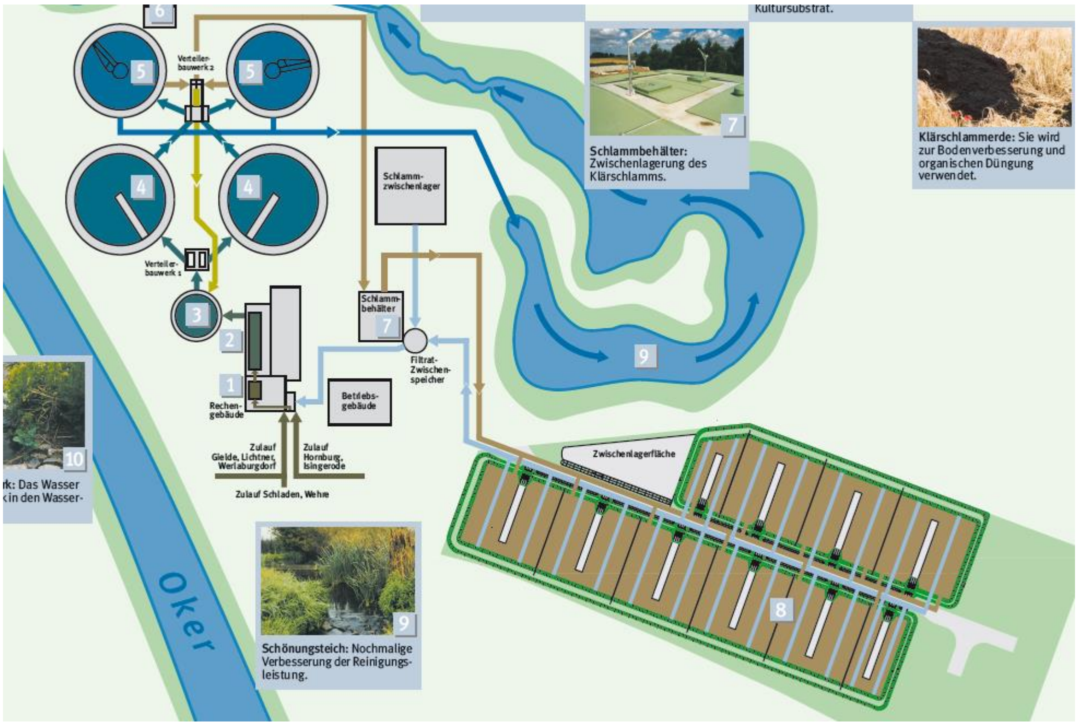

Figure 6. Scheme of Schladen sewage treatment plant (Schladen, 2018)

Moreover, on the Figure 6, it can be seen the sludge tank, which is located on the right from the aeration tanks.

The Bio-P tank is the Biological phosphate tanks, which is also called return sludge denitrification. Inside this tank, wastewater is mixed with the recycled sludge. Moreover, there is happening the accumulation of phosphate accumulating organisms (PAO) and that is the reason it is called Bio-P tank.

The plant is operated with a mode, called intermittent denitrification, where the aeration in aeration tanks controlled by the controllers.

Based on the data from the company, the process runs as following. First, it is a nitrification process, which is 1-hour long. It is done with aeration with 1.3 mg/L (O_2). Then, the amount of NH_4 is checked and if the concentration is > 4 mg/L, then it blows Further, until it changes to < 3 mg/L, up to 2 hours. As well, if after 1-hour nitrification, the concertation of NH_4 is < 4 mg/L, then the blowers stop. Then comes to denitrification phase. In there, the is 1 hour of not aeration and in this case, the concertation of NO_3 is checked. If after 1 hour the concertation of NO_3 is < 0.5 mg/L the aeration starts again and if it is happening till the point that the concertation would be > 2 mg/L. And if after 1 hour of not aeration the concertation of NO_3 > 3 mg/L, there is 1 hour more of not aeration.

2.4 Activated sludge models (ASMs). ASM 3 Bio-P

Activated sludge models are mathematical models, which are describing biological and chemical reactions occurring in activated sludge systems. There are already some models existing and the first one was ASM 1, which was done in 1987. All of those models combining inside a lot of parameters, which are describing the process of WWTP system behaviour. Things, such as carbon oxidation, nitrification, denitrification and a lot of other reactions between large number of components. (Henze et al, 2000)

The ASM 3 model was published in 1999. Of course, there are other models, which were coming to public between 1987 and 1999, which were the improvements of the previously done ones and they were mostly combining previous information with a new one. ASM 3 gives better understanding of the biological processes in order to simulate nitrification, denitrification and degradation of COD. This model describes storage of organic substances, decay of heterotrophic organisms by endogenous respiration and smaller anoxic yields for the heterotrophic organisms. After this model, in 2 years, in 2001, Bio-P mode was integrated inside, which allows for the prediction of enhanced biological phosphorus removal. In order to see all the changes and modifications of the system, the handbook for ASM 3 Bio-P can be checked as well as all exact features and characteristic of models. (Henze et al, 2000)

During this thesis, ASM 3 Bio-P was used in order to create a simulation, which one of the latest updates of all the simulation systems and was better describing all the processes happening during the treatment.

2.5 SIMBA# simulation software

In order to module Schladen sewage treatment plant, the program, called SIMBA# was used, which was provided by practical supervisor. That is a computer modelling program, which can be used in order to model a plant. It is a modern simulation platform for mathematical modelling, optimization and management of wastewater treatment plants. It has a big library for the dynamic modelling and simulation of wastewater treatment plants, and even rivers. (Inctrl.ca, 2018)

With a help of this program it was possible to simulate the analysed sewage treatment plant by inserting all parts of it, connecting them and adjusting the data, which was given by the personal of a Schladen sewage treatment plant. The process of modelling the existing plant described in the section METHODS as well as the modelling of a plant with new elements.

The activated sludge model 3 Bio-P was used in Simba# in order to model the sewage treatment plant.

The Appendix 1 illustrates the interface of it.

There are a lot of different blocks available in this program, which illustrates and works as the real parts of the plant in real life. That is happening due to the ASM inserted to the program. In order to simulate something, there is a need to choose the right blocks, connect them correctly and choose the needed parameters, which can be easily adjusted at any time of modelling. That was the main reason to use modelling in order to check the results of the simulation. All the blocks and their explanations can be seen in the Simba# manual, where all the blocks are illustrated and explained how they are working. As well, in the manual, there is an explanation for the processes and for the models, inserted to the program.

3 METDODS

In order to simulate all the situations in Schladen sewage treatment plant modern simulation platform for mathematical modelling, optimization and management of wastewater treatment plants program SIMBA# was used.

Before starting main simulation of each case, 1 year was simulated in order to start all the processes and after that, the starting point was saved and only after that, the real simulation started. That was done individually for all simulations.

3.1 Simulation 1. Current situation in Schladen treatment plant with aerobic sludge stabilization

As it was already mentioned in the Theory section in a paragraph about Schladen sewage treatment plant, there are 8 main elements on their territory (p.20). However, not all are needed in order to simulate the program. The simulation of it was called simulation 1.

The data about the sizes of the tanks and as well the flows was taken from the company database. Due to the fact that the company had troubles with a program that measure all of those values in order to give the values from the current period, the inflow data was used during this thesis work was from 1st of September 2010 till 31st of August 2011.

Moreover, the outflow data was taken for the period between 1st of September 2003 till 31st of August 2004, due to lack of data for the years 2010 and 2011.

The Figure 7 on the next page represents the Schladen sewage treatment plant simulation 1, which was done with Simba# modelling software by using activated sludge model 3 Bio-P. The Figure 7 shows mostly the inflows and outflows of the plant. The detailed view on the main parts of the plant can be seen later.

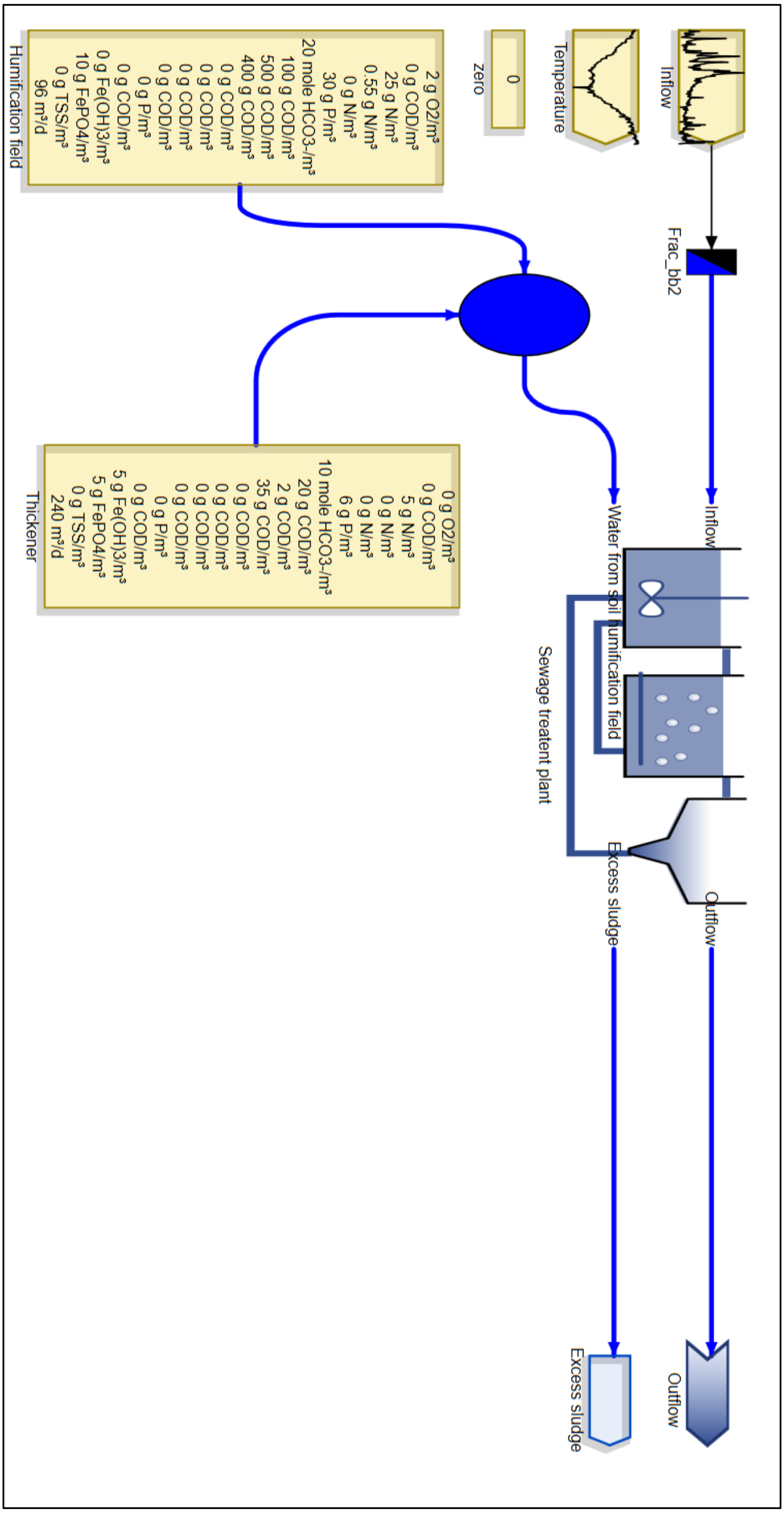

Figure 7. Simulation 1. Schladen sewage treatment plant

Figure 8 shows more detailed view on the flows and connections inside the plant.

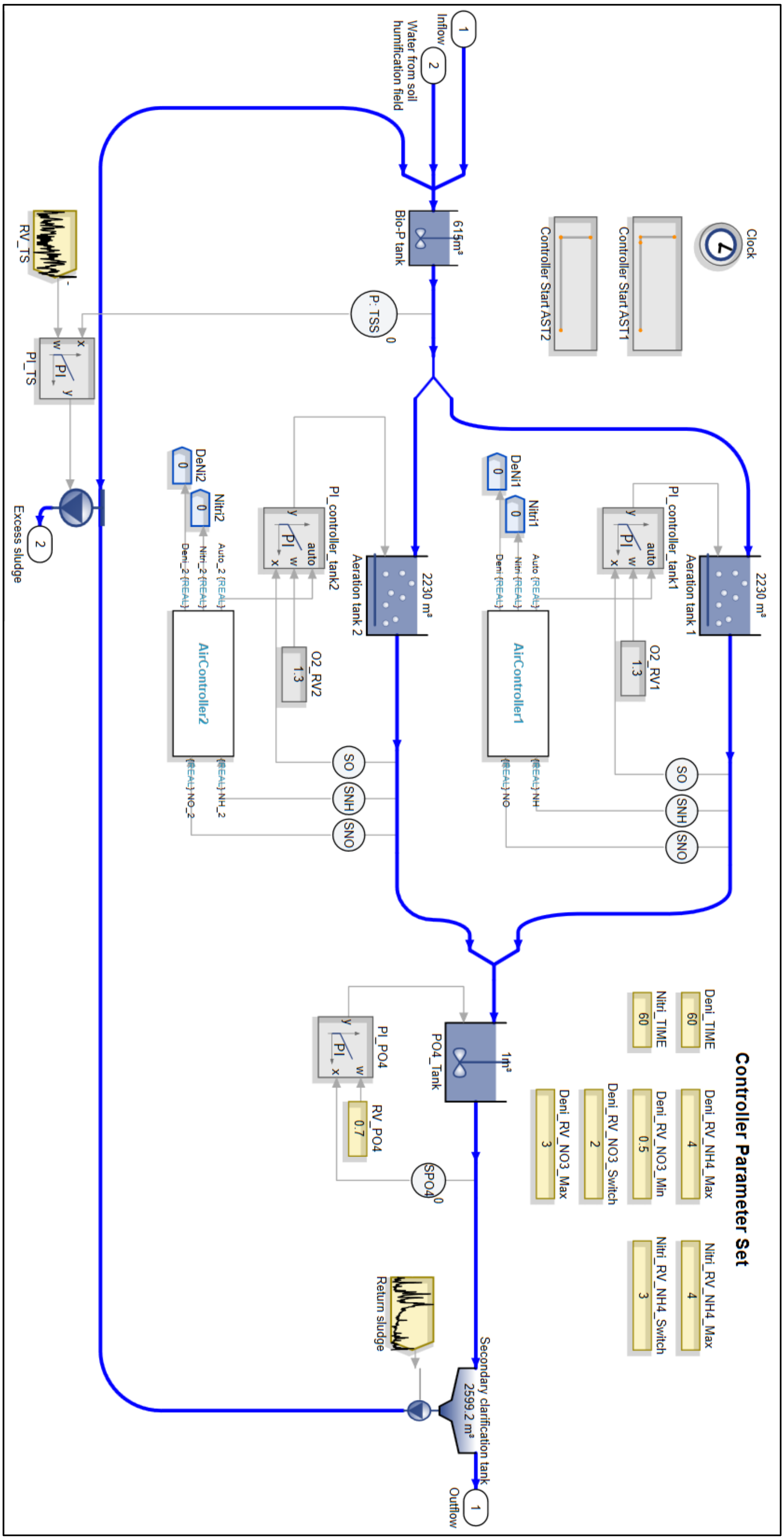

Figure 8. Simulation 1. Schladen sewage treatment plant. Detailed view

In order to show the inflow of the waste water and the water from the soil humification field, 2 influent blocks were created. The data from the company was used to put it to the inflow block. Moreover, there was a fraction data block, called “Frac_bb2” which fractionate the starting data.

There it can be seen “zero” block and “temperature” block, which were used with the hidden connections to some of the parts. For instance, temperature to the Bio-P tank or aeration tanks. And zero for the Bio-P tank for the inflow for Fe. The temperature variation can be seen on the Figure 9 below.

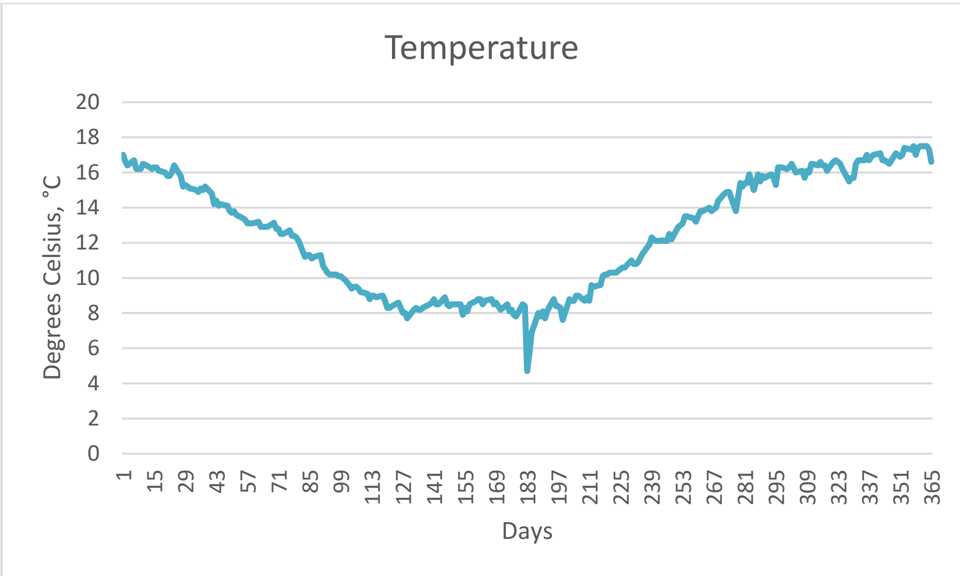

Figure 9. Temperature change between 01.09.2010 and 31.08.2011

Further, 2 outflows can be seen. The first outflow was the outflow of cleaned water and the second one was the excess sludge outflow.

Meanwhile, there were 2 blocks, which represents the flow from the Humification field and from the thickener. This data was provided from the company Schladen. Those 2 inflows were connected to the main part as was shown of the Figure 7.

In the detailed view, it can be seen again 2 inflows, 1 was the waste water inflow, which comes to the sewage treatment plant, and the second one was the inflow from the soli humification field (Figure 6, number 8) (p.21). Next goes the Bio-P tank, which can be also called return sludge denitrification tank with the volume 608 m^3 and the high of the tank 3.95 m and 2 aeration tanks (Nitri blocks) with 2230 m^3 volume of each. Then, there was a secondary clarification tank with 2600 m^3 volume, which in this case we have only one, besides the fact that the Schladen sewage treatment plant has 2. That is because there is no difference for the program how much of them we have, and it gives the same value. That means it separates the sludge almost 100 % from the water. And the number of tanks is irrelevant in that case. Finally, there were 2 outflows: the outflow with a cleaned water and the excess sludge outflow.

The data of the inflow and the inflow main parameters can be seen from the Figures 10-13.

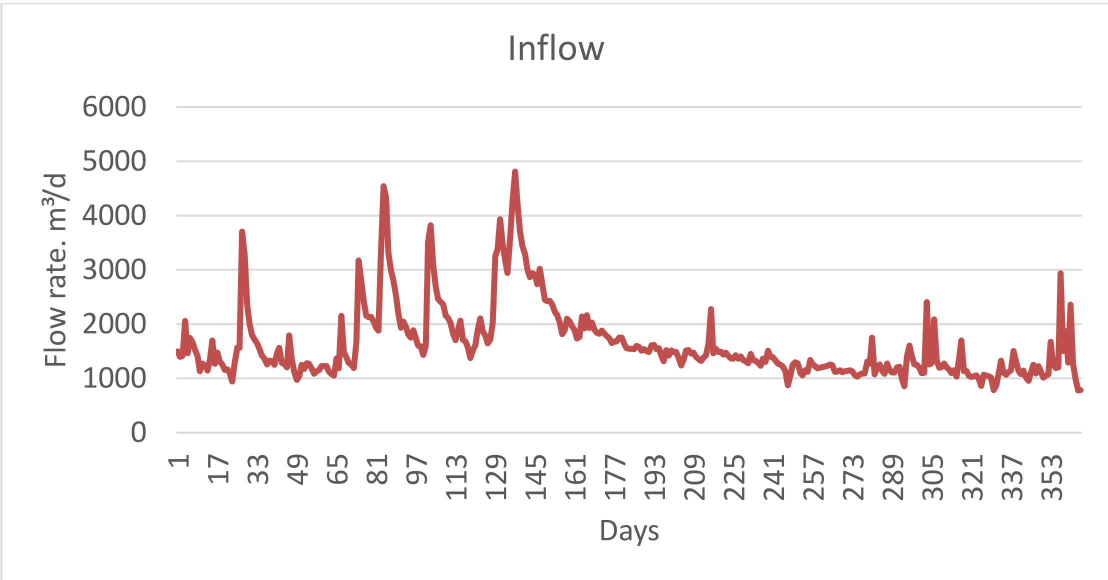

Figure 10. Inflow rate between 01.09.2010 and 31.08.2011

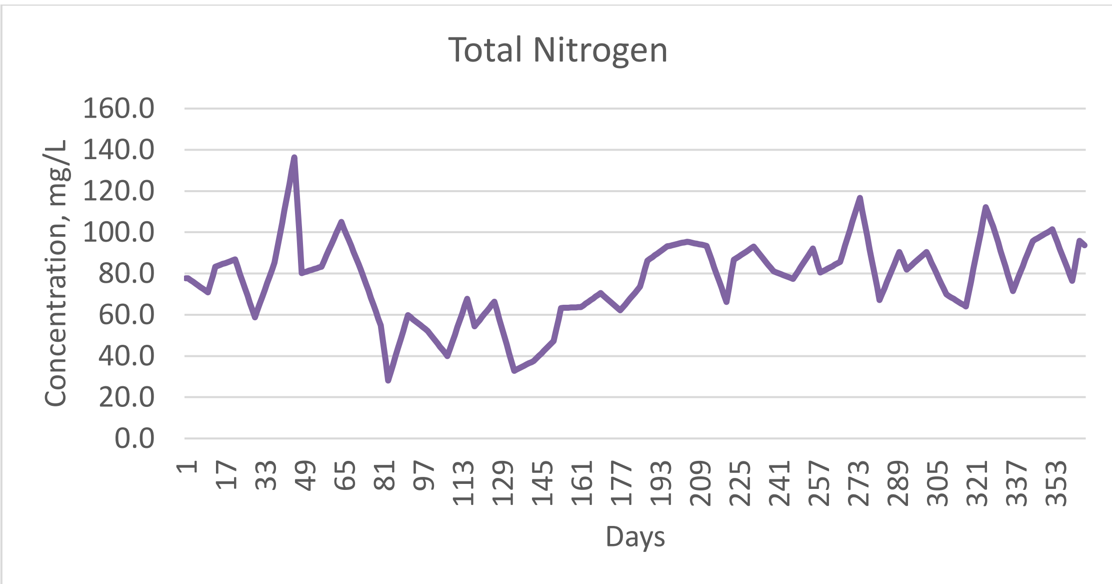

Figure 11. Total Nitrogen inflow data between 01.09.2010 and 31.08.2011

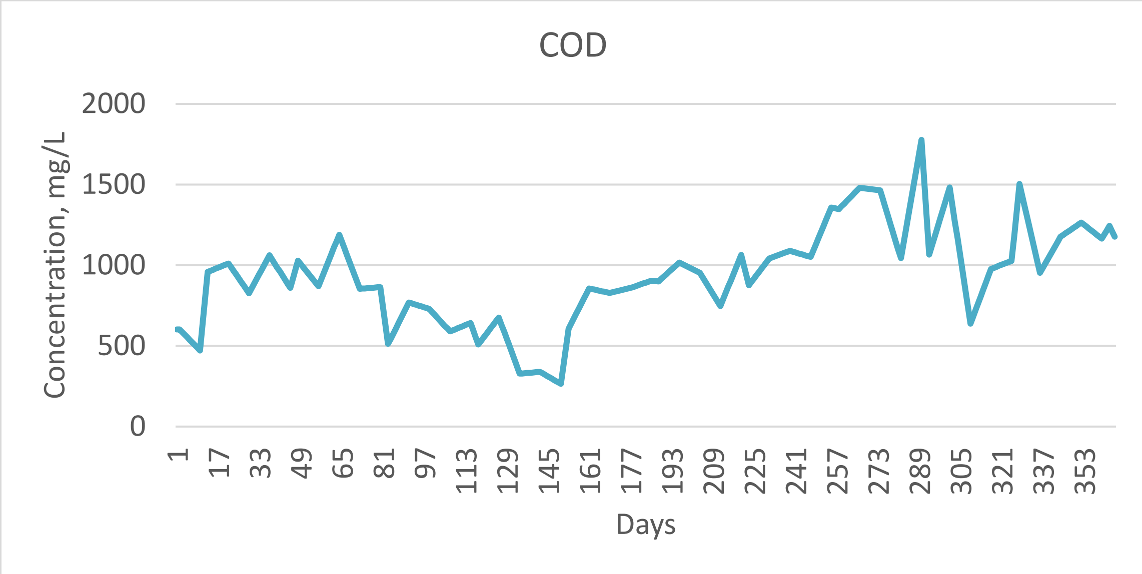

Figure 12. COD inflow data between 01.09.2010 and 31.08.2011

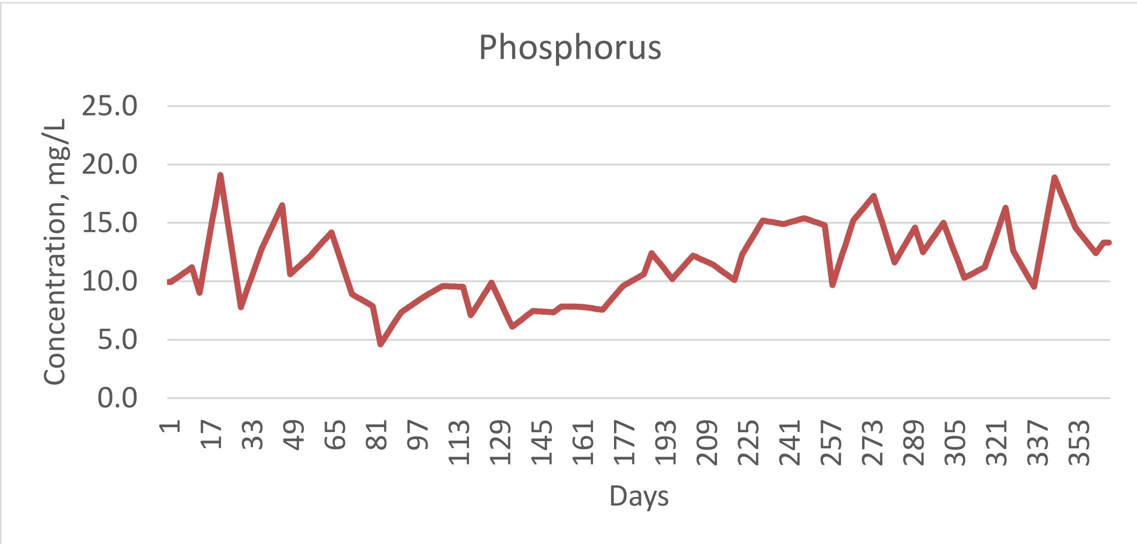

Figure 13. Phosphorus inflow data between 01.09.2010 and 31.08.2011

Moreover, the "PO4_tank" can be seen from the Figure 8, however, that is not a real tank, it is just a place, where the 2 flows from the aeration tanks were mixing and there a measurement of PO_4 was done. That was done in order to implement it to the SIMBA# program. There was a control block next to it, which was called "Pl_PO4". The reference value was set to 0.7 mg/L.

Next step was to connect those parts. The direction of the flows can be seen with arrows. As well, the pump was added in order to process the excess sludge flow. Moreover, as it can be seen from the Figure 8, there are 3 inflows and 1 outflow in the aeration tanks. For the input, there was 1 inflow of the water, then, air flow. Moreover, there was one more input there, which was temperature, which had a hidden input and it was used in several tanks and in order not to clutter up the figure, it was decided to hide it and it can be seen on the main page.

Further, control blocks were added to each of the aeration tanks. They are controlling dissolved oxygen, which can be seen on the right and was called “SO”. Control blocks were called “Pl_Controller_tank1” and “Pl_Controller_tank2”. Each of them had 3 inputs: w – reference value and x – controlled variable. And “auto”, which was a switch between automatic and manual mode. The reference value is the value, which is also called “must have” value and those control block were controlling the amount of oxygen, for instance, to be on specific level. And controlled variable was the element, which need to be controlled. As well, it can be seen that there are lines, which were going to the aeration tanks from each of control blocks. The reference value for oxygen was set to 1.3 mg/L.

Moreover, it can be seen a block, called “AirController”, which represents the programmed formula for a switch between aeration and not aeration. The Programmed code can be seen in the Appendix 2.

As well, there are 2 blocks in each of aeration tank, which are sinks, they were called “Nitri1”, “DeNi1” and “Nitri2”, “DeNi2”, which were created in order to see which of the Nitrification or Denitrification mode is “ON” at specific time period.

And Clock block was created in order to program the process, as there was supposed to be a starting point and it was as a reference value for programming the time. It is connected via hidden connection to the air controller input and can be seen on the right.

Then, there “Controller Start AST1/2” blocks were created as well. They were giving signals to the “Air Controller” blocks 1 and 2 in order to let them work.

On the right side of the Figure 8 can be seen Controller Parameter Set, which was also connected to the Air controller 1 and 2. Those were values, needed for programming. For instance, “Deni_RV_NH4_Max” was created in order to control to top range of the concentration of NH_4 in the program, which was in mg/L.

Next, control block “Pl_TS” was added in order to control the pump, which was taking the access sludge and as well as measurement block of Total solids, which was called “RV_TS”. There, it can be seen the reference value for the TS, taken from the data from the company. The data can be seen on the Figure 14.

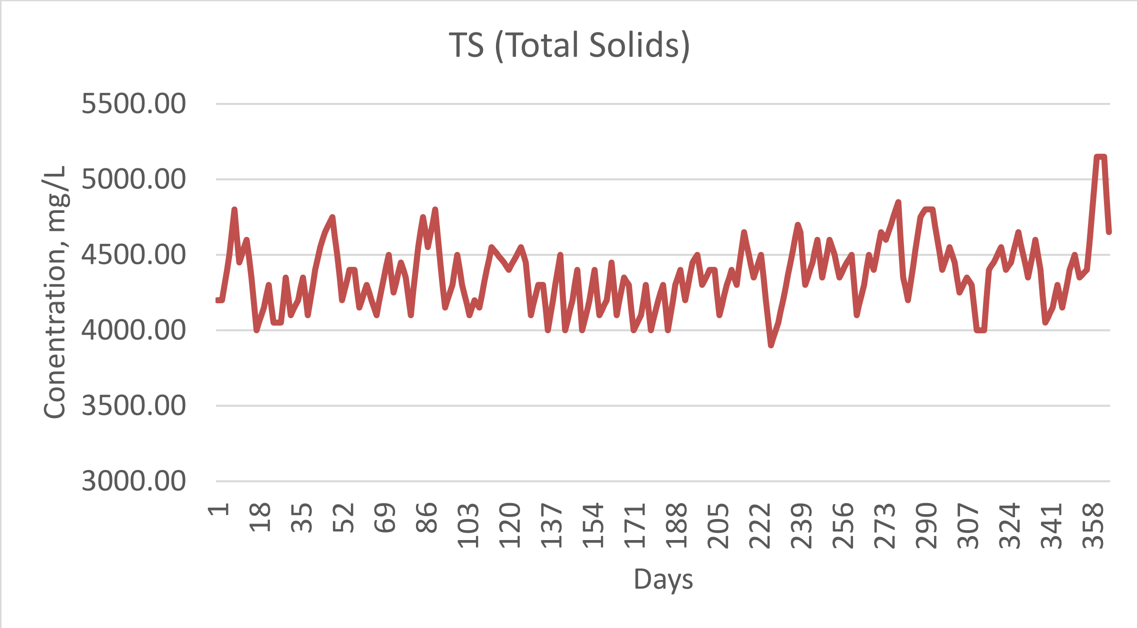

Figure 14. TS reference value for the period between 01.09.2010 and 31.08.2011

Return sludge flow was as well connected to the secondary clarification tank and the data was taken from the company. The values for the return sludge was set as an inflow value. The data can be seen below from the Figure 15.

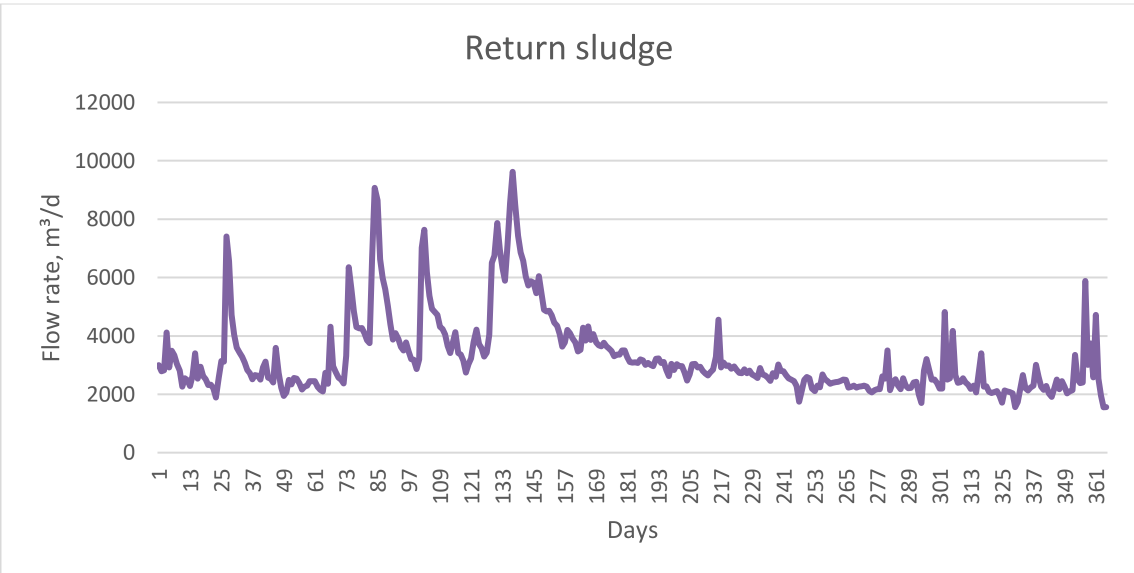

Figure 15. Return sludge reference value for the period between 01.09.2010 and 31.08.2011

The process of water flow described as following. First, polluted water comes to the plant and it is the inflow block. Then in goes through the fraction block, where the data is fractionated and can be processed further. From here the water is going to the first tank, which is called Bio-P tank. In this tank, water from the inflow and one more flow is mixing. The second flow is the water from humification field and as well as from thickener. In the Bio-P tank, they are mixing together, and the process going further, but before, there is a TS controller, that checks the TS amounts and gives signal to the TS pump and then the flow is divided into 2 parts. Half of the water is going to first aeration tank and half to the second one. There are nitrification and denitrification happening with a control of 2 air controllers, which were programmed with a code. At this stage there are 3 controllers of oxygen, NH_4 and NO_3. Then, those 2 flows are mixing together and there is a PO_4 controller standing further. Then, the water is going to secondary clarification tank, where there is a return sludge reference value. Cleaned water is going to the outflow and the return sludge is going back to the Bio-P tank and the process starts again.

3.2 Simulation 2. New anaerobic sludge stabilization system with primary clarification tank

The simulation represents possible ideas about installation of anaerobic sludge digestion systems to the Schladen sewage treatment plant. During this simulation, two connections of the digestors were used.

3.2.1 Simulation 2.1. Serial connection of digesters

During this simulation, the serial connection of digestors was used. The Figure 16 illustrates new picture of the Schladen sewage treatment plant in Simba# software with serial connection of digesters with new elements added to the system.

The main part of the plant, which is called “Sewage treatment plant” stayed without changes and all the data programmed left the same as it was described before in the Simulation 1.

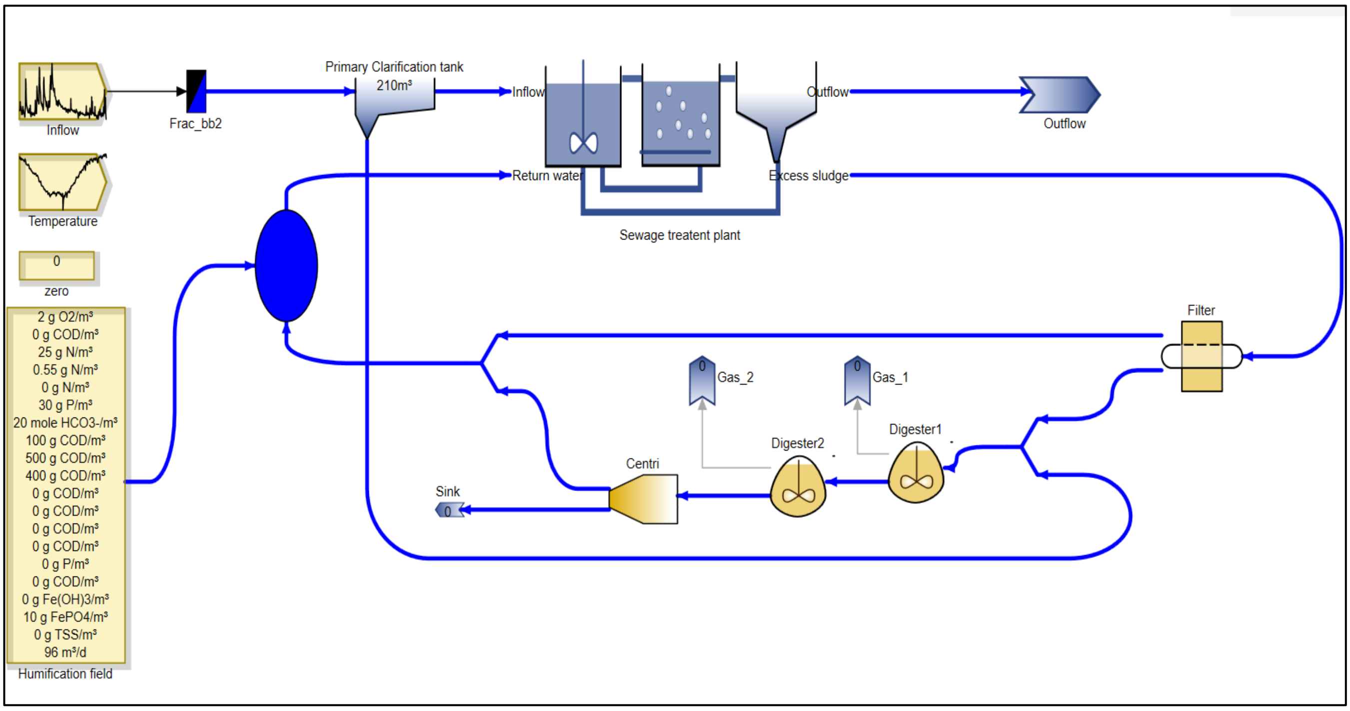

Figure 16. Simulation 2.1 Serial connection of digesters

New block, which was called "Primary Clarification tank" was added to the system. The size of it was calculated from the inflow data and with the time constant, which was taken from the DWA-Regelwerk (2016). The formula 8 can be seen below.

$$\frac{V}{V_0} = t \qquad (8)$$

Where:

V – volume of the tank, m^3

V_0 – inflow rate, m^3/d

t – time constant, d

The time constant was chosen as 1 and as for the inflow rate it was taken the maximum value of the inflow, which was 4811 m^3/d.

$$V = V_0 * t = 4811 \; {m^3}/{d} * \frac{1}{24} d \approx 210 \; m^3$$

The value of about 210 m^3 for the volume of the tank was found, which can be seen from the Figure 16.

Moreover, it can be seen that the block with the flow from the thickener was taken out from the system due to the new connections and new block “Filter” plays the same role in new case.

For the new block filter, the 95% of sludge removal was chosen as the program can only accept the range between 80 and 100 %. And the sludge is going to the digesters 1 and 2, which are connected consistently as shown on the Figure 16.

The volume of the digesters was calculated the following way. Schladen sewage treatment plant is using manual control of the excess sludge pump and in most of the cases it has a flow with 10 m^3/h, which is 240 m^3/day and in order to start the process of getting the gas from it there is a need to wait for about 15 days and as in our case 2 digesters were used, the volume of each was rounded to 2000 m^3.

Those digesters have gas output and it was marked as “Gas_1” and “Gas_2”. After the digesters, next step was “Centri”, which also separated sludge and water, with 95% efficiency as it was again should be chosen between 80 and 100 percent. And from “Centri” block water was going back to the system and rest sludge was going to the block “Sink”.

The sludge flow described as following. First, the sludge is going through the excess sludge pump to the Filter, which separates 95 % of sludge. There, all the separated water going further to the Bio-P tank and the rest is going to the digesters. The digestion happening there, and the gas outflow can be seen. Next, there is a centrifuge, which separates the sludge. Again 95% of sludge is separated. And the separated water going back to the Bio-P tank and the separated sludge going to the sink. As well, it can be seen one more flow, which is a primary sludge, which is done after primary clarification, this is going straight to the place, where is mixing with the secondary sludge.

3.2.2 Simulation 2.2. Parallel connection of digesters

This simulation represents the new system with parallel connection of the digesters. The Figure 17 below shows the new situation.

The same data was used as for the Simulation 2.1, and the only difference was in connection of the digesters.

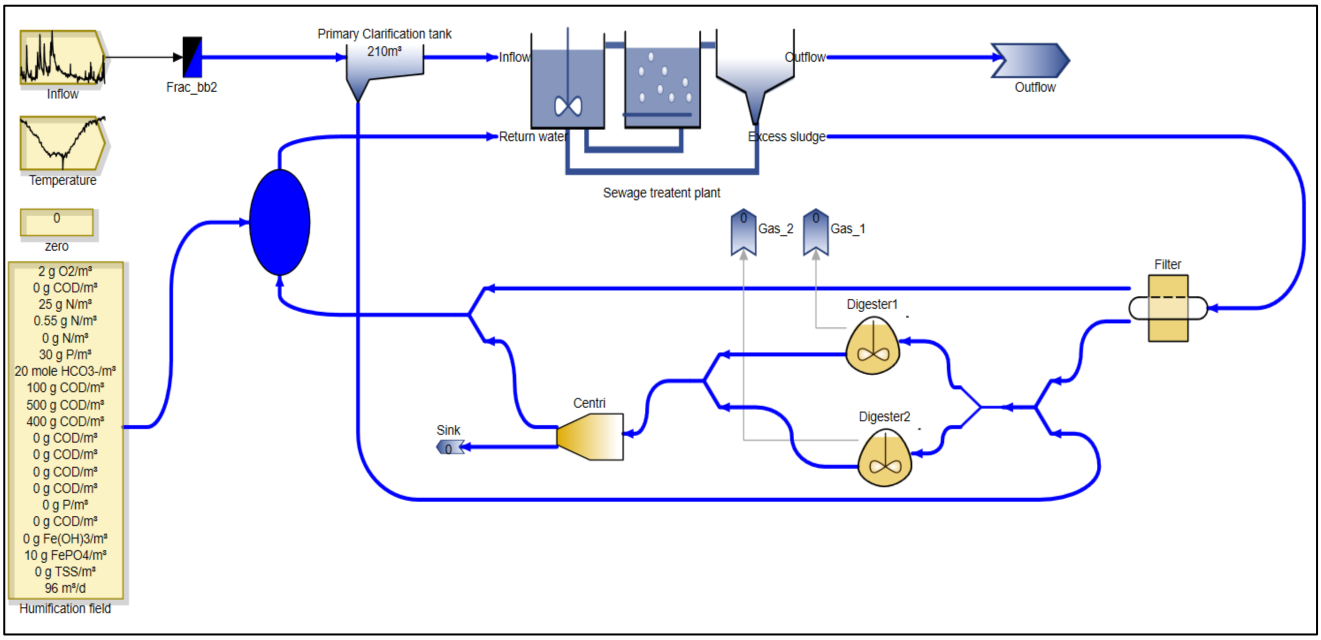

Figure 17. Simulation 2.2 Parallel connection of digesters

3.3 Simulation 3. New anaerobic sludge stabilization system with fine screen

This simulation represents a new anaerobic sludge stabilization system with fine screen installed at the beginning instead of primary clarification tank. And again, there were 2 possibilities in installation of the digesters, which were showed below. The idea of using fine screens is that it can also separate sludge.

The HUBER Rotary Drum Fine Screen ROTAMAT was used. The information on the screen can be found on their homepage (Huber.co.uk, 2018).

3.3.1 Simulation 3.1. Serial connection of digesters

In this simulation, the serial method of connection digesters was shown (Figure 18).

As it can be seen from the Figure 18, there was a new block “Filter1” installed instead of Primary clarification tank. Due to the fact that the sludge amount, which was going through such screening systems equal to 60 % (Kink, 2016) and in the program, it was not possible to set 60%, there was a need to insert a split block and create a sink, which takes 40% of the flow and the rest 60 %, which was needed going further to the digesters. And the Filter1 efficiency was set to 100% in order to get all the sludge down.

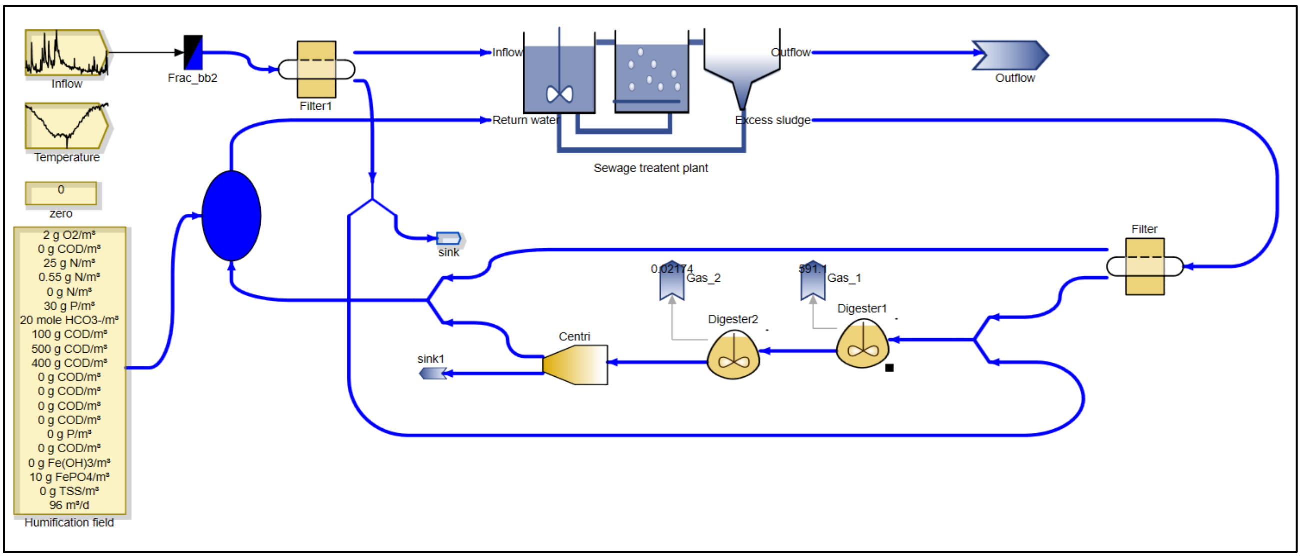

Figure 18. Simulation 3.1. Serial connection of digesters

Same data as for the Simulation 2 was used and only difference was in the adding Filter 1 to the system and it does not change the main flow.

3.3.2 Simulation 3.2. Parallel connection of digesters

Simulation 3.2 shows the new model with a fine screen as the Simulation 3.1, however, in this case, the digesters were connected parallelly. The Figure 19 shows the new system.

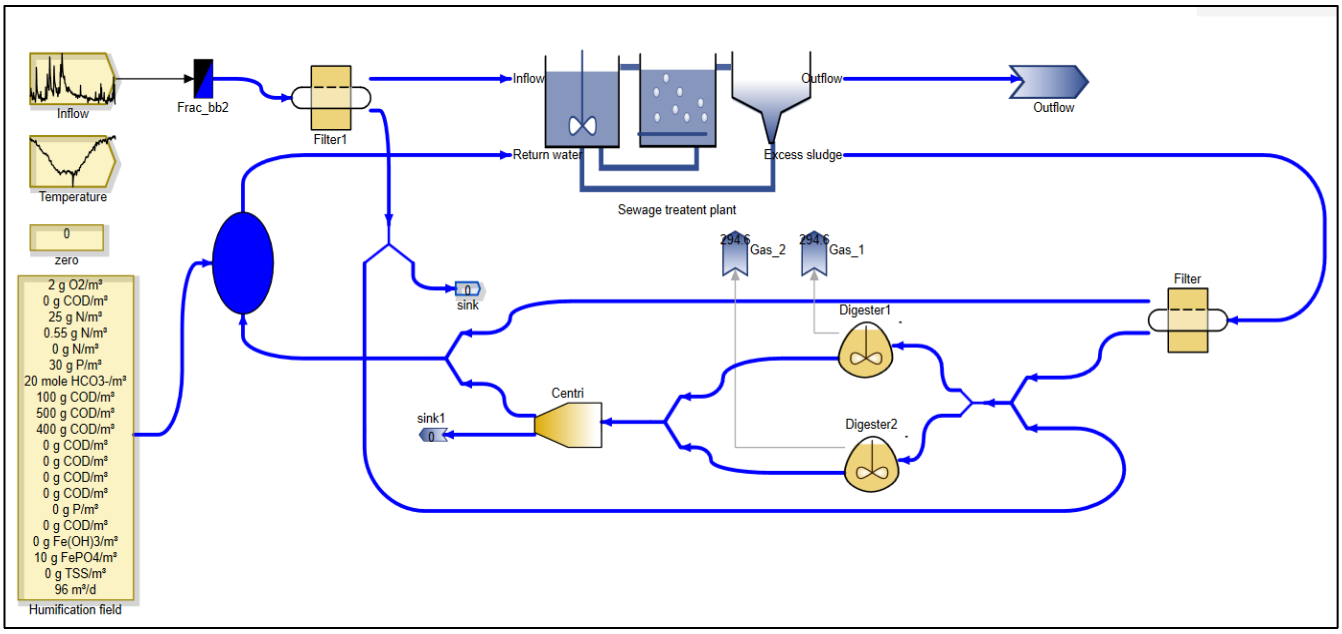

Figure 19. Simulation 3.2. Parallel connection of digesters

The Results of all simulations can be seen in the following section.

4 RESULTS

In this section, the results of the simulations of an existing Schladen sewage treatment plant and new models would be shown. The inflow data was set between period 01.09.2010 to 31.08.2011, provided from the Schalden sewage treatment plant. The outflow results were also provided from the plant, was between 01.09.2003 and 31.08.2004.

4.1 Simulation 1. Current situation in Schladen treatment plant with aerobic sludge stabilization

Before coming to the main results, it is good to shown that the simulation was working, and it can be seen from the oxygen change after in the aeration tanks, which represents the change between aeration and not aeration. See Figure 20 below. In order to see the change better, the short time period was chosen for illustration.

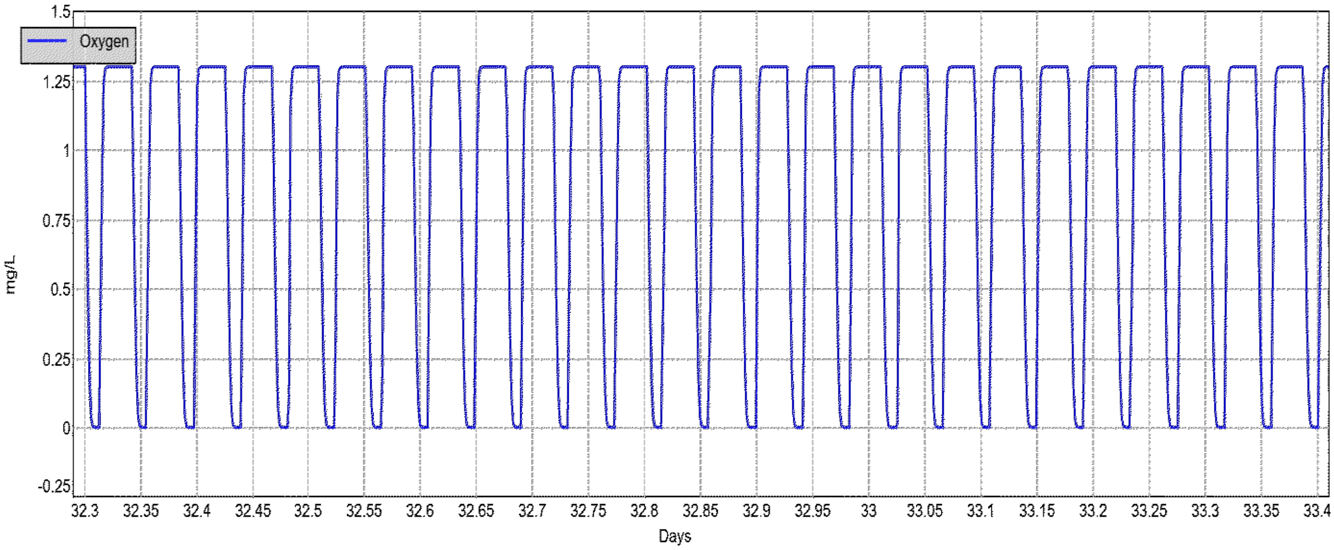

Figure 20. Simulation 1. Oxygen change in time

Furthermore, the Figure 21 shows 3 parameters, such as Oxygen, NH_4 and NO_3. Where it can be seen that during aeration, the amount of NO_3 is increasing and NH_4 decreasing and when there is no aeration, the NO_3 going down and NH_4 rising up. The oxygen was illustrated with a blue colour and NH_4 and NO_3 were in red and blue colours respectively.

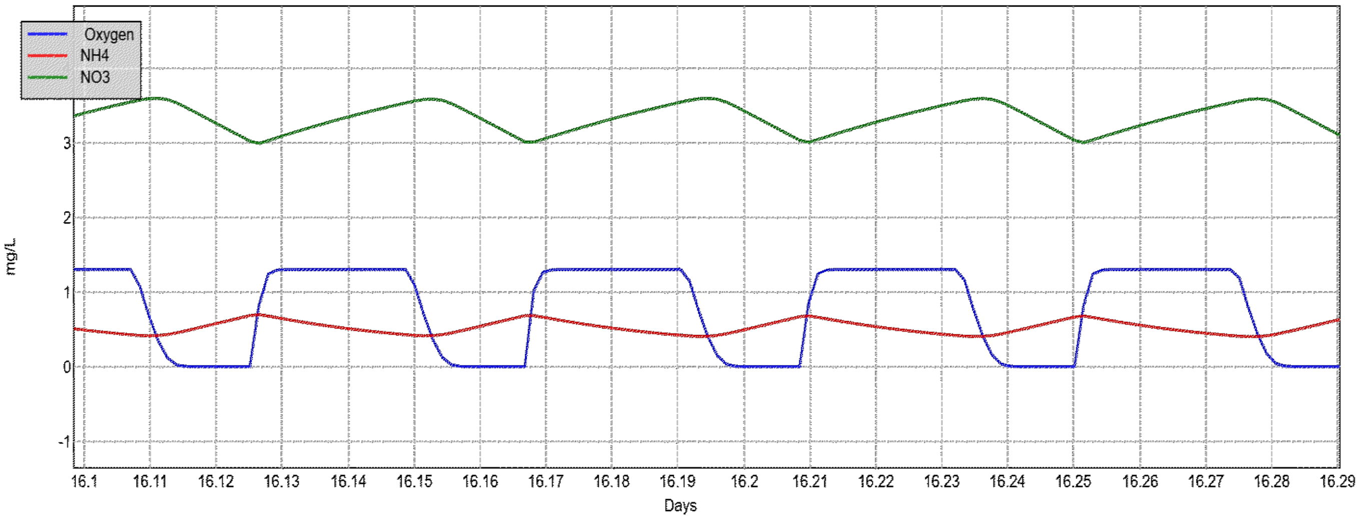

Figure 21. Simulation 1. Oxygen, NH_4 and NO_3 change

Based on the inserted data, which was discussed in the Methods section, the outcome can be seen from the Figures 22 - 25 below.

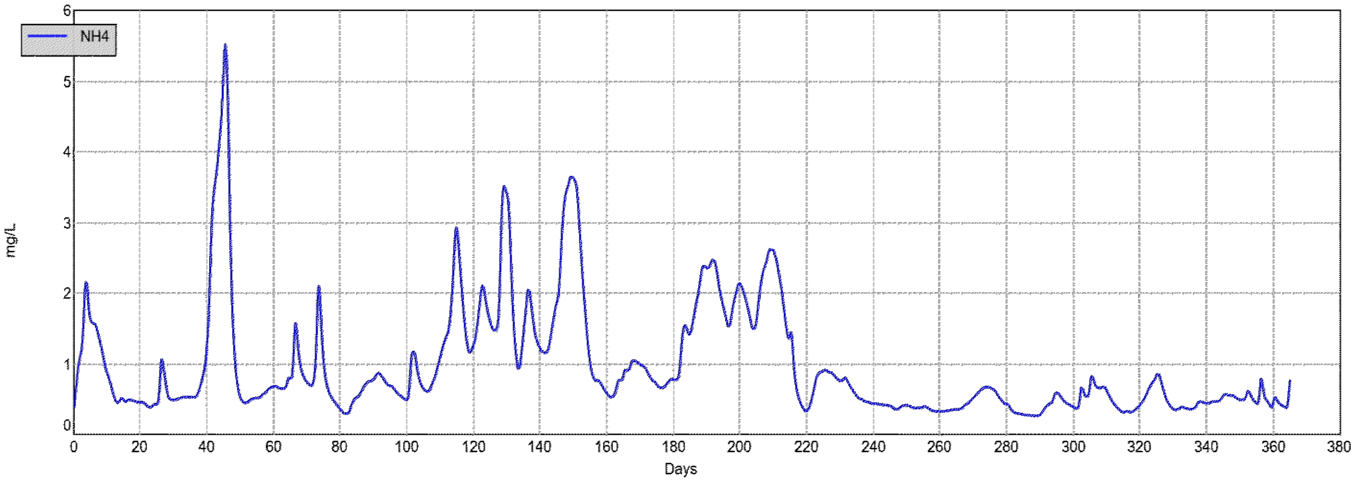

Figure 22. Simulation 1. NH_4 outflow data from Simba# between 01.09 and 31.08

As it can be seen from the Figure 22, there are couple of peaks, which were around day 50 with the concentration of about 5.5 mg/L of NH_4 and as well around days 110, 130 and 150, where the concentration was close to 3.5 mg/L in the outflow of NH_4.

For the rest time period, the concentration of ammonium stayed below the range 2.5 mg/L and the lowest concentration can be seen during the period starting around day 220 till the day 365.

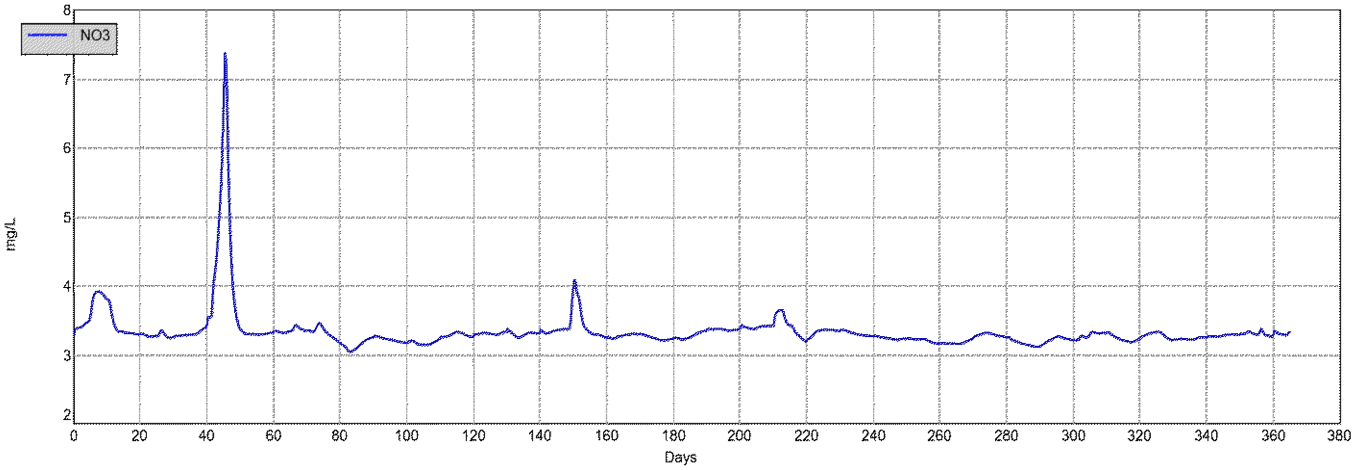

Figure 23. Simulation 1. NO_3 outflow data from Simba# between 01.09 and 31.08

Form the Figure 23, it can be noticed that the concentration of NO_3 stayed almost without changes for the whole period of 365 days and was around 3.5 mg/L. However, there was 1 peak with the concentration of 7.5 mg/L of NO_3 around day 50.

There was a big peak of NH_4 around the same day that NO_3 had and that would be discussed further.

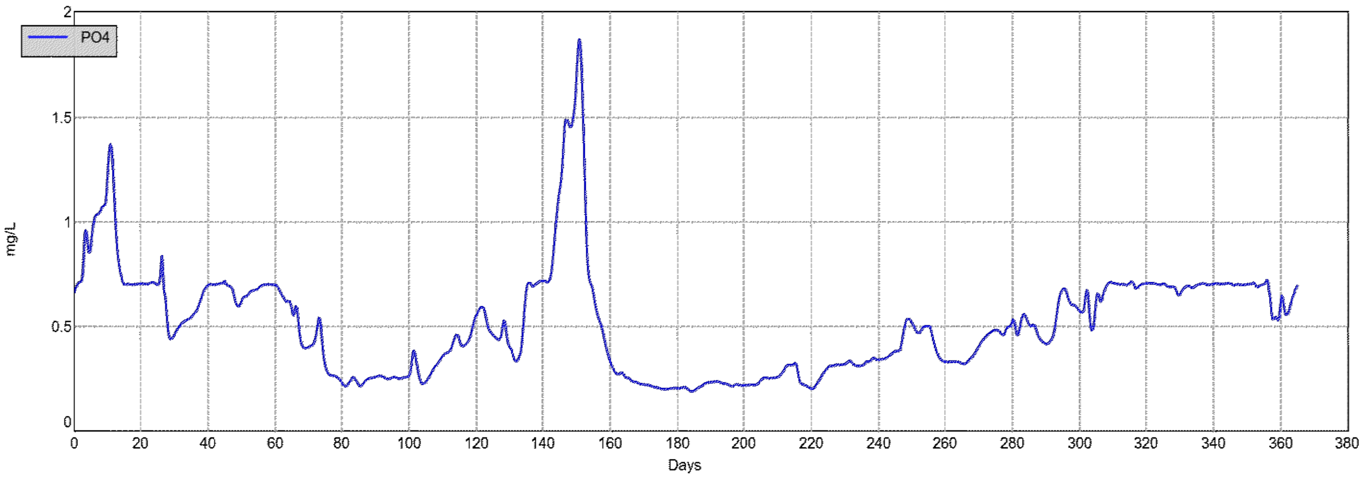

Figure 24. Simulation 1. PO_4 outflow data from Simba# between 01.09 and 31.08

From the Figure 24 it can be seen that there were 2 peaks of the PO_4 during the whole year at the beginning (around day 10) and in the middle (around day 150) with concentrations close to 1.5 mg/L and 2 mg/L respectively. For the rest time period, the concentration of PO_4 stayed below 0.8 mg/L.

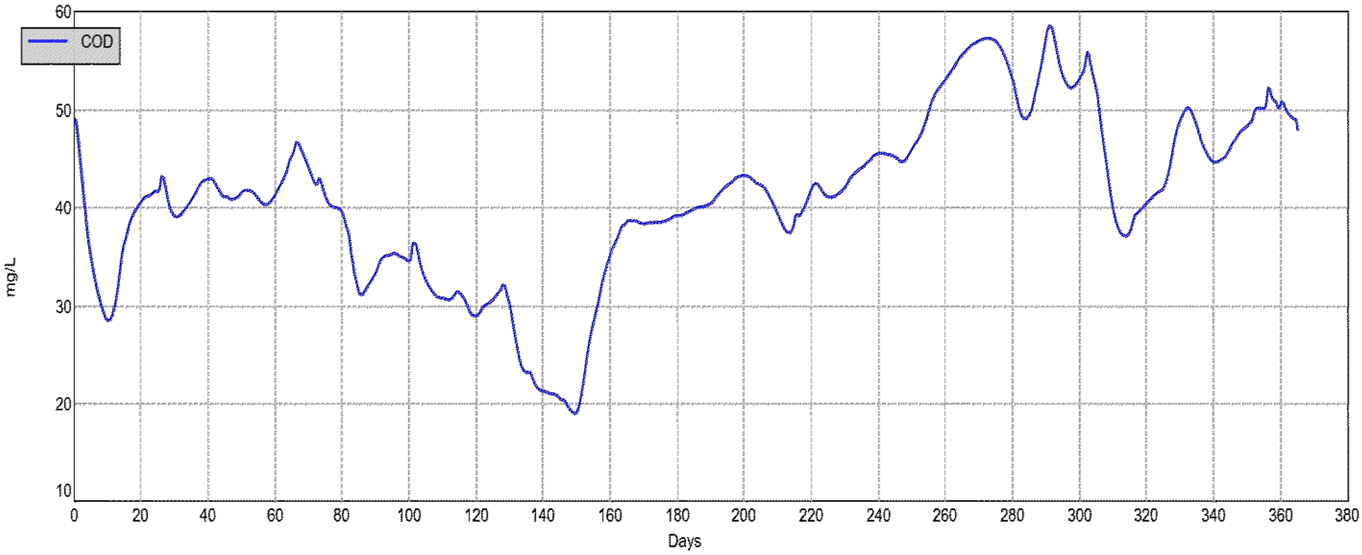

Figure 25. Simulation 1. COD outflow data from Simba# between 01.09 and 31.08

The COD Figure shows that the concentration of it was varying between 30 and 50 during first 130 days and then there was a decrease in its' concentration down to 20 mg/L and then, after about 10 days, it significantly increased back to 40 mg/L and stayed in a rage between 40 and 60 mg/L.

Further, Figures 26 - 28 show the comparison between values from Simba# software with real values from the Schladen sewage treatment plant. As it was explained before, due to the fact that there was no data provided for the years 2010 - 2011 from the plant for the outflow, the data was taken from the years 2003 - 2004 for the same time interval, starting from September and end of August.

The comparison was shown for the first 100 days in order to see the changes better. Total nitrogen, COD and Phosphorus were analysed and compared. Total Nitrogen was provided from the company as 1 value and there were no data separately for NH_4 and NO_3. That is why there was a need to combine values from Simba# software of NH_4 and NO_3 in order to compare them.

The data, which was simulated with Simba# software was shown as green line, and data, which was provided from the Schladen sewage treatment plant was in blue colour.

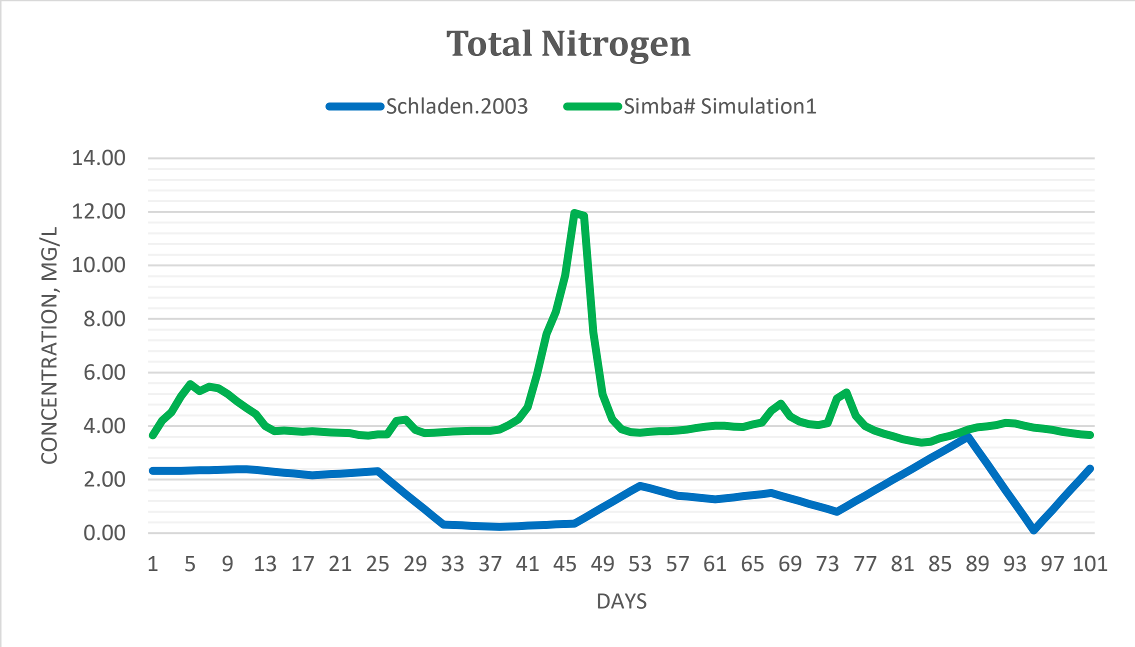

Figure 26. Simulation1 Total Nitrogen comparison between Simba# and Schladen real values

As it can be seen from the Figure 26, the data from the Schladen sewage treatment plant was 2 times lower during the whole-time period which was compared, 2 mg/L and 4 mg/L respectively, and during some days even 4 times smaller (days 30 – 46). As well, the peak around the day 48 showed the data from Simba software, which was 12 times higher than the real value from Schladen.

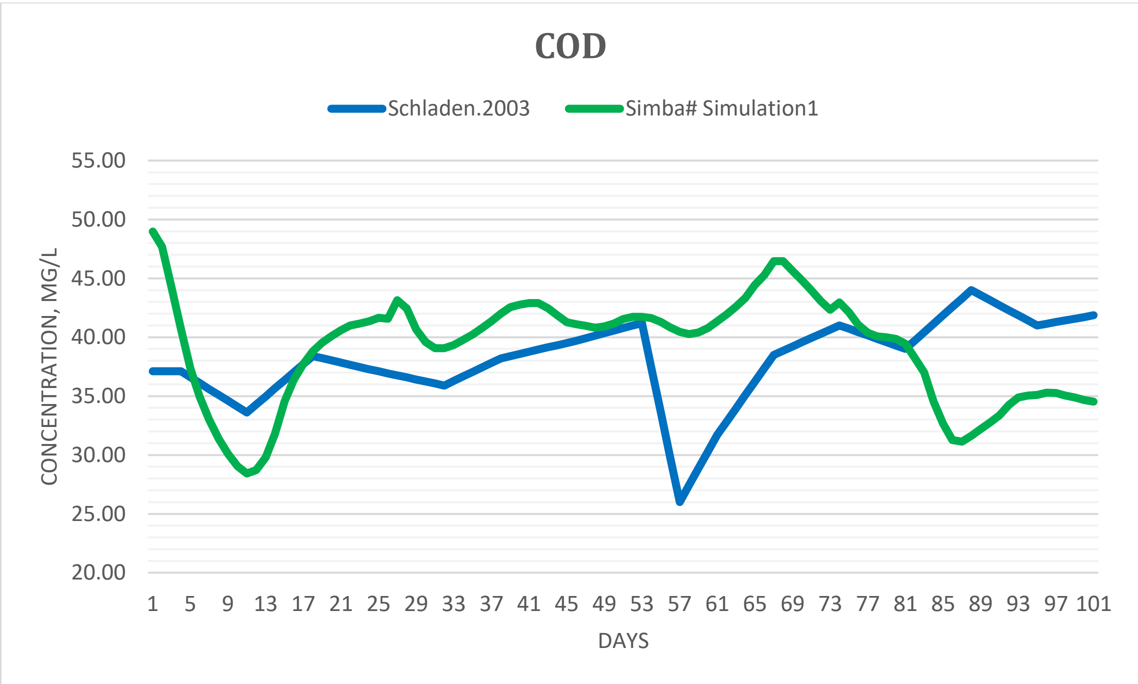

Figure 27. Simulation1. COD comparison between Simba# and Schladen real values

From the Figure 27, it can be noticed that the data of COD concentration was similar during the time periods between days 18 and 55 and as well 77 and 82 and for the rest period the values showed different concentrations and as well there were some periods (days 82 – 94), where the concentration changed in a opposite direction, as the real data represented an increase in 5 ml/L and Simba# software showed a decrease in 10 mg/L.

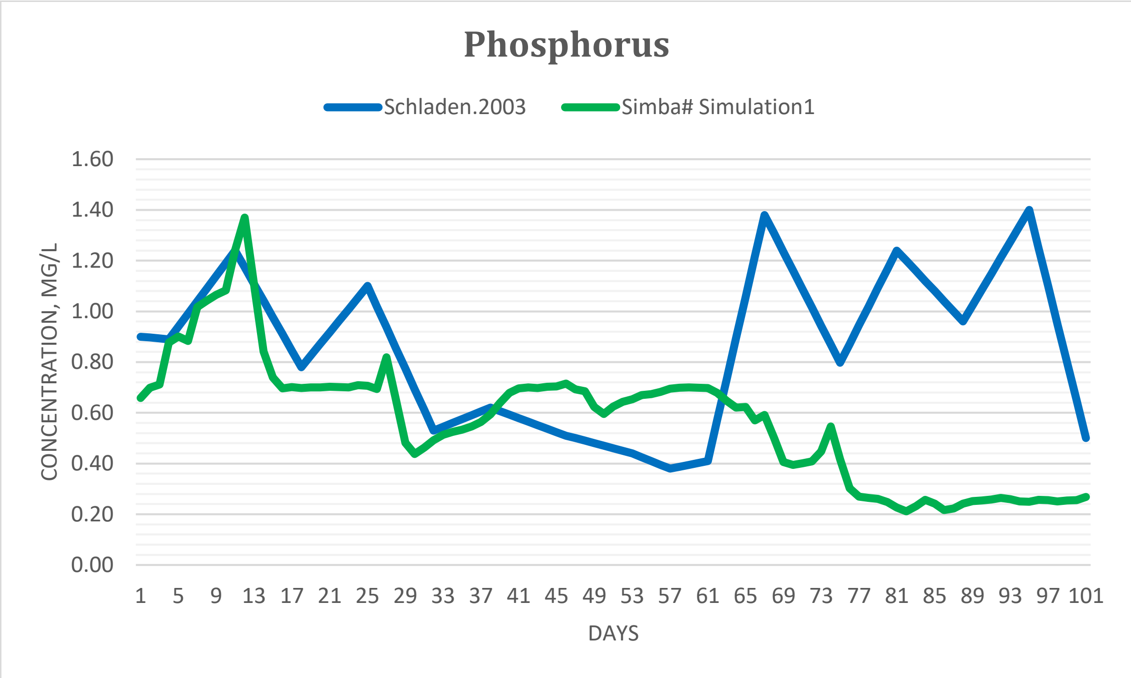

Figure 28. Simulation1. Phosphorus comparison between Simba# and Schladen real values

Based on the data from the Figure 28, it can be seen that during first 61 days, the real data and the simulation showed more or less the same concentration of PO_4 and the value ranged between 0.4 mg/L and 1.4 mg/L. However, after day 62, the concentration of phosphorus significantly raised based on the real values from the Schladen and went up to 1.4 mg/L and on the other side, Simba# software showed a slight decrease down to 0.2 mg/L of PO_4.

Moreover, below it can be seen from Figures 29 and 30 the result of COD and TS in excess sludge outflow.

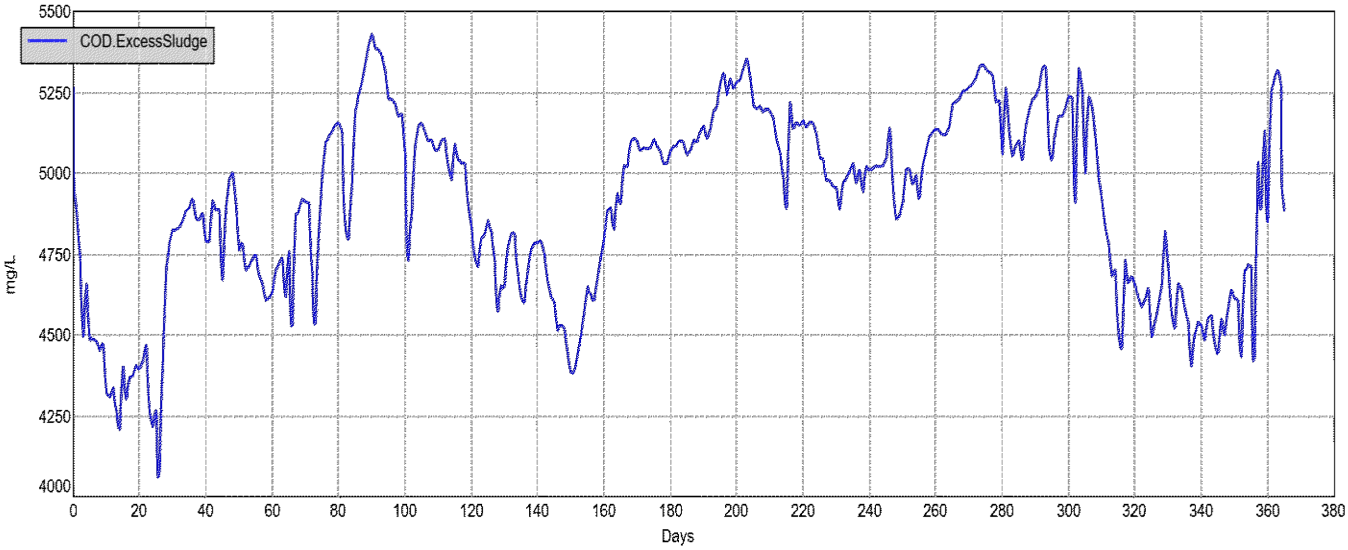

Figure 29. Simulation1. COD in excess sludge outflow

From the Figure 29, it can be seen that the concentration of COD in the excess sludge outflow was changing during the whole year analysed, with drops down to 4000 mg/L around day 25 and peaks up to 5400 mg/L around days 90, 210, 275, 290 and 365

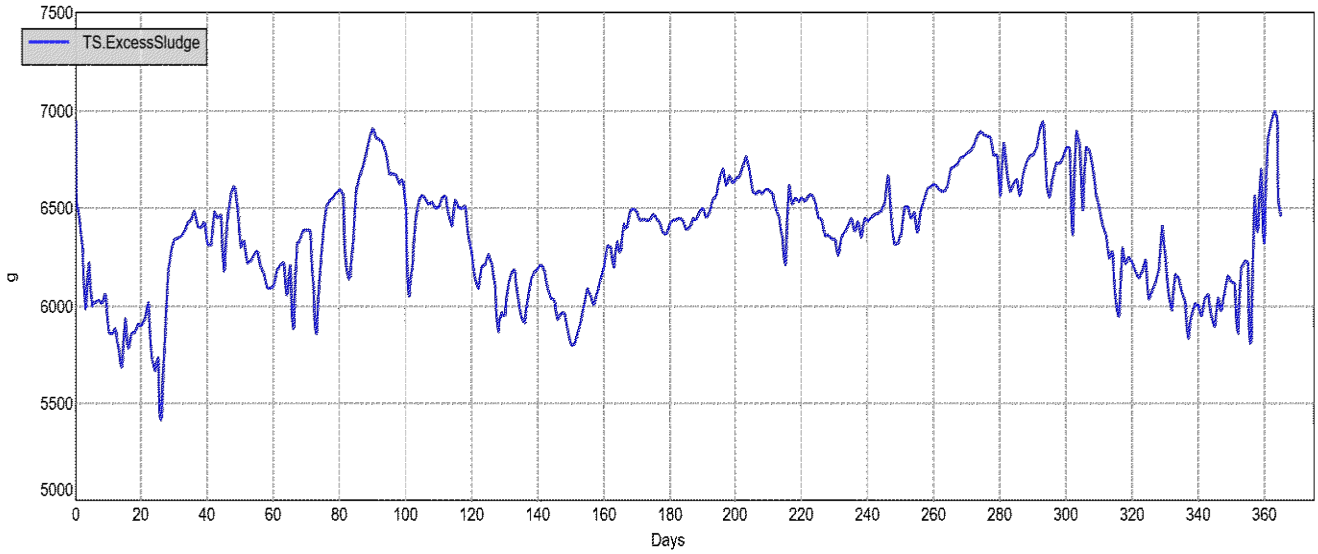

Figure 30. Simulation1. TS in excess sludge outflow

The TS value, based on the Figure 30, stayed in the range between 5500 and 7000 g. The drops and jumps of the TS were during the same time periods as the COD Figure showed before (Figure 29). The drop was around day 25 and the peaks around days 90, 210, 275, 290 and 365.

4.2 Simulation 2. Outcome of a new anaerobic sludge stabilization system with primary clarification tank

The Simulation 2 was modelled and the results with serial and parallel connection of digesters can be seen. The Simulation 2.1 was with serial connection of digesters and the Simulation 2.2 was with parallel connection of digesters.

The Figures 31 - 34 show the main parameters of the outflow from the plant with new system with primary clarification tank by using serial connection of digesters. The concentrations of NH_4, NO_3, PO_4 and COD can be seen below for the whole year.

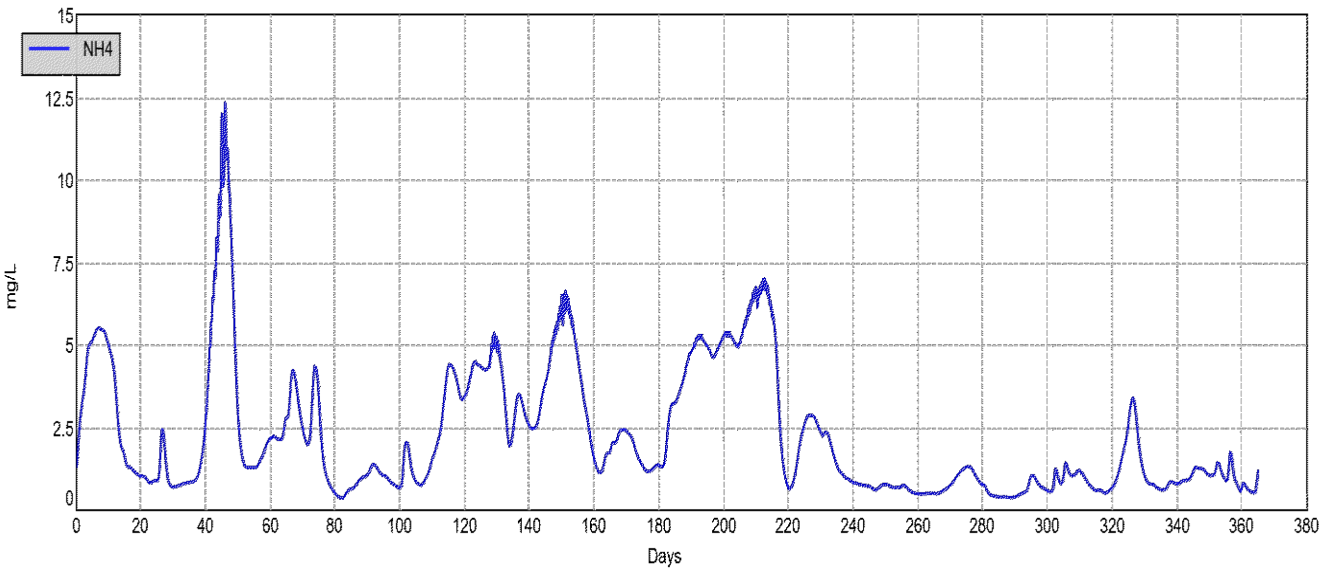

Figure 31. Simulation 2.1. NH_4

As it can be seen from Figure 31, the ammonium concentration had some peaks around days 10, 70, 130, 150 and 210 with the concentration around 5 mg/L. As well, it can be noticed that there was a sharp increase up to 12.5 mg/L of NH_4 around day 50. That is above the limit, which is 10 mg/L. For the rest of the year, the concentration remained more or less stable with less than 2.5 mg/L.

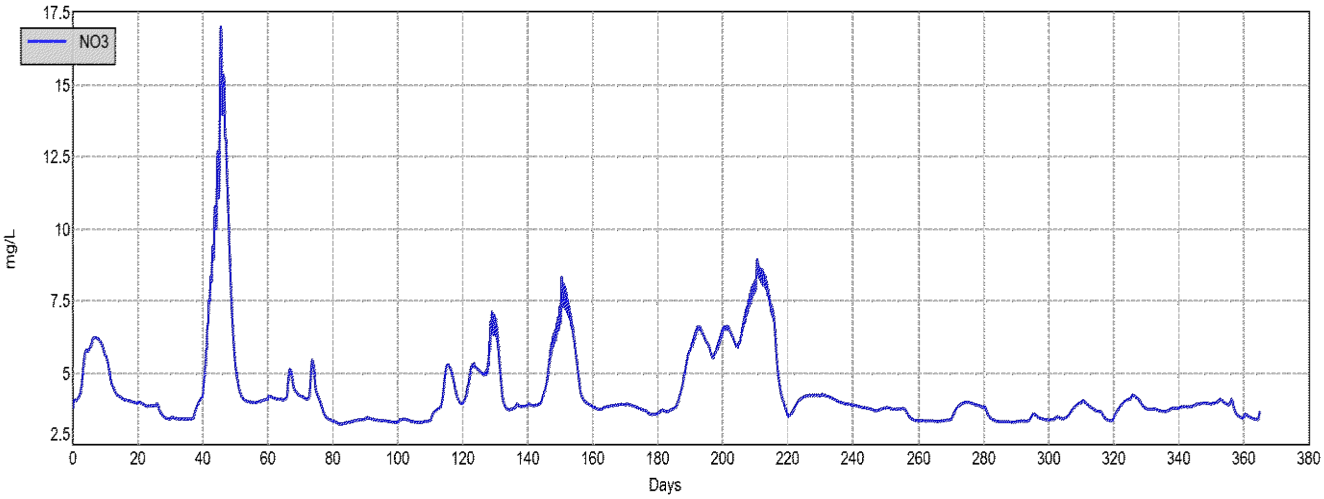

Figure 32 Simulation 2.1. NO_3

From the Figure 32, it can be seen small peaks of NO_3 concentration up to 7.5 mg/L around the days 130, 150 and 210. Moreover, there was a big increase in concentration of NO_3 around day 50 up to 17.5 mg/L. For the rest year, the concentration remained more or less constant with less than 5 mg/L of NO_3.

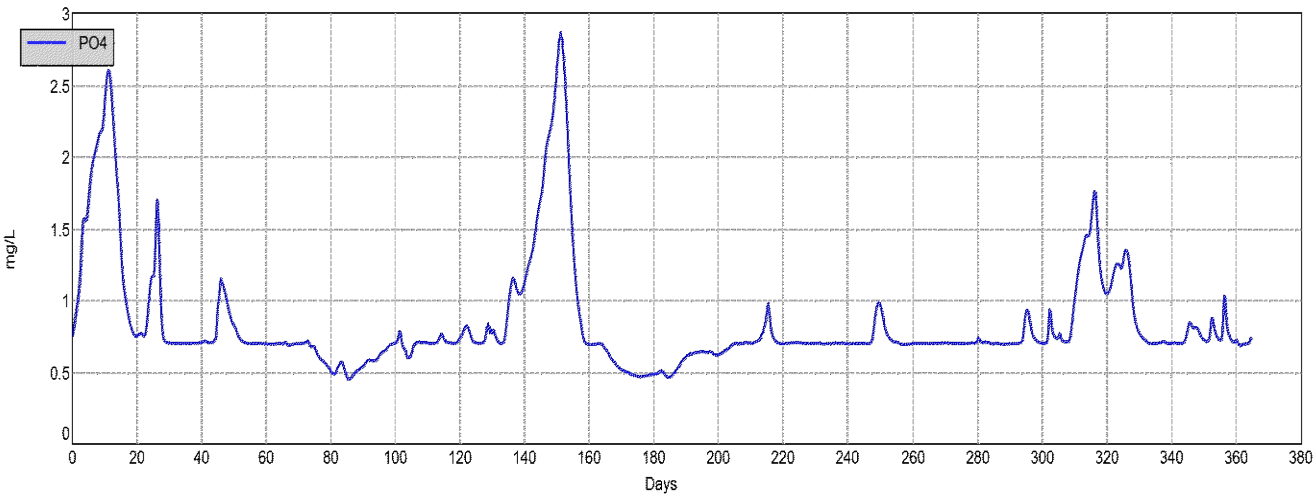

Figure 33. Simulation 2.1. PO_4

Peaks up to 2.5 mg/L of PO_4 concentration can be seen from the Figure 33. There were as well increases up to 1.7 mg/L around days 25 and 315. For the rest of the year the PO_4 level stayed between the range 0.5 and 1 mg/L.

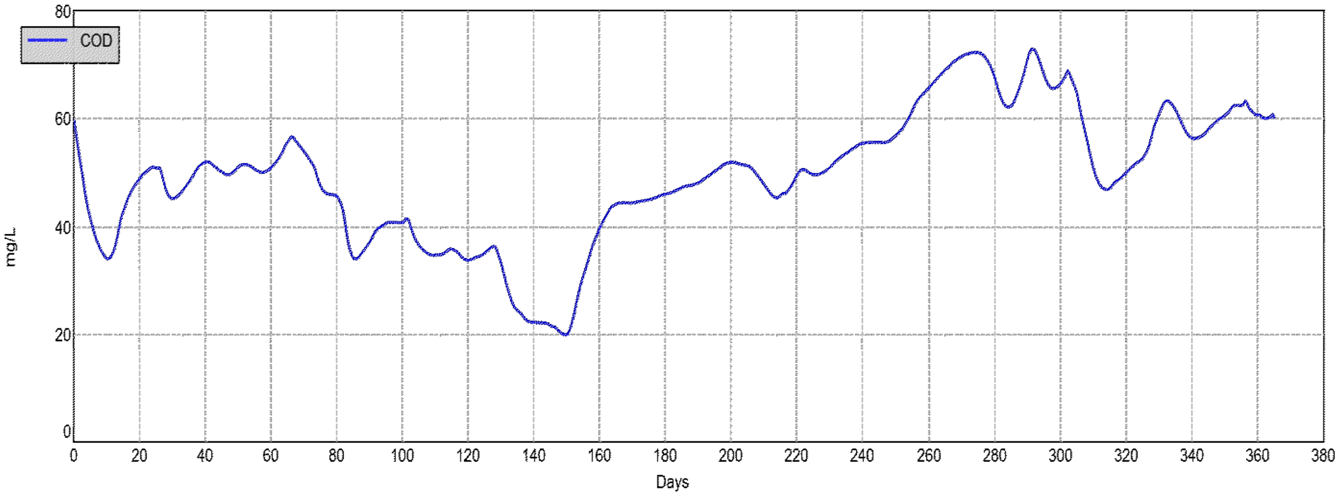

Figure 34. Simulation 2.1. COD

Simulation 2.1 showed the COD concentration between the range 40 mg/L and 60 mg/L for the first 130 days and then, there was a sharp drop to 20 mg/L on the day 130 and then it went back to the concentration 40 mg/L and after 10 days started slightly increasing till the rest of the year till 60 mg/L (Figure 34).

Moreover, Appendix 3 shows the return values from the digesters after second filter with the water from the first filter, which were installed before digesters.

Simulation 2.2 showed the same values in the outflow as the Simulation 2.1. That means that there is no difference in outflow concentrations between serial and parallel connection of digesters.

4.3 Simulation 3. Outcome of a new anaerobic sludge stabilization system with fine screen

The results of the simulation 3 can be seen below. As it was already seen from the Simulation 2, there is no difference in outflow values with different connection of digesters. That is why, only one simulation would be shown in this section (Figures 35 - 38).

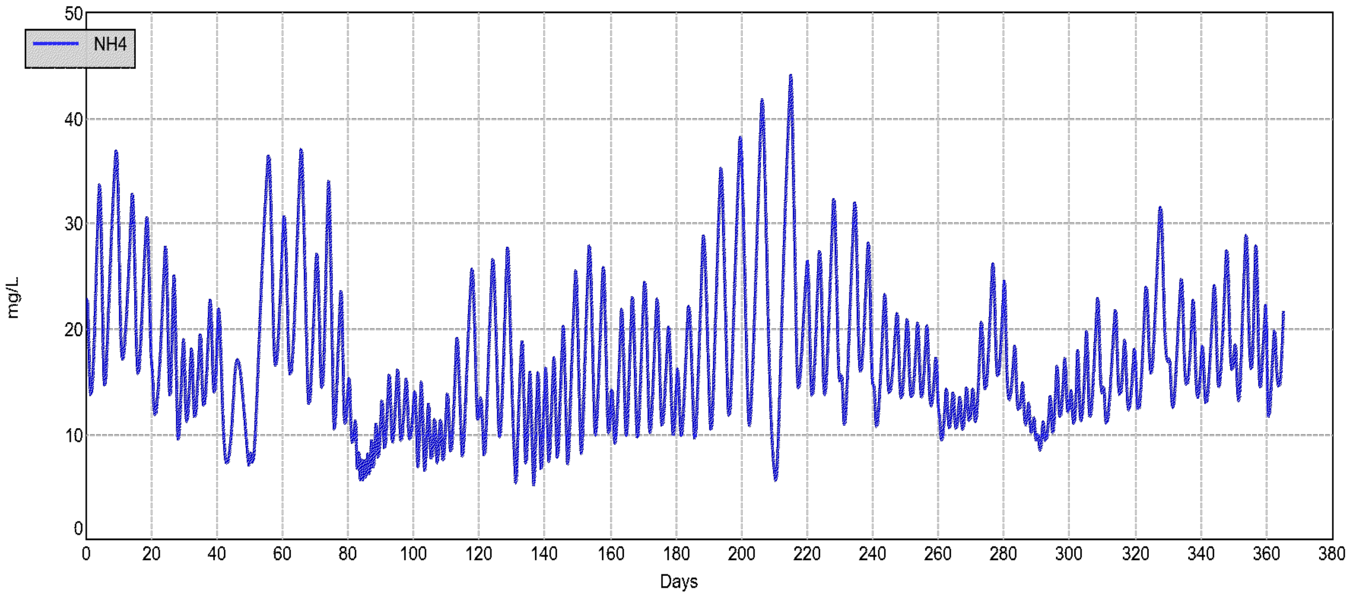

Figure 35. Simulation 3. NH_4

As it can be seen from the Figure 35, the concentration of NH_4 was not stable for the whole-time period of 1 year with sharp drops and raises. The concentration varies between 10 and 30 mg/L for most of the period with bigger peaks in the middle (around days 190 – 210) with concentration of NH_4 up to 40 mg/L.

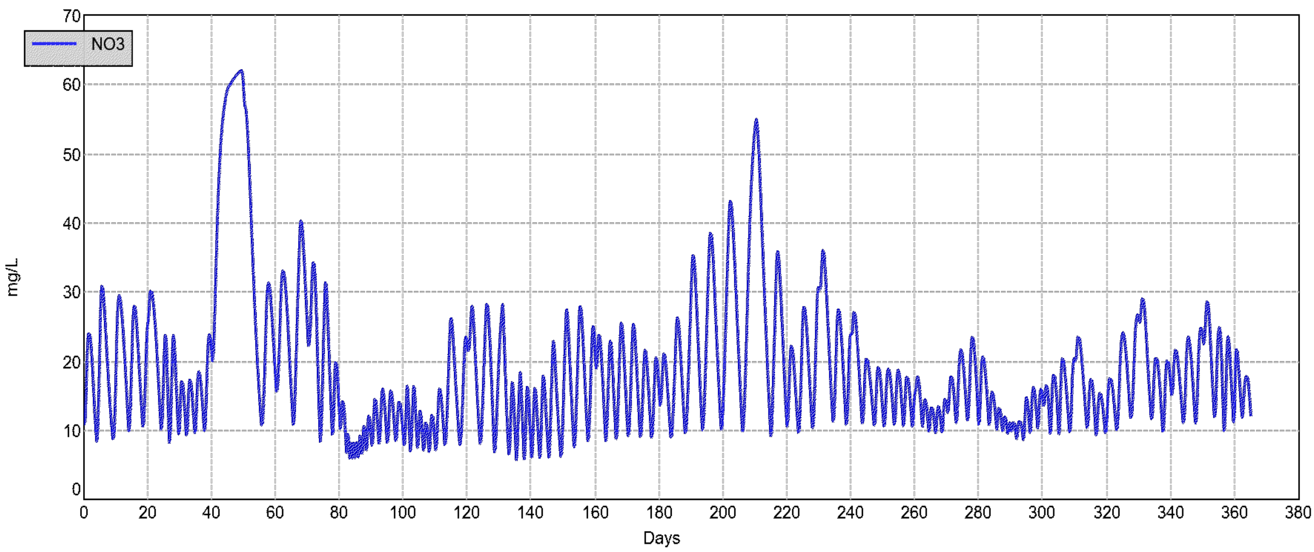

Figure 36. Simulation 3. NO_3

As it can be seen from the Figure 36, the concentration of NO_3 had a lot of sharp changes for the 1-year interval with high peaks between the days 190 and 210 as for the NH_4 concentration (Figure 35) and as well it can be seen another peak with concentration around 60 mg/L around day 50. For the rest of the time, the concentration of NO_3 vary between 10 and 30 mg/L.

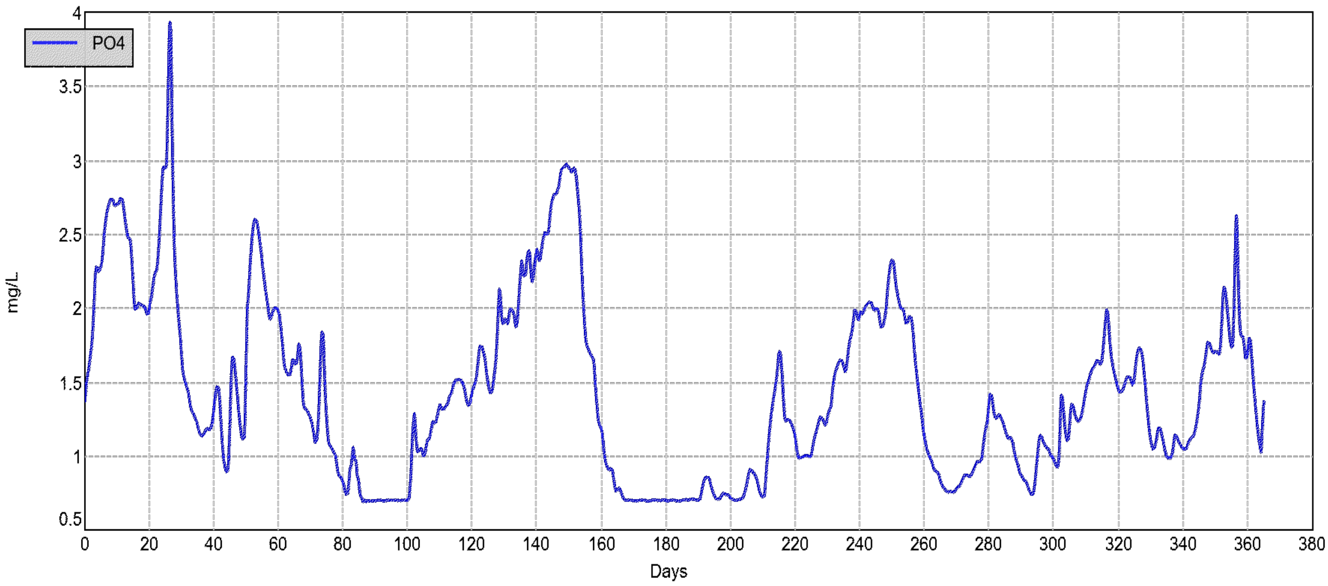

Figure 37. Simulation 3. PO_4

The Figure 37 illustrates the concentration of PO_4 during simulation with fine screen installed and as it can be seen, that there were a lot of peaks up to 4 mg/L around day 25, up to 3 mg/L around days 15, 150 and up to 2.5 mg/L around days 55, 320 and 360.

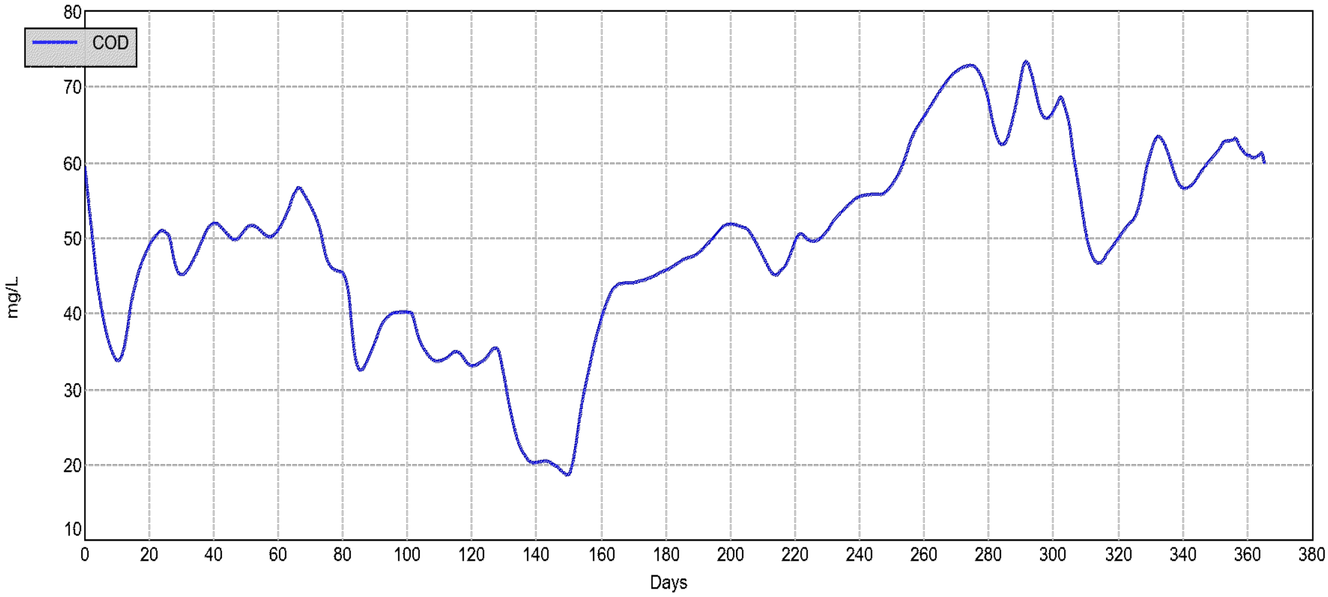

Figure 38. Simulation 3. COD

The COD concentration of Simulation 3 can be seen above from the Figure 38. It showed the range between 35 and 60 mg/L for the first 130 days and then again as for the Simulation 2, there was a sharp decrease down to 20 mg/L and after 10 days, a significant increase to 40 mg/L with slight raise up to 60 mg/L till the end of the year.

Moreover, Appendix 4 shows the return values from the digesters after second filter with the water from the first filter, which were installed before digesters.

4.4 Gas outflow. CH_4

Gas outflows from the digesters can be seen in the Table 1 below. It is clear that in the serial connection of digesters, most of the work takes the first one and with parallel connection – both digesters were working with the same output. Moreover, it was noticed from Simba# that the gas outflow started after 20 days with continuous connection and after next 20 days the second digester started to give the gas too. And in parallel connection of digesters, both of them started to produce gas after 40 days.

Table 1. Gas outflow from digesters of the Simulations 2 and 3

Simulation №	Digester 1, kg/d	Digester 2, kg/d	Digesters 1+2, kg/d
Simulation 2.1	509	2.2	511.2
Simulation 2.2	257.3	257.3	514.6
Simulation 3.1	591.1	0.02	591.12
Simulation 3.2	294.1	294.1	588.2

From the Table 1, it can be seen that the gas outflow from the Simulation 2 was around 513 kg/d of CH_4 and around 590 kg/d of CH_4 for the Simulation 3 in average.

5 DISCUSSIONS

Based on the modelling the current situation of the Schladen sewage treatment plant, there are some thing, which should be considered.

The data from the company was used for the period between 1st of September 2010 and 31st of August 2011.

However, due to the fact, that there was no data provided from the Schladen plant for the year 2010 about the phosphorus outflow, the same period was taken for the year 2003 starting from 1st of September and finishing at 31st of August 2004. The average of the values for the whole year was taken and put into the program, which was 0.7 mg/L. That was the reference value for the controller.

Talking about the influent block, where there were only 4 flows, such as COD, total nitrogen, phosphorus and inflow and with a help of fraction data block it is possible to divide it to 20 more fractions. Due to the fact that there is not enough information about fractions from the data of the company, the already existing one in the program was used, which corresponds to the ASM 3 Bio-P model.

Talking about TS control block, there was a possibility to put in behind the aeration tanks, however, after modelling it was decided to change the position behind the Bio-P tank, due to the fact that the effect is faster and there is no need for the controller in order to wait for water going through aeration tanks, which would take some time.

Originally company is using manual change in the flow for the return sludge. The responsible person is checking how much return sludge the plant has at the point of secondary clarification tank and open the pump. Usually it is 10 m^3/h, and if it is less sludge, then it can be slower, for example 8 m^3/h And in Simba# program is being not possible to set this model and it was decided after discussions with responsible person from the company to set the amount, which is double to the amount of the inflow.

Due to the fact that there is no data provided from the company for the years 2010/2011 about the outflow, the data was taken from the years 2003/2004 for the same period starting with September. Moreover, the values from the company provided were only one measurement per day and usually this measurement was taken every 4th or 3rd day. That is why the data was filled manually, by continuing the trend. For instance, if the value for 1st day was 40 and for the 4th day was 46, by using excel it was filled 42 for the 2nd day and 44 for the 3rd day.

Due to that fact, in the comparison between the values from the company and Simba#, there were a lot of differences as there were no information about all of the days and moreover, Simba# measures the value about 130 times per day and that is why it might be a lot of changes during that period. Meanwhile, the data of the inflow and the outflow was taken from the different year. And that is the second reason for not the same values. And mostly there were differences double to the real data from the Schladen sewage treatment plant.

Overall, the results from the Simulation 1 was successful in a way if we take that the main idea was to get main measurements at specific range and not above the limit. For instance, the consecration for NH_4 in the outflow was supposed to be not higher than 10 mg/L and 5.5 mg/L maximum. For the N total – max 18 mg/L and the highest peak was 12 mg/L. Furthermore, max concentration of phosphorus should be 2 mg/L and it was successful with 1.4 mg/L max peak. And as well for COD concentration, the limit is 60 mg/L, which was not get higher than that value during the simulation.

And on the other side, it can be said that those values cannot be compared between each other due to the fact that there is not enough data provided from the Schladen company as it was explained before. Only 1 measurement per 3 – 4 days and there is no information about what was happening during this period. Other fact is that the values are taken from different years (2003 and 2010), where we have 7 years difference. That is a long-time period, where it can be a lot of changes.

The results of the Simulation 2 were collected as well. The outcome of it shows that the outflow values are below the limit. The Limits are 10 mg/L of NH_4 and total Nitrogen, which is the sum of NH_4 and NO_3 should be less than 18 mg/L (based on the company regulations). PO_4 should be less than 2 mg/L. Those values can be seen from the results of the Simulation 2. However, there are some peaks, which are a bit higher than the limit. The peaks can be seen in NH_4 and NO_3. They appeared at about day 40 and that is exactly the day, when the digesters were filled completely, and the sludge water started to come back to the plant. The aeration programming did not work exactly as planned and it can be seen from the Figure 39 below.

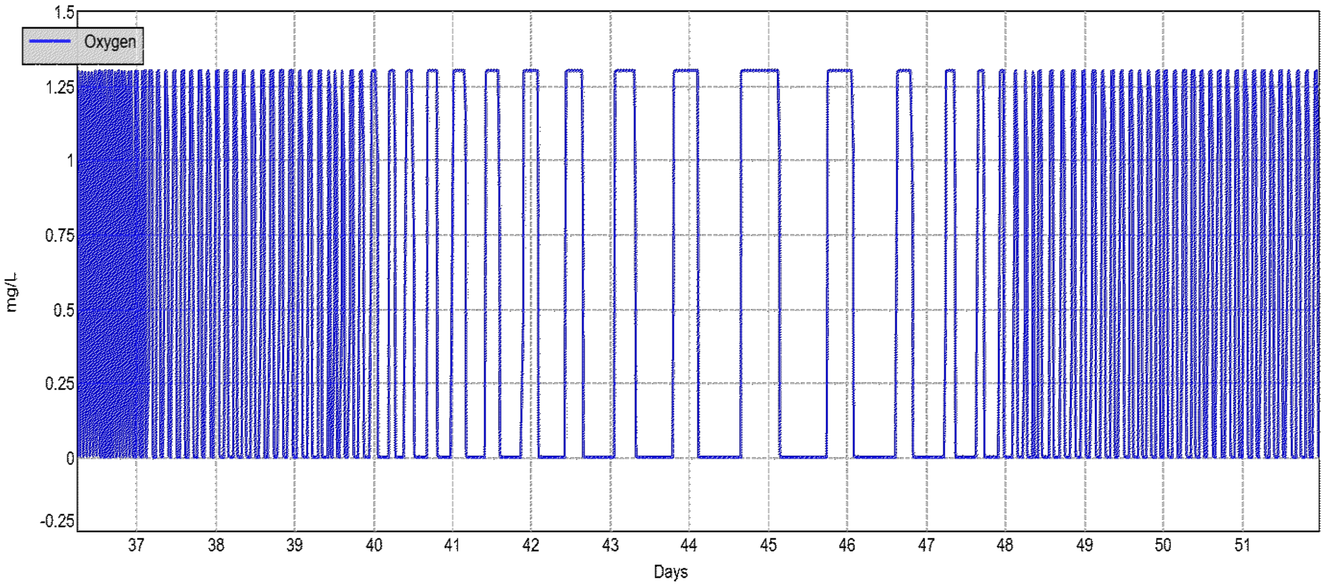

Figure 39. Simulation 2. Oxygen change

As it can be seen, the change between 2 stages between aeration and not aeration is too long in order to have those peaks. The reason for that is the amount of extra NH_4 and NO_3 as well as PO_4 coming after digesters back to the system. The information about them can be seen in Appendix 3. There, it can be seen the peak in NO_3.

Moreover, the COD concentration during Simulation 2 went higher than the limit, which is 60 mg/L, however that was only during the end of the year, started from the day, around 260 till the day 310 and then it went down for couple of days and raised above the limit again for a short time period.

The Simulation 3 went not so positively as the 2^{nd} one. And it can be seen from the figures, which were showing the results of Simulation 3. All of the tracked elements were higher than needed during the whole year. And the aeration was not working as planned during whole time period and it can be seen from the Figure 40.

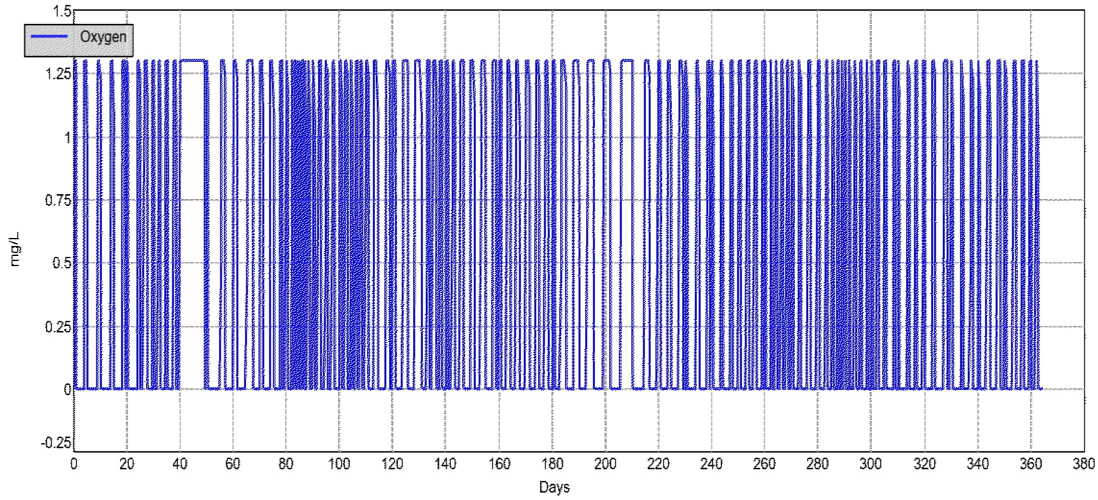

Figure 40. Simulation 3. Oxygen change

It can be seen, from the Figure 40, that there are a lot of constant aeration periods (around 10 days) between days 40 and 60 and as well some periods without aeration for 1-2 days.

Moreover, the data from the Return water from the digesters were also showing high results and can be seen from the Appendix 4.

The reason to have 2 digesters was due to the fact that in case of some accident, there would not be a need to stop the whole plant and as well in case of maintenance. It would be possible to stop only one and the second one would be working for some time period. That is why there was a need to check what kind of connection is better, serial or parallel. And as the result were showing, it does not affect the outflow of the sewage treatment plant, but it was affecting the gas outflow. There was a problem with adjusting the temperature for the digesters as that was not possible for the blocks, which were available. In current version of Simba# software, it is not possible to connect to such system the digester, where it is possible to adjust the temperature and a lot of other parameters. The only one, which was available, was the volume of the tank. That is why it was hard to estimate it. That is the problem with ASM 3 Bio-P model as it is a new one, installed in Simba# software and it should be optimized for all of the blocks.

The results of gas outflow were successfully measured and noted down the starting points as well as the difference between continuous and parallel connection of digesters and how it changed the result.

That was also noticed that the gas outflow started after around 20 days with serial connection of digesters and after around 40 days with parallel connection of digesters. That explains that with parallel connection both of digesters are working with the same load and with the same power. On the other side, with serial connections of digesters there is time for the first digester to filled in with the sludge and only after it is filled, the second one started to be filled and that is the reason, why it has this around 20 days delay. Later, it is showing small amounts of gas outflow. In series operation, the digester feed to send to the first digester, the digested sludge from the first digester is transferred to the second digester, and digested sludge from the second digester is transferred to the solids disposal/dewatering process. Based on the research of Chapman et al (2010), the serial connection of digesters supposed to give the better performance due to the double the solids loading rate to the first digester in series (relative to parallel operation), while maintaining the equivalent hydraulic retention time (HRT) though the digestion system. And the HRT is the time required for the influent feed to spent inside the reactor. Serial connection of digesters should improve the gas production, gas quality and in several cases, it will improve the stability of the digestion process as measured my alkalinity, volatile acid and pH. By placing the digesters in series, the process approaches plug-flow design and offers improved process performance, and a design with tanks in series will reduce the potential for short circuiting and improved pathogen reduction (Chapman et al, 2010).

However, it this work, there were no increase of gas production with serial connection of digesters, compared to the parallel ones. The reason for that can be in the Simulation program, the other type of digesters was used in order to connect to the system, where the ASM 3 Bio-P model was used and with future updates of the program it would be possible to simulate the process better and it would show other results.

The idea of using the simulation program in order to see the results and the outcome of possible improvements for the plant is that in such programs, like Simba#, it is always possible for a fast change between paraments. Adding new blocks to the system and after starting the simulation, the results are already can be seen and if the result of the simulation is still not satisfying, the same can be repeated again in order to get the best outcome and finally implement it in real life.

6 CONCLUSIONS

All in all, the work went well, and the results were obtained for all of the simulations.

First of all, the Simulation 1, which was the simulation of the current situation of the Schladen sewage treatment plant was simulated and programmed all the processes with the data from 2010-2011. The results were collected and compared with real values, however with different year (2003-2004).

Besides that, results and the simulation itself were discussed with responsible person in Schladen sewage treatment plant, which were close to reality and he was satisfied with the model done for the current simulation of the plant. The results showed good concentrations of NH_4, NO_3, COD and PO_4. The regulation limits were not exceeded almost during the whole-time period, which was in this work 1 year. The difference between compared was due to the fact that the outflow data from Schladen was provided in the way that there in only 1 measurement during 3 - 4 days of each element and Simba# were calculating around 130 times per day all the elements. And it was hard to say what was exactly happening during those 3 days in Schladen sewage treatment plant. As well, the inflow data was taken for the period between the year 2010 and 2011 and the outflow data was taken between the years 2003 and 2004, which also affected the results.

That is why it can be said that there is no point in comparison of the data between the simulation and the real values due to a lot of differences with the dates and measurements. And on the other side, the most important point was not to exceed the limits, which were set from the Schladen treatment plant. That is the reason for future research and simulation of possibilities for improvements in the current system with digesters.

Secondly, Simulation 2, which was the simulation of the new anaerobic system with primary clarification tank showed the results, which were not exceed the limit almost for the whole time-period of 1 year, which was analysed. In there, 2 possible connections of digesters, such as serial and parallel were showed. There were only 2 peaks of traced elements in the outflow. The reason for that was high concentrations of PO_4 and total N in the return water from the digesters. And that was the reason that the aeration was not working as before in the Simulation 1. The amount of gas with serial and parallel digesters was the same, however, with serial connection, mostly all of the gas was getting out from the fist tank and with parallel both of the tanks were showing the same gas outflow.

Comparison with other sources for the different connection of digesters did not show the same results, which was expected. The reason for that could be in the Simba# simulation program and the new model, ASM 3 Bio-P, which was used, and it still needs some improvements in order to properly simulate the case. However, based on the research, which was done, the serial connection of digesters would be recommended to apply for better outcome.

Finally, Simulation 3 did not work as planned due to very high concentrations of NH_4, NO_3, PO_4 in the outflow and the limits were exceeded almost during the whole-time period, which was analysed. For instance, the concentration of NH_4 in average exceed the limit in 4 times. And again, the reason for that were even more higher concentration of elements in the return water after digesters and in this case, the aeration in the aeration tanks were not working for the whole period, compared to the Simulation 2, where that happened only at one-time period.

7 RECOMMENDATIONS

Due to the fact that there is always something to improve, it can be mentioned here that further research would be good idea. First of all, there would be good to have more data from the company in order to put it inside of all controllers and inflow in order to have the simulation closer to reality. And get the outflow values look exactly the same or with around 10 % range between them. Moreover, there would be good to create for the company automatic sludge controller and do not have the manual one, where responsible person just opens the pump and adjusting its' flow based on the visual situation inside the plant.

Furthermore, creating more simulation with adjusting the sizes of digesters and their temperature with programming for instance in order to get better outflow of gas, sludge and water. Probably, it the future updates of the Simba# modelling software, there would be more possibilities in order to choose the ASM 3 Bio-P model for more blocks, such as digesters.

Moreover, choosing other filters and their sludge removal percent and putting their data to the program in order to get the result closer to reality. That is as well, up to the company, what kind of filters they would like to have and then the modelling can happen again in order to see the real picture.

And finally, start calculating the income from selling the gas and for example using it inside the plant. As well, calculating all possible invested money in order to see possible profits and then again, the sizes of new tanks can be adjusted with different connections.

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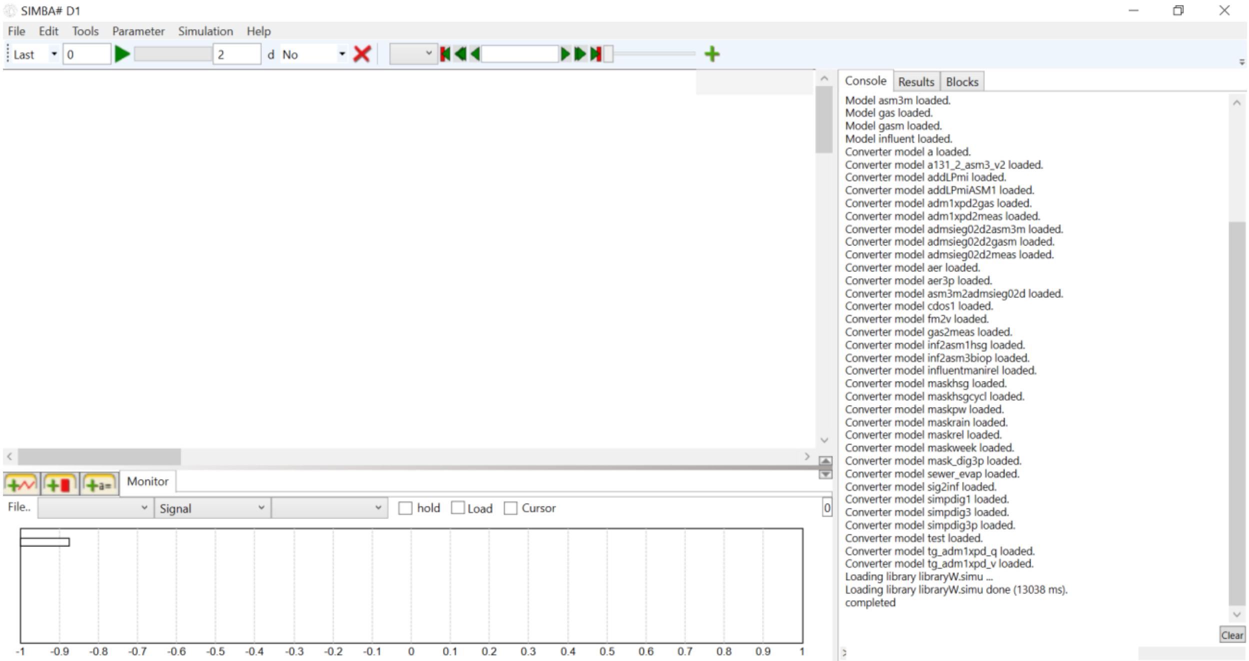
APPENDICES

Appendix 1. SIMBA# software. Interface.



Appendix 2. Programming aeration in Aeration tanks.

```
FUNCTION_BLOCK AirController1
VAR_INPUT
        ti:             REAL;        (* TIME input *)
        NH:             REAL;        (* NH4 measurement input *)
        NO:             REAL;        (* NO3 measurement input *)
        START:          REAL;        (* Startsignal input *)
        DNt:            REAL;        (* Time for Deniphase input *)
        Nt:             REAL;        (* Time for Nitriphase input *)
        DN_NH_Max:      REAL;        (* Maximum NH4 Value in Deniphase input *)
        DN_NO_Min:      REAL;        (* Minimum NO3 Value in Deniphase input (Start aeration until 2 mg/l NO) *)
        DN_NO_Max:      REAL;        (* Maximum NO3 Value for switch to Nitriphase in Deniphase input *)
        DN_NO_Sw:       REAL;        (* NO3 Value for switch to Deniphase back after aeration input *)
        N_NH_Max:       REAL;        (* Maximum NH4 Value for switch to Deniphase in Nitriphase input *)
        N_NH_Sw:        REAL;        (* NH4 Value for switch from Nitriphase 2 to Deniphase input *)
END_VAR
VAR_OUTPUT
        Auto:           REAL;        (* Output for Controller *)
        Nitri:          REAL;
        Deni:           REAL;
END_VAR
```

Appendix 2.1 Programming aeration in Aeration tanks. Stage 1.

```
VAR
        t1:             REAL;
        tsetN:          REAL;
        tsetDN:         REAL;
        t1set:          BOOL;
        Ni:             BOOL;
        Ni2:            BOOL;
        DN:             BOOL;
        DN2:            BOOL;
        DNL:            BOOL;        (* Longer Deniphase *)
END_VAR

IF (START = 1.0) THEN
        Ni:= TRUE;
        Ni:= TRUE;
        Ni2:= FALSE;
        DN:= FALSE;
        DN2:= FALSE;
        DNL:= FALSE;
        t1set:= TRUE;
```

Appendix 2.2 Programming aeration in Aeration tanks. Stage 2.

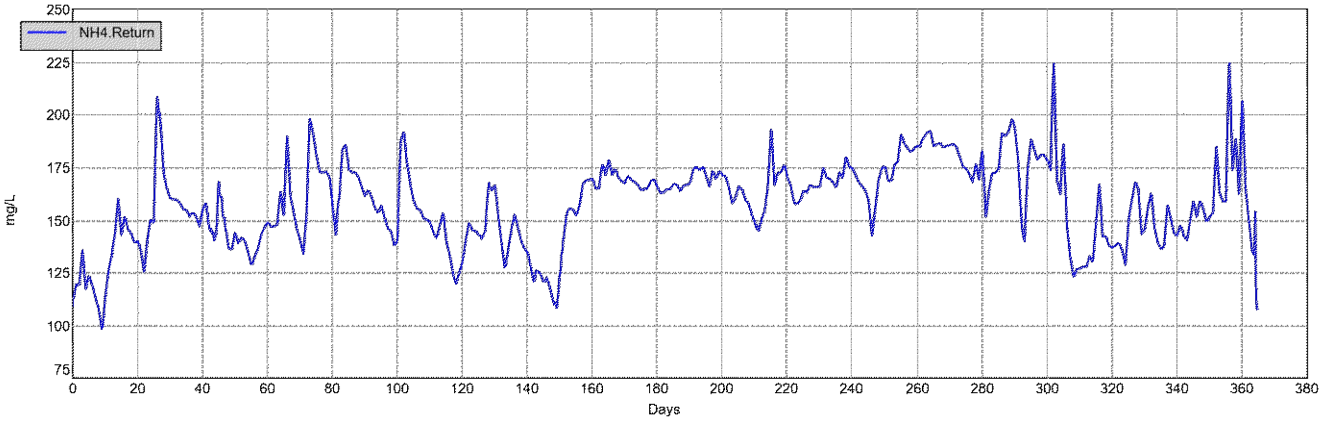
```
IF (t1set) THEN
       t1:= ti;
       t1set:= FALSE;
END_IF;

IF Ni THEN
tsetN:= Nt/(24.0*60.0);
       IF (ti < (t1 + tsetN)) THEN
              Auto:= 1.0;
              Nitri:= 1.0;
       ELSIF ((ti > (t1 + tsetN)) AND (NH > N_NH_Max)) THEN
              Auto:= 1.0;
              Nitri:= 2.0;
              Ni2:= TRUE;
       ELSIF ((ti > (t1 + tsetN)) AND (NH < N_NH_Max) AND (NOT Ni2)) THEN
              Auto:= 0.0;
              Ni:= FALSE;
              DN:= TRUE;
              t1set:= TRUE;
              Nitri:= 0.0;
       ELSIF ((ti > (t1 + tsetN)) AND (NH < N_NH_Sw) AND Ni2) THEN
              Auto:= 0.0;
              Ni:= FALSE;
              Ni2:= FALSE;
              DN:= TRUE;
              t1set:= TRUE;
              Nitri:= 0.0;
       END_IF;
END_IF;
```

Appendix 2.3 Programming aeration in Aeration tanks. Stage 3. Nitrification mode.

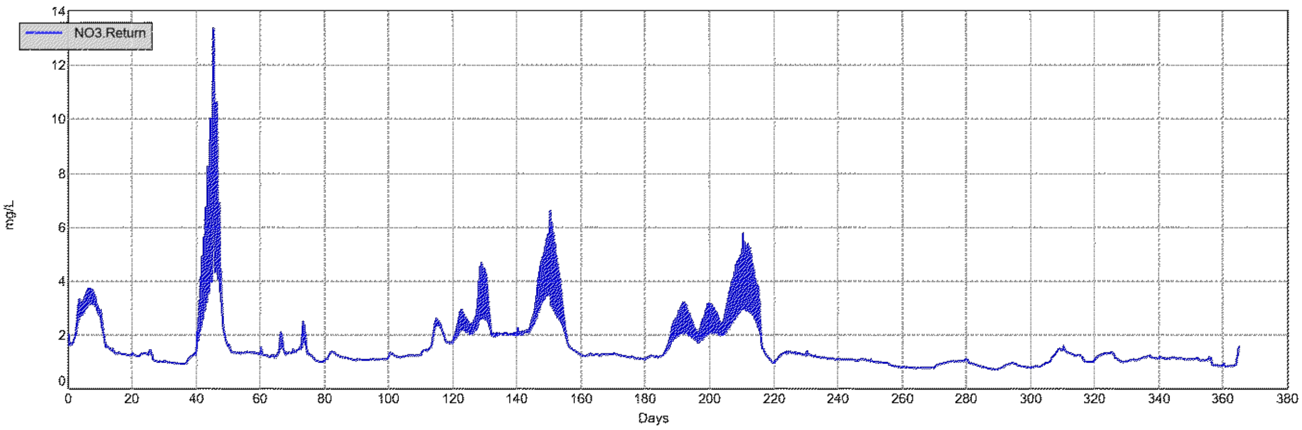
```
IF (t1set) THEN
       t1:= ti;
       t1set:= FALSE;
END_IF;

IF DN THEN
tsetN:= DNt/(24.0*60.0);
       IF ((ti < (t1 + tsetDN)) AND (NOT DN2) AND (NH < DN_NH_Max)) THEN
              Auto:= 0.0;
              Deni:= 1.0;
       ELSIF ((ti < (t1 + tsetDN)) AND (NOT DN2) AND (NH > DN_NH_Max)) THEN
              Auto:= 1.0;
              Deni:= 1.0;
       ELSIF ((ti < (t1 + tsetDN)) AND (NO < DN_NO_Min)) THEN
              Auto:= 1.0;
              DN2:= TRUE;
              Deni:= 2.0;
       ELSIF ((ti < (t1 + tsetDN)) AND (NO < DN_NO_Sw) AND DN2) THEN
              Auto:= 1.0;
              Deni:= 2.0;
       ELSIF ((ti < (t1 + tsetDN)) AND (NO > DN_NO_Sw)) THEN
              Auto:= 0.0;
              DN2:= FALSE;
              Deni:= 1.0;
       ELSIF ((ti > (t1 + tsetDN)) AND (NO > DN_NO_Max) AND (NOT DNL)) THEN
              t1:= ti;
              DNL:= TRUE;
              Deni:= 3.0;
       ELSIF ((ti > (t1 + tsetDN)) AND (NO < DN_NO_Max)) THEN
              Auto:= 1.0;
              Ni:= TRUE;
              DNL:= FALSE;
              DN:= FALSE;
              DN2:= FALSE;
              Deni:= 0.0;
       END_IF;
END_IF;

END_FUNCTION_BLOCK
```

Appendix 2.4. Programming aeration in Aeration tanks. Stage 4. Denitrification mode.

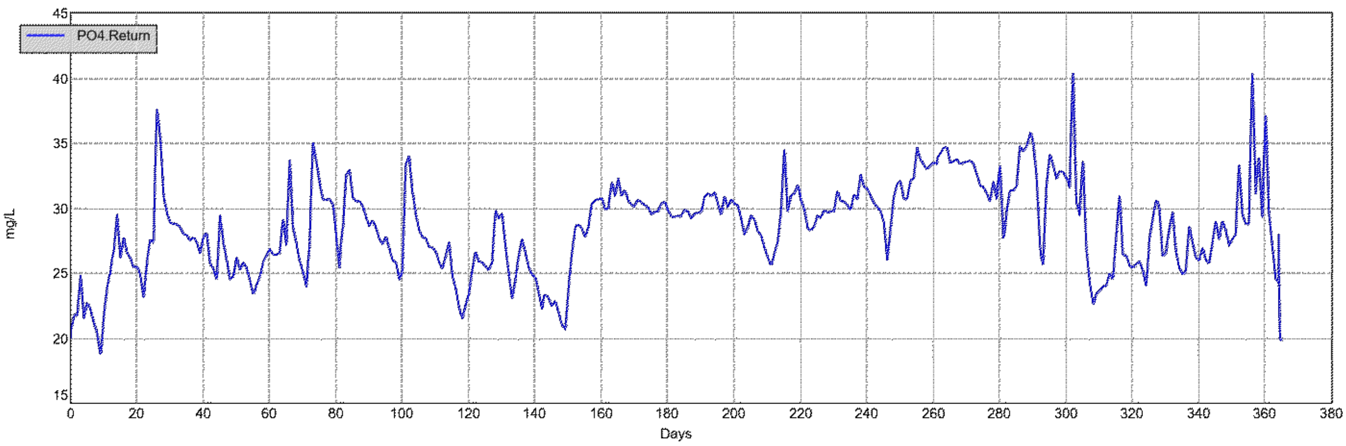
Appendix 3. Simulation 2. Return values after digestion.



Appendix.3.1. Return values of NH_4

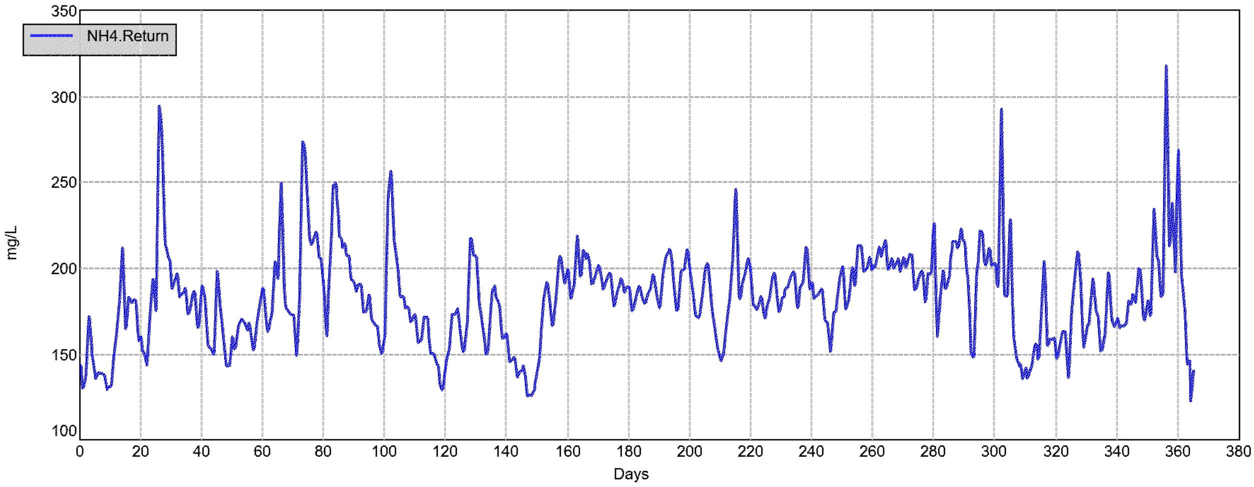


Appendix 3.2. Return values of NO_3

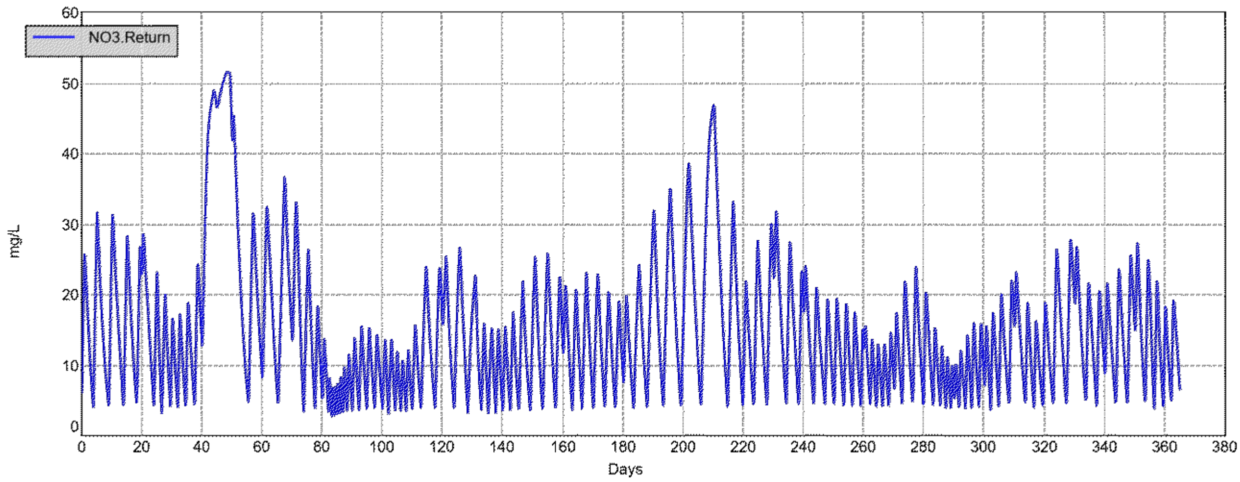


Appendix 3.3. Return values of PO_4

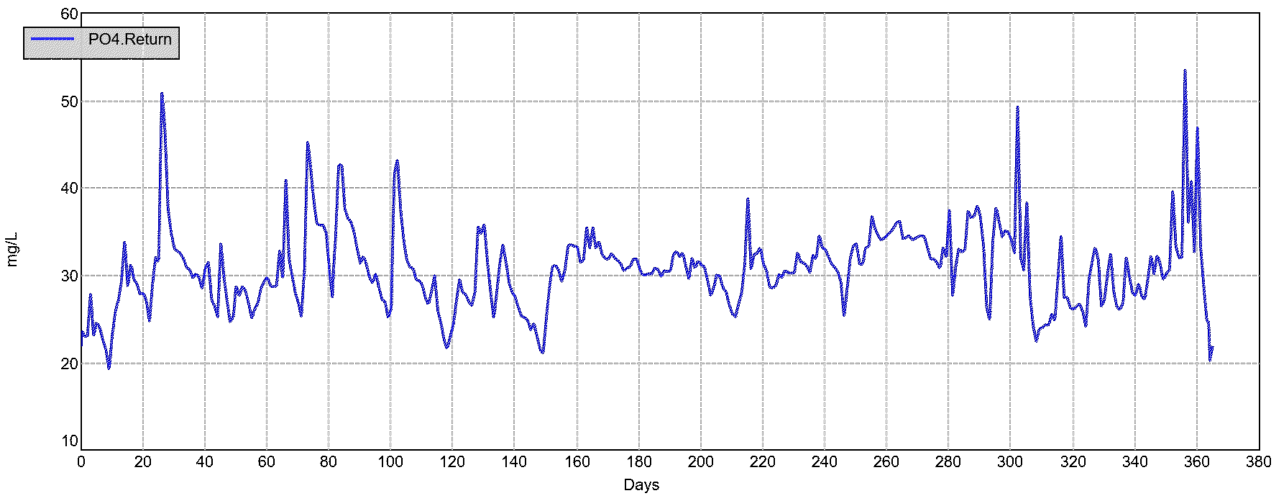
Appendix 4. Simulation 3. Return values after digestion.



Appendix 4.1. Return values of NH_4



Appendix 4.2. Return values of NO_3



Appendix 4.3. Return values of PO_4