

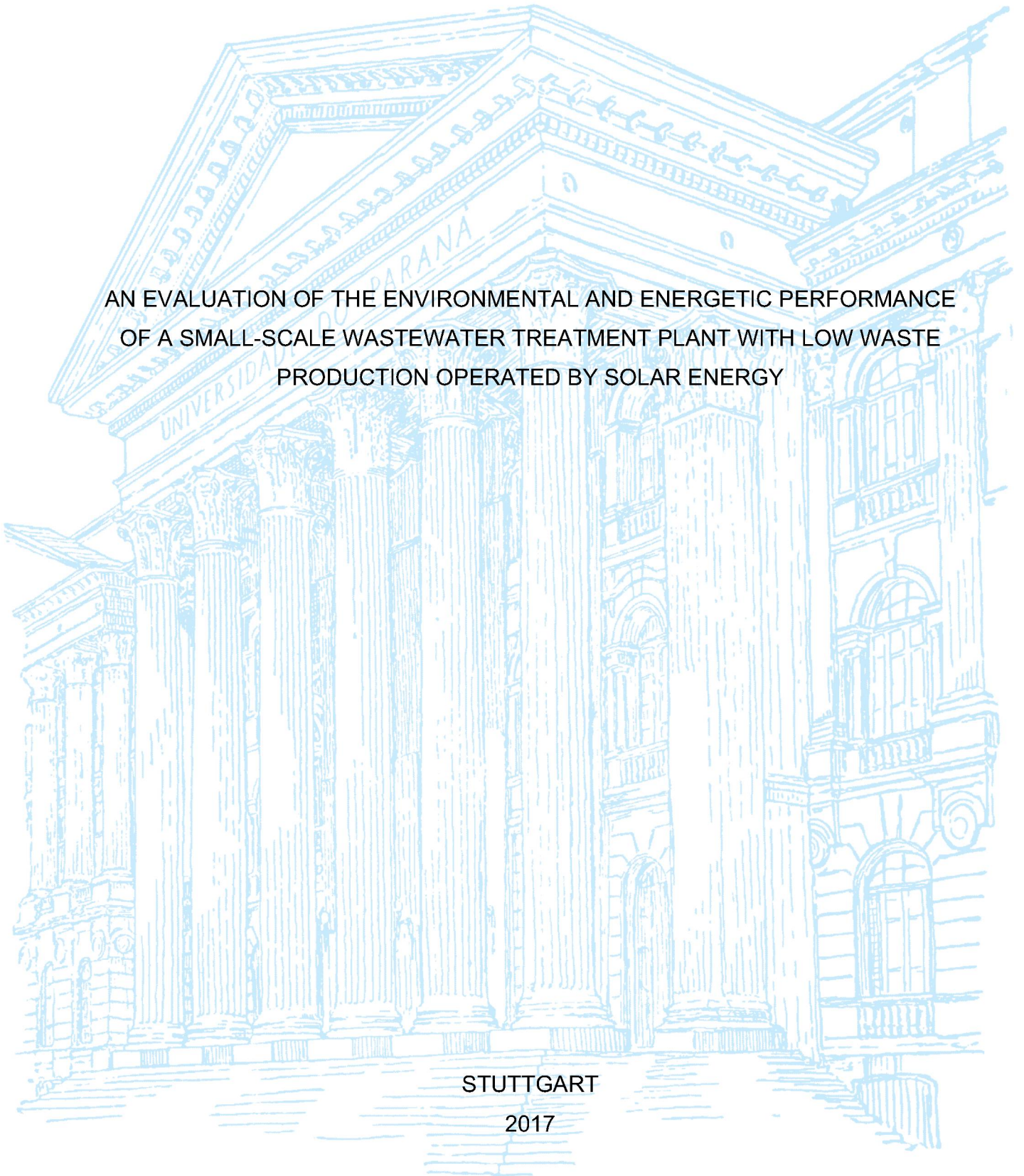
UNIVERSIDADE FEDERAL DO PARANÁ

FRANCINE SANTIAGO BUCCO

AN EVALUATION OF THE ENVIRONMENTAL AND ENERGETIC PERFORMANCE
OF A SMALL-SCALE WASTEWATER TREATMENT PLANT WITH LOW WASTE
PRODUCTION OPERATED BY SOLAR ENERGY

STUTTGART

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Dissertação apresentada ao curso de Pós-graduação em Meio Ambiente Urbano e Industrial, Setor de Tecnologia Universidade Federal do Paraná, em parceria com o curso de Mestrado Waste, da Universidade de Stuttgart como requisito parcial à obtenção do título de Mestre em Meio Ambiente Urbano e Industrial.

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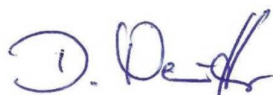
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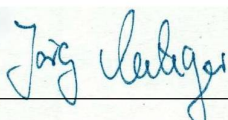
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Water and Sanitation is one of the primary drivers of public health. I often refer to it as “Health 101”, which means that once we can secure access to clean water and to adequate sanitation facilities for all people, irrespective of the difference in their living conditions, a huge battle against all kinds of diseases will be won.

Dr LEE Jong-wook, Director-General, World Health Organization.

RESUMO

No capítulo 1, é apresentada a introdução das estações de tratamento de efluente compactas, que vem sendo usadas na Alemanha nos últimos 15 anos, pelo menos, e também em países como China e Dinamarca. Como água e esgoto ainda são um problema preocupante em países em desenvolvimento, como o Brasil, o objetivo desse projeto apresentada no item 2 é avaliar a eficiência de uma estação de tratamento de efluentes compacta com baixa geração de lodo e operando com energia solar, para no futuro aplicar o projeto no Nordeste brasileiro. Projetos como esse apresentam grande importância para o desenvolvimento de países como o Brasil onde falta investimento em saneamento e em pesquisas. No capítulo 3, são apresentados parâmetros de tratamento de esgoto por lodos ativados, bem como a eficiência de remoção de carbono e nitrogênio esperada para uma estação compacta como a utilizada na pesquisa, que são respectivamente >90% e entre 10-70%. As legislações alemãs e brasileiras são também apresentadas, sendo que na Alemanha existe a norma DIN EN 12566-3, específica para estações compactas, diferentemente do Brasil, onde não existe legislação específica, porém cada existe a obrigatoriedade de tratar o esgoto produzido em uma residência quando rede de tratamento de esgoto não é disponível de acordo com o DECRETO Nº 7.212/10. No item 4, a estação de tratamento de efluente compacta é apresentada, chamada BioTopp, foi inicializada para o equivalente populacional de 6 pessoas e parâmetros como temperatura, pH, oxigênio, volume de lodo, demanda bioquímica de oxigênio (DQO) e nitrogênio foram analisados em três diferentes fases, sendo fase de avaliação com os controles operacionais fornecidos pelo fabricante e teste 1 e 2, onde foram alterados tempo de aeração e pause no processo, respectivamente. Os resultados, no capítulo 5, mostraram que a planta atinge as condições pré-estabelecidas para remoção de nutrientes, através da nitrificação e desnitrificação, além de redução de carga orgânica. A planta apresentou eficiência na remoção de DQO entre 74 e 93% e 59 a 94% de eficiência na remoção de amônio. Foram observadas variações nas condições de entrada do efluente, o que pode ter comprometido o tratamento, levando em consideração que a estação é sensível a variações tanto no afluente quanto nos parâmetros de controle operacionais. Durante o teste 1, a planta apresentou os melhores resultados em remoção de matéria orgânica e, no teste 2, a planta apresentou melhores resultados na remoção de nitrogênio. De acordo com o órgão ambiental responsável na Alemanha, a estação pode ser classificada como classe C. Conclui-se por fim, no capítulo 6, que a planta é uma boa alternativa para casas sem acesso a saneamento. Além disso, a planta é operada automaticamente durante os meses analisados, sem requerimentos de manutenção e a operação com painéis solares mostrou-se possível e eficiente durante o verão europeu onde os valores apresentados de irradiação solar horizontal global são menores que no Brasil.

PALAVRAS CHAVE: Estação de tratamento de efluente compacta, efluente doméstico, energia solar.

ABSTRACT

Water and wastewater management is still a worrisome problem in under-developed and developing countries, like Brazil. Small scale wastewater treatment plants (WTP's) have been used in Germany for at least in the last 15 years and also in other countries, such as China and Denmark. For this reason, the aim of the current study is to evaluate the efficiency of a compact WWTP with low waste production operated by solar energy in order to consider the application of this project in the future in the Northeast region in Brazil. Projects such as this one contribute to their development by providing new technologies to supply the lack of investment in sanitation and in research. A small-scale WWTP, BioTopp, was started up for 6 populations equivalent (PE) and parameters like temperature, pH-value, oxygen and settled sludge volume were analysed during one month. The results of the first evaluation showed that the plant achieves the conditions for nitrification and denitrification process. After that, another parameters started being analysed, such as COD, ammonium, nitrite, nitrate, solids content and sludge volume index. Biotopp showed efficiency in COD removal between 74 to 93%, ammonium 59 to 94%. However, it was observed that the small-scale plant is very sensitive to variations in the inflow characteristics and in the controlling parameters. According to DIBt, the plant can be classified as class C and it showed to be a good alternative for households located in places without wastewater collection and treatment. The plant operates automatically and during the European summer the solar panels and batteries supplied all of the power demand.

KEY WORDS: Small-scale wastewater treatment plant, domestic wastewater, solar energy.

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LIST OF ABBREVIATIONS

A/O	– Anaerobic/oxic
ANA	– <i>Brazilian National Water Agency</i>
ABNT	– <i>Associação Brasileira de Normas Técnicas</i> (Brazilian Association of Technical Standards)
AER	– Aeration
ANEEL	– <i>Agência Nacional de Energia Elétrica</i> (Brazilian National Electric Power Regulator)
BEDW	– <i>Bundesverband der Energie- und Wasserwirtschaft</i> (German Association of Energy and Water)
BNR	– Biological nutrient removal
BOD	– Biological oxygen demand
CO ₂	– Carbon dioxide
COD	– Chemical oxygen demand
CONAMA	– <i>Conselho Nacional do Meio Ambiente</i> (National Environment Council)
CREA	– <i>Conselho Regional de Engenharia, Arquitetura e Agronomia</i> (Regional Engineering, Architecture and Agronomy Council)
CSTR	– Continuous stirred tank reactor
CW	– Constructed wetland
DIBt	– <i>Deutsches Institut für Bautechnik</i> (German Institute for the Construction Sector)
DWA	– <i>Deutsche Vereinigung für Wasserwirtschaft, Abwasser und Abfall e.V.</i> (German Association for Water, Wastewater and Waste)
EN	– European Standard
EU	– European
F/M	– Food/microorganism
GHI	– Global Horizontal Irradiance
IBGE	– <i>Instituto Brasileiro de Geografia e Estatística</i> (Brazilian Institute for Geography and Statistics)
ISO	– International Organization for Standardization

ISWA	– <i>Institut für Siedlungswasserbau Wassergüte- und Abfallwirtschaft</i> (Institute for Sanitary Engineering, Water Quality and Solid Waste Management)
MBR	– Membrane bioreactor
MLSS	– Mixed liquor suspended solids
NBR	– <i>Norma Brasileira</i> (Brazilian Standard)
NH ₃	– Ammonia
NH ₄ ⁺	– Ammonium
NO ₂	– Nitrite
NO ₃	– Nitrate
O ₂	– Oxygen
PC	– Per capita
PE	– Population equivalent
pH	– Potential of hydrogen
PO ₄	– Phosphate
RES	– Renewable energy sources
SBR	– Sequencing batch reactors
SEMA	– <i>Secretaria Estadual do Meio Ambiente</i> (State Secretariat of the Environment)
SO ₄ ⁺²	– Sulphate
SRT	– Solids retention time
SV	– Sludge volume
SVI	– Sludge volume index
THCW	– Tertiary hybrid constructed wetland
TN _b	– Total nitrogen
TS	– Solids content
UASB	– Upflow anaerobic sludge blanket reactor
UFPR	– <i>Universidade Federal do Paraná</i> (Federal University of Paraná)

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1 INTRODUCTION

Approximately 1.3 billion people in the developing world lack access to adequate quantities of clean water, and nearly 3 billion people are without adequate means of disposing of their faeces. An estimated 10,000 people die every day from water- and sanitation-related diseases, and thousands more suffer from a range of debilitating illnesses. (BOSCH *et al.*, 2002, p. 373)

According to the Brazilian National Water Agency (ANA), 43% of the Brazilian population is connected to the sewage systems, 12% has septic tank, being that is considered that 55% of the sewage generated by the population receives adequate treatment; 18% of the sewage is collected but not treated and 27% is not collected and treated. On the one hand, it is observed higher values in states like Paraná and São Paulo. In the state of Paraná, for example, 64% of sewage is collected and treated and 11% of sewage is treated according to an individual solution and in São Paulo, 76% is collected and treated. On the other hand, there are states that show lower percentages from the national average, like Rio Grande do Norte and Alagoas, where 24% and 16% is collected and treated and 22% and 12% is treated according to an individual solution, respectively (ANA, 2016).

In Germany, according to the the Federal Statistical Office of Germany (*Statistisches Bundesamt*), in 2010, approximately 95.7 % of the population was connected to the sewage system with centralized wastewater treatment and 3.4 % had decentralized treatment, being that only 0.09% of the population did not have any kind of wastewater treatment. Moreover, more than 2.2 million people were connected to a small-scale wastewater treatment plant (WTTP) in Germany (*Statistisches Bundesamt*, 2010; Durth and Kolvenbach, 2014).

Small-scale WTTPs have been used in many countries, such as Germany, Denmark and China as an alternative solution for septic tanks or to avoid the discharge of domestic wastewater directly into watercourses, lakes, or the sea. The domestic wastewater is from households, restaurants and hotels that are located in rural or remote areas without sewage collection and treatment (Brix and Arias, 2005; Matamoros *et al.*, 2009; Wu *et al.*, 2011; Wu *et al.*, 2015).

Water and wastewater management is still a worrisome problem in under-developed and developing countries, like Brazil. Wastewater treatment problems associated with remote areas, such as rural areas, involve the fact that usually the population is dispersed and there are limited finances, operational expertise and energy (Matamoros *et al.*, 2009; Ren *et al.*, 2009).

This project is the evaluation of a small-scale WWTP with low waste production operated by solar energy which shows a suitable solution for areas without public wastewater treatment because it requires low maintenance, no need of operational expertise to run the treatment and it uses renewable energy. In Brazil, this project could be applied in areas with low-incoming houses, that is why it is an important technology with low costs. Besides that, maintenance and operational expertise can be very expensive in under-developed and developing countries, showing the importance of projects with low requirement of both.

According to Bezerra and Santos (2016), only 0.01% of the renewable power used in 2015 was from solar energy. South Brazil represents the region with lowest values for the annual average of solar irradiation in the country, around 1642 kWh/m². The Brazilian state of Bahia is the one that shows the highest solar irradiation in Brazil, with an annual average of 6500 kWh/m², being that the average in the North-West region in Brazil, is 5500 kWh/m². However, this value is higher than the most favoured part of Germany, which shows 1300 kWh/m² (Salamoni and R  ther, 2007; Bezerra and Santos, 2016). Therefore, it is extremely important to motivate the use of renewable energy in Brazil.

For this reason, the aim of this project is to evaluate the environmental and energetic efficiency of a small-scale WWTP with low waste production operated by solar energy in order to consider the application of this project in the future in Brazil where projects such as this one contribute to their development by providing new technologies that are cost effective.

2 GENERAL AND SPECIFICS OBJECTIVES

2.1 GENERAL OBJECTIVE

Evaluate the environmental and energetic performance of a small scale WWTP with low waste production operated by solar energy during the European summer.

2.2 SPECIFIC OBJECTIVES

- A. Evaluate the efficiency of nutrients and organic matter removal of a wastewater treatment plant;
- B. Improve the efficiency of wastewater treatment with regards to nutrients and organic matter removal;
- C. Establish the ideal operational parameters by analysing physical and chemical parameters (chemical oxygen demand, nitrate, nitrite, ammonium, oxygen, pH, temperature, sludge volume, solid content and sludge volume index);
- D. Verify the operation of the solar panels in German summer and compare to the Brazilian conditions;

3 LITERATURE RESEARCH

3.1 DOMESTIC WASTEWATER

Domestic wastewater, municipal wastewater or sewage, can be considered as the wastewater produced by a community of people that is carried away from households, restaurants, hotels or any other building that contains toilets or a kitchen. The sewage composition depends of its source but on average 99.9% is essentially bath water, soaps, wash water with a small fraction (0.1%) composed of urine and faeces. About 25% of the organic matter present in sewage is in the of faeces and 2.5% from urine (Von Sperling, 2012; Jordão and Pessoa, 2005).

Domestic wastewater has typical characteristics inherent to the anthropogenic origin of the waste stream. The organic matter existent in wastewater are of particular interest in sanitary engineering for the process of controlling. It is not practical to determine all of the organic matter present in wastewater because there are an enormous number of different matter. As a result, the concept of organic material was introduced to indicate the combined concentration of all organic matter in wastewater. There are two main parameters used for this purpose, the biological oxygen demand (BOD) and the chemical oxygen demand (COD) (Van Haandel and Van der Lubbe, 2012).

BOD is the mass of oxygen which is required by microorganisms during a test in closed flasks over a period of 5 (BOD_5), 7 (BOD_7), 10 (BOD_{10}), or 20 days (BOD_{20}) at a constant temperature of 20°C, pH 7 – 8 and after the addition of nutrients. It is an important parameter to determine how polluted the raw water and treated water is, to calculate the size of the wastewater treatment plant and to measure the process efficiency. Usually, the BOD value in domestic wastewater is between 100 to 400 mg/L. However, BOD is not a good operational parameter because the result is only given after 5, 7, 10 or 20 days (Wiesmann, Choi and Dombrowski, 2007; Jordão e Pessoa, 2005).

The COD is defined as the mass of oxygen needed to completely oxidise an organic compound present in water and its value in domestic wastewater is usually between 200 to 800 mg/L. Wastewater is considered biodegradable when it presents a BOD/COD ratio above 0.2, municipal wastewater normally presents a ratio between 0.4 to 0.6 (Wiesmann, Choi and Dombrowski, 2007; Porto, 1991; Von Sperling, 2012).

Wastewater treatment plants are usually designed based on their daily contamination, such as the standard contamination load of one contaminant in BOD₅/day, or the wastewater load for one inhabitant. In Brazil, the Brazilian Association of Technical Standards (ABNT – *Associação Brasileira de Normas Técnicas*) in one of its standards associates inhabitants income, for example, for an upper class household the wastewater load for one person a day is 160 L (Table 1), therefore, for a middle class household the wastewater load for one person a day would be around 130 L. In Germany, the German Association for Water, Wastewater and Waste (DWA - *Deutsche Vereinigung für Wasserwirtschaft, Abwasser und Abfall e.V. – ATV-DVWK*) defines the daily load of one population (P) for Germany as 150 L/d (ABNT NBR 7229, 1993; ATV-DVWK-A 116, 2004).

TABLE 1 – BRAZILIAN WASTEWATER LOAD ACCORDING TO ACTIVITY

Activity	Unity	Wastewater (L/day)
1 – Permanent		
Households:		
Upper class	Person	160
Middle class	Person	130
Lower class	Person	100
Hotel (without kitchen and laundry)	Person	100
Accommodation	Person	80
2 – Temporary		
Industry	Person	70
Office	Person	50
Public buildings	Person	50
Schools	Person	50
Pubs	Person	6
Restaurants	Meal	25
Cinemas, theatres	Seat	2
Public toilets	Bowler sanitary	480

SOURCE: Adapted from ABNT NBR 7229, 1993

Different wastewater treatments have been used for domestic wastewater, however the most popular method is the activated sludge process, which is explained in the next chapter.

3.2 ACTIVATED SLUDGE PROCESS

The activated sludge process was developed in England in 1914 by Arden and Lockett. The process was so named because it involved the production of an activated mass of microorganisms capable of aerobically stabilizing the waste. Different versions of the original process are used today but they are all essentially similar (Metcalf & Eddy, 2013).

In this process, the waste, typically domestic sewage, is stabilized biologically in a reactor under aerobic conditions achieved using diffused or mechanical aeration. The reactor contents are denoted as the mixed liquor. The waste is treated in the reactor and after that, the resulting biological mass is separated from the liquid in a settling tank. A portion of the biological solids is recycled and the remaining mass is wasted. The desired treatment efficiency and other considerations related to growth kinetics, state the level at which the biological mass should be maintained (Von Sperling, 2012; Grady et al., 2011).

In the activated sludge process, the bacteria are the most important microorganisms because they are responsible for the decomposition of the organic material in the influent. In the reactor, a portion of the organic waste matter is used by aerobic and facultative bacteria to obtain energy for the synthesis of the remainder of the organic material into the cells. Only a portion of the original waste is actually oxidized to low energy compounds, such as NO_3^- , SO_4^{+2} and CO_2 ; the remainder synthesized into cellular material (Grady et al., 2011).

Besides bacteria, there are other metabolic activities from other microorganisms that are also important in the activated sludge process. Protozoa and rotifers act as effluent polishers. Protozoa consume dispersed bacteria that have not flocculated and rotifers consume any small biological floc particles that have not settled (Jordão e Pessoa, 2005).

Further, while it is important that bacteria decompose the organic waste as quickly as possible, it is also important that they form a satisfactory floc, which is a prerequisite for the effective separation of the biological solids in the settling unit. It has

been observed that as the mean cell residence time is increased, the settling characteristics of the biological floc are enhanced. The reason for this is that, as the mean age of the cells increases, the surface charge is reduced and the microorganisms start to produce extracellular polymers, eventually becoming encapsulated in a slime layer (Von Sperling, 2012).

There are four factors that are common to all activated sludge process, these are:

1) a flocculent slurry of microorganisms (mixed liquor suspended solids [MLSS]) is used to remove soluble and particulate organic matter from the influent waste stream;

2) liquid/solid separation is used to remove the MLSS from the process flow stream, producing an effluent that is low in suspended solids;

3) concentrated solids are recycled from the liquid/solid separator back to the bioreactor;

4) excess solids are wasted to control the solids retention time (SRT) to a desired value (Grady et al., 2011).

The bioreactor containing the MLSS is commonly referred to as the aeration basin, and it is aerobic throughout, as indicated by the term AER. Mixing energy provided by the oxygen transfer equipment (and supplemental mixing equipment in some cases) maintains the MLSS in suspension (Metcalf & Eddy, 2013).

There are many operational parameters to control and evaluate the activated sludge process, however the main parameters are related to the sludge which is the principal characteristic of the process. The food-to-microorganism ratio (F/M) is one such parameter and is based on the concept of the amount of food availability per mass unit of microorganism. The higher the F/M ratio, the lower the treatment efficiency will be (Jordão e Pessoa, 2005; Von Sperling, 2012).

The sludge volume index (SVI) was first introduced by Mohlman in 1934 and is used in the activated sludge process to describe the settling characteristics of sludge in the aeration tank. SVI is one of the standards used to measure the physical characteristics of this process. It can be defined as the volume in millilitres occupied

by one gram of sludge after settling for 30 minutes. According to Jordão and Pessoa (2005), usually SVI values between 40 to 150 mL/g are considered to be good, indicating a good quality of sludge. Values above 200 mL/g indicate poor quality sludge, which means it does not settle properly. Clifton (1998), classifies the sludge that presents less than 80 mL/g as a sludge that is dense and has quick settling characteristics, between 100 to 200 mL/g as a high-quality effluent and 250 mL/g or higher as the sludge that settles very slowly and compacts poorly. However, the ideal SVI is inherent to each specific process (Jordão e Pessoa, 2005; Clifton, 1998).

Temperature, pH-value and O₂ are also important parameters related to the microorganisms control and will be discussed in the item 3.3.

3.3 NITROGEN REMOVAL

In the last few years, in order to avoid eutrophication of water bodies as a consequence of receiving untreated wastewater and the effluent of wastewater treatment plants, the importance of nutrient removal has increased (Van Haandel and Van der Lubbe, 2012).

The most difficult biochemical operations developed for wastewater treatment are the biological nutrient removal (BNR) systems. These systems were derived from activated sludge systems and similar to the original process they come in a number of configurations. The usual feature of all BNR processes is that they are divided into zones containing different biochemical environments which allow for nitrogen and/or phosphorus removal (Grady *et al.*, 2011).

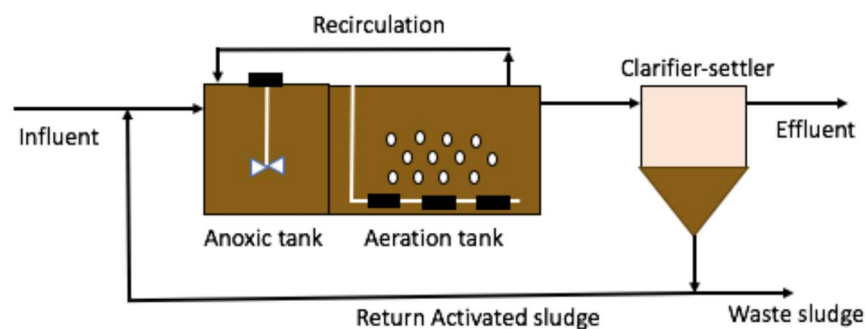
In the case of nitrogen removal, the development of nitrification in an activated sludge process is practically unavoidable if the wastewater achieves temperatures between 22 to 24°C, which will be the reality for at least part of the year in tropical and subtropical regions. The nitrate is formed and it can be used by most micro-organisms as a substitute to dissolved oxygen. This nitrate reduction by organic matter to nitrogen gas is called denitrification (Van Haandel and Van der Lubbe, 2012).

Biological nitrification and denitrification together form the most convenient processes to remove nitrogen. Ammonium is first oxidized to nitrite or nitrate by aerobic chemolitho-autotrophic bacteria during the nitrification process. In the denitrification, nitrite and nitrate are reduced to N_2 gas by chemoorgano-heterotrophic denitrifying bacteria under anoxic conditions (Wiesmann, Choi and Dombrowski, 2007).

Inorganic ammonium nitrogen is frequently the main composition of nitrogenous matter in wastewater, and can be present in gaseous (NH_3) or ionic form (NH_4^+), or as organic nitrogen (urea, amino acids and other organic compounds with an amino group). Occasionally wastewaters contain traces of nitrite (NO_2^-) and nitrate (NO_3^-), which are oxidised forms of nitrogen. The nitrogen concentration can be measured in its different forms by quantitative analysis (Van Haandel and Van der Lubbe, 2012).

Usually separate stage nitrification and denitrification systems work single continuously stirred tank reactors (CSTRs) or CSTRs in series with cell recycling to degrade ammonia to nitrate and nitrate to nitrogen gas. These systems are normally used as downstream treatment additions to existing arrangements. A separate denitrification system consists of an anoxic zone followed by aerobic zone (Figure 1) and collects an influent that has earlier been nitrified. It is also necessary to have a small aerobic zone in these reactor to release entrained nitrogen gas prior to the downstream clarifier (Grady *et al.*, 2011).

FIGURE 1 – DENITRIFICATION FOLLOWED BY NITRIFICATION ACTIVATED SLUDGE SYSTEM



SOURCE: Adapted from VON SPERLING, 2002.

The total nitrogen concentration in municipal wastewater usually is in the range of 40 to 60 mg N/L, which means a fraction in the range of 0.06 to 0.12 of the influent COD. Moreover, typically about 75% of the total nitrogen concentration will be in the form of ammonium nitrogen while the 25% remaining is mostly made up of organic nitrogen. During the activated sludge process, organic nitrogen is converted rapidly and almost quantitatively to ammonium nitrogen, through a process called ammonification. If nitrification takes place and the oxygenation capacity is enough, the oxidation of ammonium nitrogen will be almost complete. After nitrification, if the formed nitrite is removed by denitrification, the total nitrogen concentration in the effluent is usually less than 5 to 10 mg N/L. This biological nitrogen removal from municipal wastewater method has an efficiency of 90% or more (Van Haandel and Van der Lubbe, 2012).

A biological phosphorus removal system is fundamentally an activated sludge system employing CSTRs in series, in which the first bioreactor is anaerobic to support the growth of specialized phosphorus-storing bacteria and the second bioreactor is aerobic. The prototype biological phosphorus removal is the A/O (anaerobic/aerobic) process (Grady *et al.*, 2011).

3.3.1 Nitrification

To obtain energy for growth and maintenance, the autotrophic bacteria oxidize inorganic nitrogen components while they obtain carbon for cell building by the reduction of carbon dioxide (CO_2). Nitrosomonas and Nitrobacter are the bacteria responsible for the oxidation of ammonium to nitrite (nitrification) and of nitrite to nitrate (nitrification), correspondingly, as presented in TABLE 2.

TABLE 2 – BASIC COMPARISON BETWEEN NITRIFYING AND DENITRIFYING BACTERIA

Indication	Nitrifiers		Denitrifiers
	<i>Nitrosomonas</i>	<i>Nitrobacter</i>	
Carbon source	Inorganic (CO ₂)	Inorganic (CO ₂)	Organic carbon
Cell shape	Coccus (spherical)	Bacillus (rod-shaped)	–
Cell size	1.0 – 1.5 μm	0.5 – 1.0 μm	–
O ₂ requirement	Strictly aerobic	Strictly aerobic	Facultative aerobic
pH range	5.8 – 8.5	6.5 – 8.5	6.5 – 8.5
t _g	8 – 36 h	12 – 60 h	0.25 – 0.5 h
Growth range of temperature	5 – 30 °C	5 – 40 °C	

SOURCE: Adapted from WIESMANN, CHOI AND DOMBROWSKI, 2007.

The overall oxidation of ammonium by the cited group of bacteria is represented in equation 1, during this process a big amount of oxygen is needed and the pH decreases in water with low buffer capacity if no pH control is implemented (Wiesmann, Choi and Dombrowski, 2007).



There are some parameters which influence the capability of a population of nitrifying bacteria to oxidize ammonia to nitrate. The interaction of factors like oxygen concentration, pH, temperature microbial numbers, acclimation and inhibiting compounds impacts the rate in which nitrification occurs. Oxygen concentration and pH are considered the most important in this case because the nitrification rate is limited entirely if oxygen is not supplied. For effective process, the amount of oxygen kept in the aeration tank should be watched as a control parameter to ensure permanent effluent concentrations for NH_4^+ , NO_2^- and NO_3^- . Only with adequate dissolved oxygen and no inhibition, microorganisms oxidize the nitrite to nitrate (Anthonisen *et al.*, 1976).

For the growth of nitrifying bacteria, a pH of 7.2 – 8.0 is assumed to be the optimal level. A significant decrease in nitrification happens if the pH in the aeration tank is below 5.5 or above 9.0. A drop in temperature meanwhile can also result in a remarkable reduction in the growth rate of nitrifying bacteria, with low wastewater temperatures in winter significantly affecting the speed of the nitrification process. The nitrification rate is at an optimal functioning capacity between temperatures of 8°C to 30°C (Wiesmann, Choi and Dombrowski, 2007).

3.3.2 Denitrification

Denitrification is the biological reduction of nitrate to molecular nitrogen, a process in which organic matter acts as a reductor. Denitrifying bacteria are capable of removing oxidized nitrogen from wastewater by reducing it to N_2 (equation 2), which is released into the atmosphere. Most nitrifying bacteria are facultative aerobic chemoorgano-heterotrophic organisms which make up about 80% of the bacteria within an activated sludge environment. In this process, nitrogenous oxides work as respiratory electron acceptors and are reduced by a specific complex of enzymes. With this process, organisms convert virtually all of the N reduced to gas and can grow anaerobically at the expense of nitrate (Madigan *et al.*, 2014; Tiedje, 1982).



Denitrification reactions need favourable conditions, such as the presence of an organic substrate, very low oxygen concentration, correct pH and temperature. Enough organic substrate is one of the main control parameters for denitrification, the optimal ratio of organic carbon to nitrate is 0.89 g COD/g NO_3 -N. For lower ratios, the NO_3 effluent concentration is increased. There is an inhibition of denitrification in the presence of free molecular oxygen because the oxygen suppresses the formation of the enzyme nitrate reductase. pH is increased during denitrification process and the process can take place occur over a wide range of pH values, but most studies show that better results are recorded between pH 7.0 – 7.5. Temperature also affects the growth rate of the microorganisms and the removal rate of nitrate and the denitrification is limited for wastewater below 5 °C (Wiesmann, Choi and Dombrowski, 2007).

3.4 SMALL-SCALE WASTEWATER TREATMENT PLANTS

Wastewater treatment problems associated with remote areas, such as rural areas, involve the fact that usually the population is dispersed and there are limited finances, operational expertise and energy (Matamoros *et al.*, 2009, Ren et al, 2009). Therefore, a small-scale treatment process can be pondered in the treatment of household wastewater. However, many existing small-scale treatment processing

plants have limitations when offering simple operation and maintenance systems with adequate effluent quality at low cost.

Small-scale wastewater treatment plants usually show limited purification capacity for nutrients (nitrogen and phosphorus). Nitrification and denitrification can occur to a certain degree in biological systems but it depends on the plant layout and the operating conditions (Abegglen, Ospelt and Siegrist, 2007).

Table 3 shows removal efficiencies of different treatment processes from measurements in small-scale plants made by experts in Switzerland. It is possible to notice that the best purification rates comparable to a normal-scale WWTP are for Sequencing batch reactors (SBR's). One advantage of SBR systems is that the duration of the cycle and the hydraulic retention time can be easily varied, the same is valid for parameters such as volume and composition of incoming wastewater. Another advantage is that the process is easy to operate and more flexible than continuous activated sludge processes. The use of the SBR concept is widely applied when the volume of treated material is small (Mańczak, 2007; Oleszkiewicz and Berquist, 1988; Wilderer, Irvine and Goronszy, 2001).

TABLE 3 – REMOVAL EFFICIENCIES FOR SEVERAL SMALL-SCALE WWTP

Treatment	COD REMOVAL (%)	N REMOVAL (%)	P REMOVAL (%)
SEPTIC TANK	20-30	0-10	10
SBR	>90	10-70	10-70
TRICLING FILTER	>90	10-40	10
REED BED (CONSTRUCTED WETLANDS)	>80-90	10-90	10-60
SAND FILTER	>80-90	10-20	10
WWTP	95	60	90

SOURCE: Adapted from ABEGGLEN, OSPELT and SIEGRIST, 2008.

Small-scale WTTTPs have been used in many countries, such as Germany, Switzerland, Norway, Denmark and China. A membrane bioreactor (MBR) installed in the basement of a four-person household was studied in Switzerland for treating domestic wastewater. The treatment consisted of two tanks in series and the differential of this treatment was the fact that it worked with a highly fluctuating influent water flow and a lack of pre-treatment. The first test, using the first reactor as a primary clarifier, showed 50% nitrogen removal. The second one, using the first reactor as an

anaerobic/anoxic reactor by recycling sludge, showed even better results for nitrogen removal – 90%. A high level of denitrification was possible by recycling sludge, showing it to be the best alternative for this process (Abegglen, Ospelt and Siegrist, 2008).

In Norway, a system based on the principles of sub-surface flow, constructed wetlands using various types of Filtralite as a filter media and was studied for 3 years. The treatment consisted of an aerobic biofilter succeeded by an upflow saturated filter. The system showed stable behaviour with 30% nitrogen removal and 97% of the BOD₅ (Heistad *et al.*, 2006).

A Constructed wetland (CW) was studied to enhance nitrogen removal using a novel CW configuration with three stages. This became known as the towery hybrid constructed wetland (THCW), and was first designed in China. The process showed an average percentage of removal of 85%, 83% and 83% for chemical oxygen demand, ammonia nitrogen and total nitrogen respectively (Ye and Le, 2009). Constructed wetland was also studied by Danish researchers showing that the treatment fulfilled the requirements published by the Danish Ministry of Environment which is 95% removal of BOD and 90% nitrification (Brix and Arias, 2005).

In Germany, wastewater disposal of private households is a municipal responsibility. Small-scales treatment plants have been used for at least 10 years and it is the solution for households or restaurants without public sewage infrastructure.

In Brazil, the use of septic tanks is still found in old constructions when the public sewage system is not available. However, the costs for implementation of small wastewater treatment plants have been decreased in the last 10 years and the governments in states such as São Paulo, Paraná and Santa Catarina are requiring better solutions to permit the construction of new buildings and houses complexes. In São Paula, the Company of sanitation of São Paulo's state (CETESB) do not allowed septic tanks in new constructions and popular houses complexes provided by the government were built with small-scale wastewater treatment plants, most of them are operated in SBR or upflow anaerobic sludge blanket reactor (UASB). (Tegeve Ambiental, 2017; Das Brasil, 2017; Delta Saneamento Ambiental, 2017; CETESB, 2011).

3.5 LEGISLATION

3.5.1 German legislation

According to the German Institute for Standardization (DIN - Deutsches Institut für Normung e.V.) DIN EN 12566-3, a compact wastewater treatment plant is an installation that treats a maximum volume of 8 m³ per day or the population equivalent of 50 inhabitants.

The German Institute for the Construction Sector (DIBt - *Deutsches Institut für Bautechnik*) is the institute responsible for the approval and for inspection of compact wastewater treatment plants. The DIBt subdivides the compact WWTP into classes (C, N, D and +P) according to the treated water parameters, such as COD, BOD₅ and nutrient, being that the most restrictive class is +P (Table 4).

TABLE 4 – COMPACT WWTP CLASSIFICATION ACCORDING TO THE TREATED WATER PARAMETERS

Class	COD (mg/L)	BOD ₅ (mg/L)	NH ₄ -N (mg/L)	N _{inorg.} (mg/L)	P _{gas} (mg/L)
C	150*/100**	40*/25**			
N	90*/75**	40*/25**	10**		
D	90*/75**	40*/25**	10**	25**	
+P					2**

*Determined from the qualified sample

**Determined from the 24h mixing test

SOURCE: ADAPTED FROM DEUTSCHES INSTITUT FÜR BAUTECHNIK, 2014.

According to DIN EN 12566-3: 2016, the parameters to be collected from the inflow and outflow are COD, suspended solids (SS), temperature, the total power consumption of the product (when applicable), days supply. In some cases, pH-value, conductivity, parameters for nitrogen, total phosphorus, flow per hour, concentration of dissolved oxygen, sludge and ambient temperature can also be requested. The standard also recommends that the chemical analyses should be carried out by methods in which EN (European Standard), EN-ISO and/or ISO standards are applied, as showed in Table 5.

TABLE 5 – ANALYTICAL METHODS

Parameter	Measurement methods
-----------	---------------------

BOD₅	EN 1899-1
COD	ISO 6060 or ISO 15705
SS	EN 872
Ammonium nitrogen	ISO 5664 or ISO 6778 or ISO 7150-1 or EN ISO 11732 or EN ISO 14911
Kjeldahl nitrogen	EN ISO 11905-1 or EN 12260 or EN 25663
Nitrate	EN ISO 10304-1 or EN ISO 13395
Phosphorus	EN ISO 6878 or EN ISO 15681 or EN ISO 11885

Source: DIN EN 12566-3, 2016.

3.5.2 Brazilian legislation

According to the Brazilian regulation *Decreto* n. 7.217/2010, when a public wastewater treatment facility is not available, an individual solution is allowed if supervised by the existing environmental secretariat, engineering council and health ministry. One of the solutions for households without wastewater public systems is specified in ABNT NBR 13969/97 which sets the standards for the project, construction and operation of septic tank systems and, in some cases, if a public wastewater treatment becomes available after sometime, the disassembly of the septic tank.

Besides that, in Brazil there is no specific legislation for compact WWTP, but the legislation related to wastewater release and river classification is showed in TABLE 6 below.

TABLE 6 – BRAZILIAN LEGISLATION

LEGISLATION	DESCRIPTION
CONAMA 357/2005	Provides classification for rivers and water bodies and gives the environmental directives for the classification.
CONAMA 377/2006	Disposes on environmental licensing of wastewater systems.
CONAMA 430/2011	Provides conditions and standards for treated wastewater released in rivers and it complements the resolution CONAMA 357/2005.

The National Environment Council (CONAMA) provides conditions and standards for treated wastewater released in rivers in the resolution CONAMA 430/2011. In this resolution, the parameters for released treated domestic wastewater are defined. pH between 5 to 9, BOD₅ less than 120 mg/L or with a minimum removal efficiency of 60%, 1 mL/L for volume of settled material, temperature below 40°C and absence of floating material.

The classification for rivers and water bodies is given by CONAMA 357/2005, in which rivers are classified from Class 1 to 4 according to parameters such as BOD₅, OD, pH and organic and inorganic parameters. Rivers in class 1 are more restricted in their parameters and rivers in class 4 are less restricted. The parameters that should be fulfilled to released treated wastewater depends on the characteristics and classification of the water body, the four classes are explained below:

- Special class – Intended to preserve the aquatic environment and the natural equilibrium of the aquatic life;
- Class 1 – Intended to recreational activities on water (primary contact), protection of the aquatic life and professional fishing;
- Class 2 – Intended to recreational activities on water (secondary contact) and amateur fishing;
- Class 3 – Intended to navigation and landscape water;

The environmental licensing of wastewater systems is given by CONAMA 377/06, the application for a new project needs to contain the following information to acquire an operation license:

- Project's technical responsible;
- Project's general information;
- Project's description;
- Information about the area where the project will be taking place including information about the vegetation;
- Characterization of the water body where the treated wastewater will be released;
- Socioeconomic characterization;
- Plan to monitoring the area, the wastewater treatment plant and the receiving water body;
- Mitigating and compensating measures for the area.

There are specific regulations in some states in Brazil, like São Paulo, Rondônia, Alagoas, Mato Grosso and Paraná, showed in TABLE 7. In São Paulo, according to state regulation, it is forbidden to release wastewater, treated or not, in class 1 rivers whilst setting parameters for released treated wastewater in class 2, 3 and 4 rivers. In Paraná, specific regulation establishes parameters for the environmental licensing of domestic wastewater treatment plants. Domestic wastewater treatment needs to be treated in a central wastewater treatment plant taking into account the parameters defined by the state legislation in Alagoas. In Ceará, every establishment in an area without public sewage collection is responsible for the treatment and release of its own wastewater. In Rondônia, the regulation disposes on environmental protection and establishes that treated wastewater needs to attend the requirements described on it.

TABLE 7 – REGIONAL REGULATIONS

Region/State	Regulations
North Rondônia (RO)	DECRETO N° 7.903/97
Northeast Alagoas (AL)	DECRETO N°6.200/85
Central-West Mato Grosso Do Sul (MS) Mato Grosso (MT)	CECA/MS N° 36/12 CONSEMA N° 55/12
Southeast São Paulo (SP) Rio De Janeiro (RJ) Minas Gerais (MG)	DECRETO N° 8.468/76 NT-202.R-10 COPAM/CERH-MG N° 01/08
South Paraná (PR) Santa Catarina (SC) Rio Grande Do Sul (RS)	RESOLUÇÃO N° 001/07 – SEMA/PR DECRETO N°14.250/81 PORTARIA N.º 05/89 – SSMA/RS

3.6 SOLAR ENERGY

Renewable electricity development has taken different routes through countries, underpinned by different policy frameworks in order to overcome the undesirable effects on the environment and other problems associated with fossil fuels. Renewable energy is a potentially huge solution and the dominance of photovoltaic (PV) among other energy technologies is due mostly to its noiselessness, non-toxic emission, and relatively simple operation and maintenance (Moosavian, 2013)

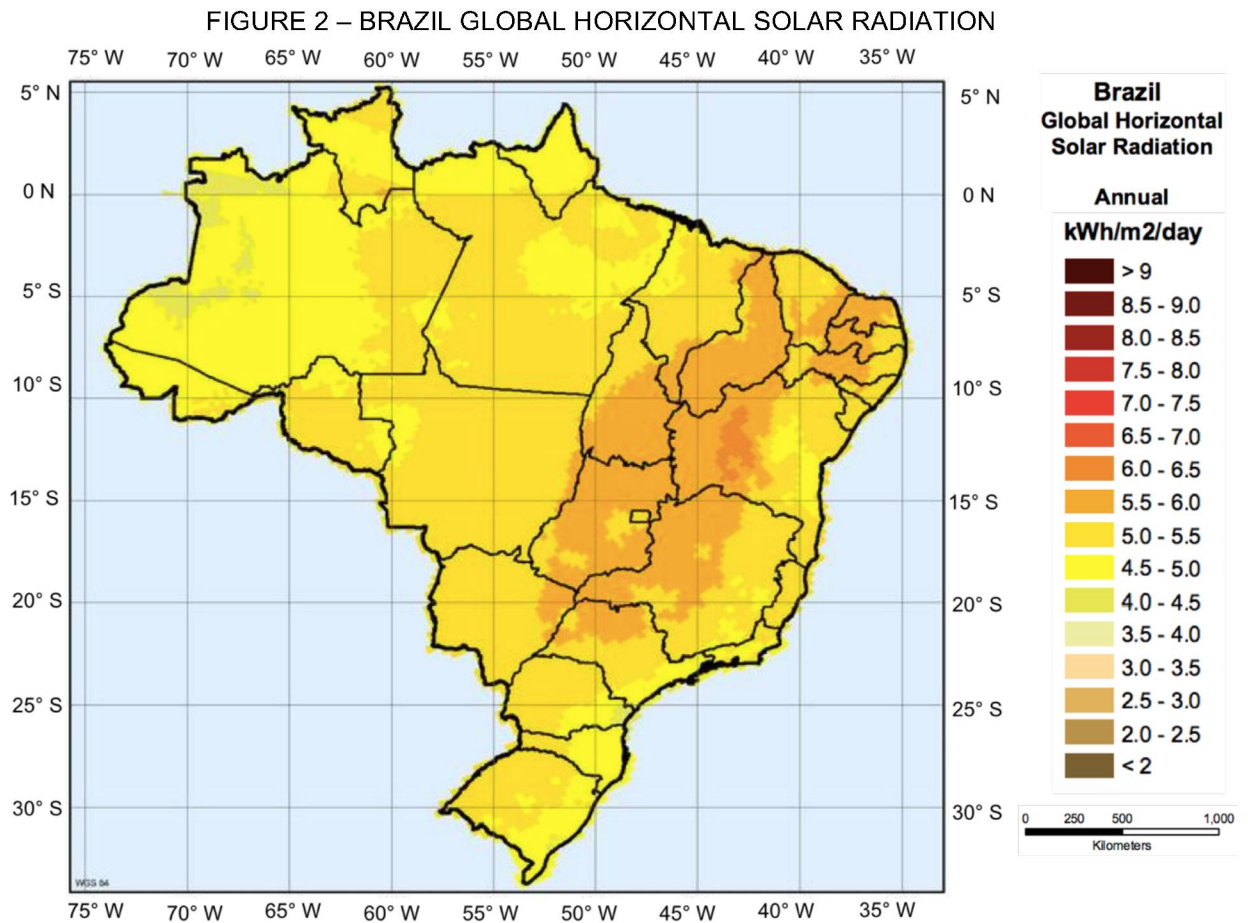
Owed by the fact that solar energy is one of the best renewable energy sources available, due to its minimal negative impacts on the environment, many countries, such as Germany, United Kingdom, Denmark and Brazil have formulated solar energy policies to increase domestic energy production through solar energy (Lipp, 2007; Saidur *et al.*, 2011).

Brazilian National Electric Power Regulator (ANEEL) reduced barriers for the incorporation of solar power in Brazil, which is an important stage in the challenge for this power source to contribute significantly more to the renewable energy market in the country. In this resolution, ANEEL allows small-scale power generators (up to 5 MW) to offset their electricity bills with credits from the power they provide. There is also a tax-exemption, as showed in *Decreto* nº 7.212/10 and ICMS 101/97, and tax of 0% on importation products used to produce photovoltaic panels (CAMEX - RESOLUÇÃO Nº 22/16; CAMEX – RESOLUÇÃO Nº 64/17). Besides that, ANEEL also brought into force legislation that reduces transmission and distribution fees up to 80% until 2017 and 50% in the next years for renewable electricity enterprises, through the ANEEL – *Resolução Normativa* Nº 77/04. ANEEL's regulatory initiatives are not comparable with policies seen in the Netherlands, the United States, the United Kingdom, Canada, Germany, Spain, China because these nations have robust policies that take into consideration solar energy from different angles, such as tax exemption, subsidies, feed-in tariffs and also investment in technological research. (Pinto, Amaral and Janissek, 2016; MME, 2017; ANEEL, 2012, 2016).

There is big potential in solar irradiation in Brazil; twice the value of Germany, world leader in photovoltaic systems. The main applications in Brazil are related to telecommunication, public services, water pumping and rural electrification. In Brazil, it is estimated that autonomous photovoltaic systems generate 20 MW a day, however 70% are located in the North, Northeast and Midwest regions and consequently only 0.153 MWp of the daily power generated is connected to the national grid network (Zilles, 2004; Varella, 2009; Martins *et al.*, 2008).

Figure 2 shows the annual averages of daily global solar irradiation in Brazil. It can be observed that the global irradiation is fairly uniform in Brazil considering the different climate and environmental conditions along Brazilian territory. Brazilian North-

eastern region presents the maximum value – more than 6.5 kWh/(m².day) – characterized by a semi-arid climate with low precipitation levels. The minimum value is between 4-4.5 kWh/(m².day) in the coastal area of the Southern region, an area with a large precipitation range.



Brazil shows a greater value for the annual sum of daily horizontal global solar irradiation (1500–2500 kWh/m²) than those for the majority of the estimated value for European cities, such as Stuttgart in Germany (1310 kWh/m²), as showed in Figure 3, Paris in France (1370 kWh/m²) and in Amsterdam in Netherlands (1260 kWh/m²) (European Database for Daylight and Solar Radiation, 2007; The European Commission's science and knowledge service, 2017).

FIGURE 3 – GLOBAL IRRADIATION AND SOLAR ELECTRICITY POTENTIAL IN GERMANY



SOURCE: JRC, 2017.

In 2008, the European (EU) climate package was adopted by the EU Parliament. It includes a variety of directives which define political targets that aim to reduce gross final consumption of energy through a 20% reduction of CO₂, a 20%

increase in energy efficiency and a 20% share of energy from renewable energy sources (RES) by 2020. Some individual member states however have set themselves higher individual targets, such as Germany with 30% (Nicolosi and Fürsch, 2009).

According to the German Association of Energy and Water (BEDW), in 2011, 21% of net energy generation in Germany came from renewable energy and from this 3% came from photovoltaic energy, showing that the country has been investing in renewable energy (BEDW, 2011).

When choosing a system to treat municipal wastewater, three major analyses should be assumed. First, the required effluent quality should be considered. Then, aspects like economic, institutional and political, climatic, environmental, land availability and properties, sociocultural and other should be examined. Lastly, a cost-effectiveness analysis must be carried out to define the optimum economically viable solution. Energy is a main contributor to the cost of treating wastewater, it can represent between 25 and 45% of operations and maintenance expenses in wastewater treatment plants (Smith and Liu, 2017; Tsagarakis, 1999). A WWTP operated by solar energy contributes to the environment by using a clean energy and save energy costs associated with operation.

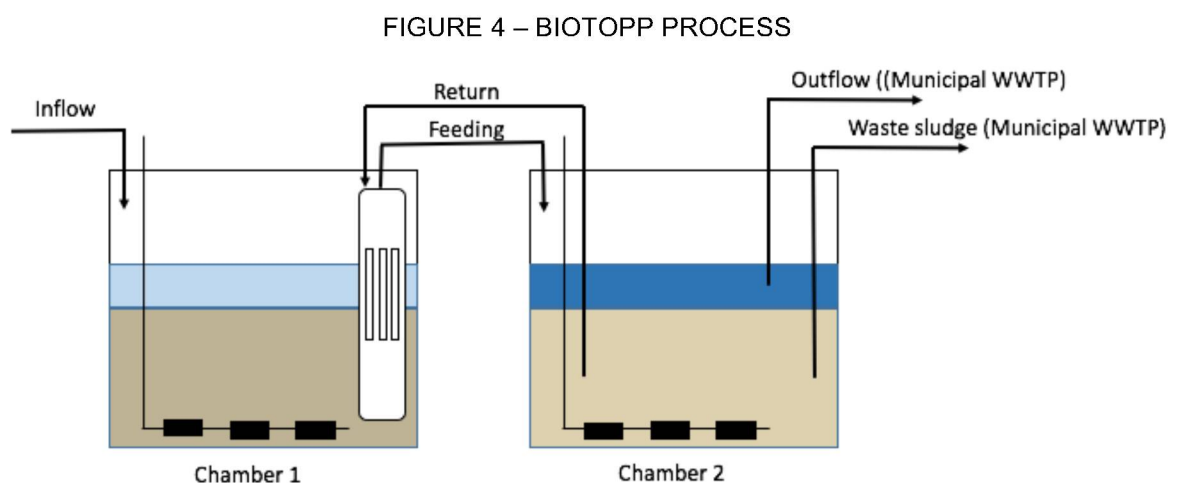
4 MATERIAL AND METHODS

4.1 MATERIAL

4.1.1 Small-Scale Wastewater Treatment Plant

The plant model for simulations was the BioTopp-Verfahren (BioTopp-Process), a small-scale wastewater treatment plant with low waste production developed by Ökoservice GmbH, located in Denkendorf – Germany. It is an only system designed to cater and treat domestic wastewater of 6 - 8 PE.

The process is an activated sludge process that is performed in two sequencing batch reactors (SBR). In the first chamber (Figure 4), the degradation of carbon, denitrification and phosphor elimination take place. The second chamber is responsible for nitrification and further carbon degradation. At this stage, the excess sludge can be directly used as fertilizer in agriculture or can be treated further in the sludge drying unit, which is not showed in the present study because the focus is wastewater treatment.



SOURCE: Author

The volume of each tank is 1.83 m^3 being that the minimum high is 0.85 m and the maximum is 1.10 m. It is projected to treat between 1200 to 900 L/d.pc, considering $60 \text{ g BOD}_5/\text{d.pc}$ and 150 L/d.pc . Both tanks are constructed of polyethylene.

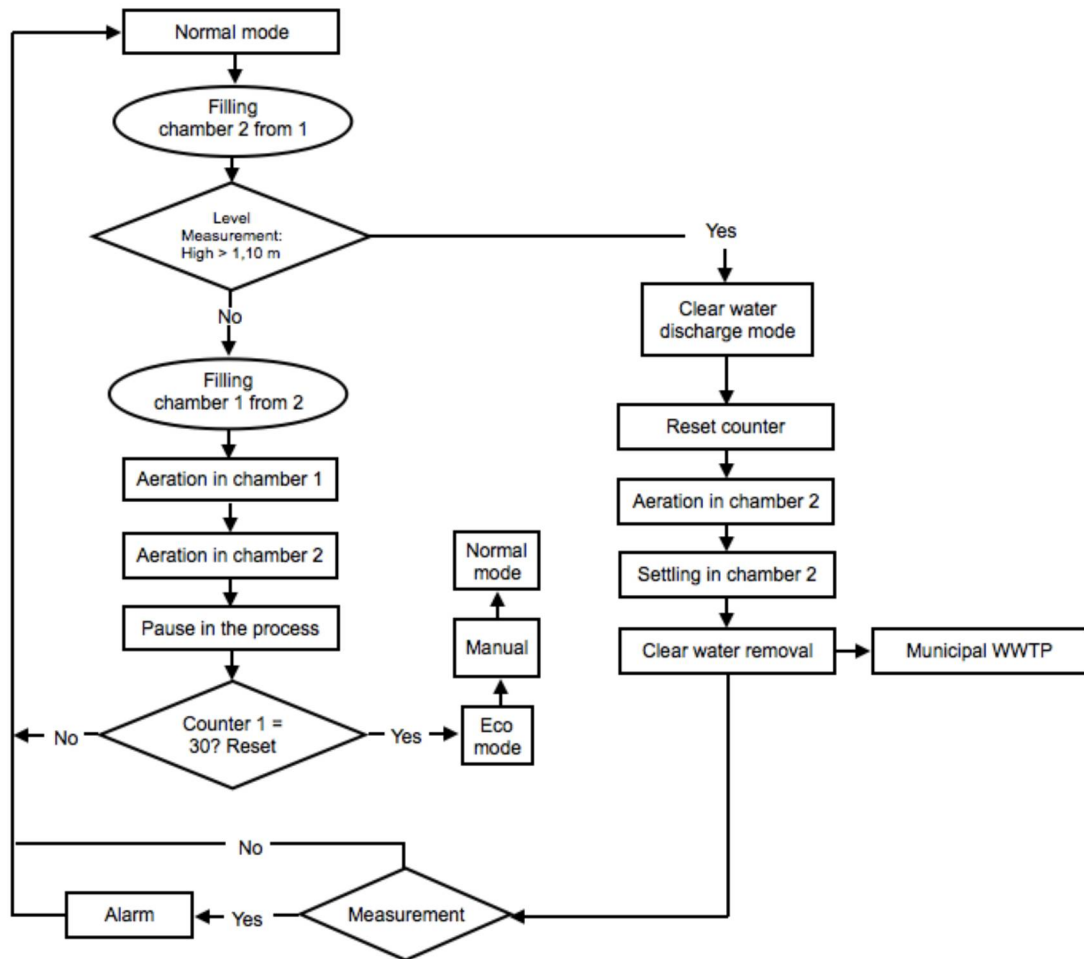
The process can be divided in five operational modes:

- Normal mode: this mode can be defined as the treatment phase. During this period the circulation, recirculation and aeration run in a closed process;
- Eco mode: the Eco mode is a special mode used to save energy and is switched on when the closed process runs 30 times without clear water discharge.
- Clear water discharge mode: this mode is switched on when the chamber 2 achieves its maximum volume. This process involves only chamber 2 and starts with aeration, followed by settling and finally clear water discharge.
- Sludge removal mode: this mode is switched on everyday at 11:30 pm.
- Feeding mode: the feeding mode runs in parallel to all of the other four steps and it is according to the graph 1 (item 4.2).

The first step of the process in the normal mode is when the wastewater is pumped from chamber one to chamber two, as showed in Figure 5. After that, the level is measured and then there are two different responses of the system depending on the water's level in chamber two. If the level in chamber two is higher than the chamber's maximum high (1.10 m), the process goes to the clear water discharge mode, which will be explained in the followings paragraphs. If the level in two is lower, than there is recirculation of the wastewater, in other words, the wastewater is pumped back from chamber two to one, characterizing in this way an activated sludge process.

After that, aeration in chamber one is started followed by aeration in chamber two. Following this, there is a pause in the process that is counted by a counter. If the process counts 30 times the pause, it means that the process ran 30 times without clear water discharge, so it changes to the Eco mode, which is a mode designed to save energy. If the counter is less than 30 times, then the first step starts again, as showed in Figure 5.

FIGURE 5 – NORMAL MODE FLOWCHART

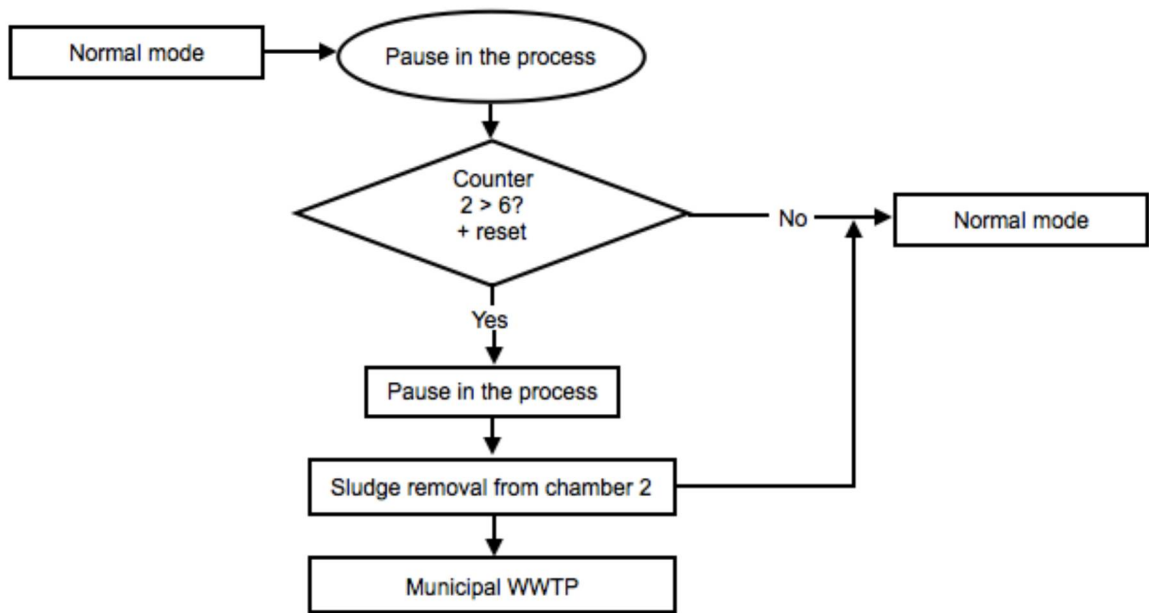


SOURCE: Author

After filling from chamber one to chamber two, as explained before, there is a level measurement and if the level is higher than 1.10 m, the clear water discharge mode takes place. The level is identified by the system when the floater placed in chamber two is lifted up. The clear water discharge starts with aeration followed by the settling of the sludge in chamber two and then finally clear water discharge.

Once a day, during the night, the process jumps to sub-process sludge removal (Figure 6). In this process, there is a pause and then sludge is pumped out of the chamber 2 and flows to the municipal wastewater treatment plant.

FIGURE 6 – SLUDGE REMOVAL FLOWCHART



SOURCE: Author

The feeding process occurs in parallel to the other steps and it will be explained in the next topics.

4.1.2 General Information

The treatment plant is located in the Institute for Sanitary Engineering, Water Quality and Solid Waste Management - ISWA (Institut für Siedlungswasserbau Wassergüte- und Abfallwirtschaft) at University of Stuttgart (Figure 5).

FIGURE 7 – BIOTOP - COMPACT WWTP (CHAMBER 2 IS IN THE LEFT SIDE AND CHAMBER 1 IN THE RIGHT ONE)

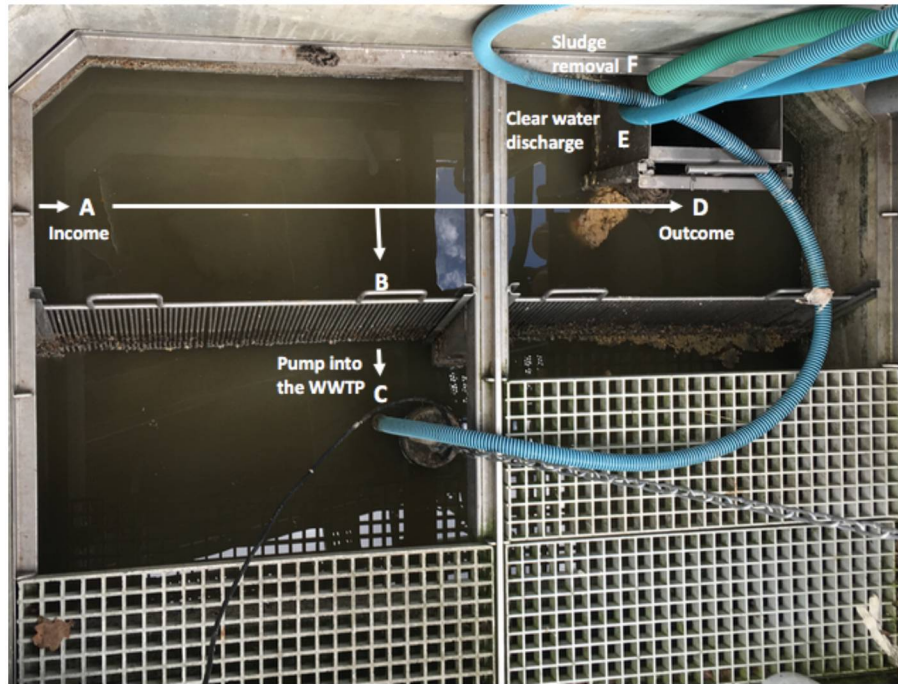


SOURCE: Author

All the wastewater that feeds the plant comes from 3 households and 1 hotel (approximately 50 PE) and flows through a channel with screens where a submersible pump is installed.

The pump feeds the plant according to the set up (item 5.1) and the exceeding wastewater flows to Stuttgart-Mühlhausen wastewater treatment plant. In the Figure 8 it is possible to see in A where is the inflow in this channel; in B is the screening that removes objects such as paper, hygienic products, plastics, and metals to prevent damage and clogging of downstream equipment, piping, and appurtenances; in C is the submersible pump used to pump wastewater into the compact WWTP; in D is where the wastewater flows to the municipal wastewater treatment plant with the clear water discharge and waste sludge from the compact WWTP; in E is the clear water discharge pipe; and in F is the sludge removal pipe.

FIGURE 8 – INCOME AND OUTCOME CHANNEL



SOURCE: Author

Figure 9 shows the wastewater treatment plant, it is possible to observe the small-scale WWTP, the controller unit and the inlet and outlet channel.

FIGURE 9 – SMALL-SCALE WWTP



SOURCE: Author

4.1.3 Controller Unit and Solar Panels

The controller unit was provided by Festo GmbH and controls all of the electronic devices in the plant, such as the air lift pump, batteries and solar panels.

The solar panels are SolarWorld SW270 mono black and during the tests 4 out of 10 panels were working connected in series. Details of these solar panels are accessible in the attachment A.

The plant operates with 6 batteries as back up in case the power generated by the solar panels is not enough to supply the process. The batteries are 6 BTL12-200 accumulators with a 24V system offering a 600 Ah capacity (2 batteries in row, 3x parallel). Details of these batteries are available in the attachment B.

The pump used to pump wastewater into the plant is a unique electronic device that is not connected to the solar panel system because in this pilot test it is not possible to use gravity flow that should be preferred in order to save energy.

4.2 METHODS

4.2.1 Start Up Phase

The plant started running on October 2016 and from this date to April 2017 it was object of study for the development of Michael Heidrich's master thesis (Heidrich, 2017).

The current study started on May 2017 with the installation of Festo's controller unit and solar panels. After that, the initial set up recommended by Ökoservice GmbH was applied and the time of each process's steps is showed in the Table 8.

TABLE 8 – SET UP TIME

Step	Time (min)
Normal mode	
Filling chamber 2 from 1	13
Recirculation and level measurement*	5
Aeration in chamber 1	15
Aeration in chamber 2	23
Pause in the process	30
Clear water discharge mode	
Aeration in chamber 2	30
Settling in chamber 2	120
Clear water discharge	30
Sludge removal mode**	
Pause	120
Sludge removal	10

* if maximum level is achieved, process change to clear water discharge mode

** this mode is switched on everyday at 11:30 pm

The start up phase started on 1st June 2017 and finished on 30st June 2017 with the objective to evaluate the compact WWTP with the new load programme and pumping time. To evaluate the operation, parameters such as temperature, pH, O₂, and settled sludge volume were measured three times a week during this period.

During the start up phase a presence of sludge was observed during the clear water discharge sequence in the first 1 to 3 minutes of the process, so an improvement was made to the pipe for the clear water discharge in 2 which was installed at a 45° angle at the beginning of the pipe inside chamber 2.

4.2.2 Evaluation Phase

After the start up phase, an evaluation phase started with the objective to analyse and evaluate the nitrification and denitrification process by quantifying COD, ammonium, nitrate and nitrite against the previous parameters. Solids content and sludge volume index were also analysed. The evaluation phase started on 1st July and finished on 30th July.

4.2.3 New Operational Times

The third phase was a simulation of different climate conditions in order to evaluate if the process can run in a special mode when the climate conditions are not

good to ensure enough power for the plant even using the batteries as back up. During the simulation, new operational times were set in the process and evaluated for 10 days. The first operational time changed in the controller unit was the aeration in chamber 2 by increasing the time in 5 minutes because it is responsible for most part of the energy consumption during the process in order to evaluate if it is possible to operate saving energy. The new time is showed in Table 9.

TABLE 9 – OPERATIONAL TIME - TEST 1

Step	Time (min)
Normal mode	
Filling chamber 2 from 1	13
Recirculation and level measurement*	5
Aeration in chamber 1	15
Aeration in chamber 2	18
Pause in the process	30
Clear water discharge mode	
Aeration in chamber 2	30
Settling in chamber 2	120
Clear water discharge	30
Sludge removal mode**	
Pause	120
Sludge removal	10

* if maximum level is achieved, process change to clear water discharge mode

** this mode is switched on everyday at 11:30 pm

The second was made by changing the pause time for 40 (10 min increased), showed in Table 10, in order to evaluate if it is possible for the process to have a higher break reducing in this way the number of cycles per day and consequently the energy requirement.

TABLE 10 – OPERATIONAL TIME - TEST 2

Step	Time (min)
Normal mode	
Filling chamber 2 from 1	13
Recirculation and level measurement*	5
Aeration in chamber 1	15
Aeration in chamber 2	23
Pause in the process	40
Clear water discharge mode	
Aeration in chamber 2	30
Settling in chamber 2	120
Clear water discharge	30
Sludge removal mode**	
Pause	120
Sludge removal	10

* if maximum level is achieved, process change to clear water discharge mode

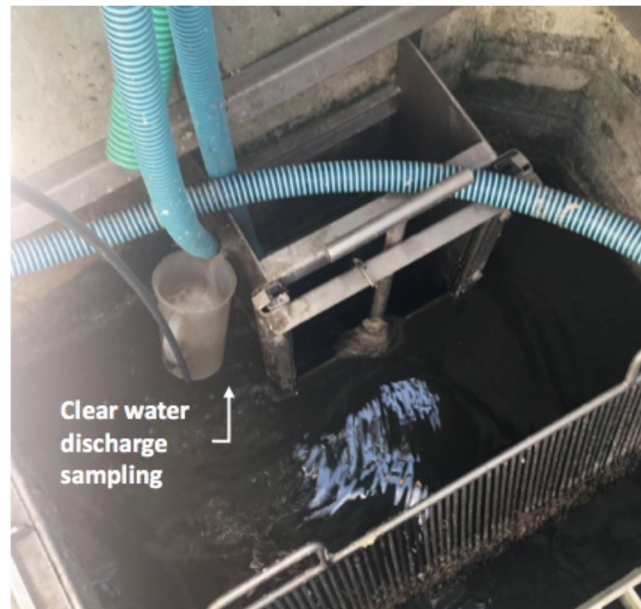
** this mode is switched on everyday at 11:30 pm

4.3 MEASUREMENTS

4.3.1 Sampling

The sampling of the inflow took place during the pumping process into the compact wastewater treatment plant.

FIGURE 10 – CLEAR WATER DISCHARGE SAMPLING



SOURCE: Author

The sampling of the outflow was taken during the clear water discharge and due to a presence of sludge in the beginning of the flow, the sampling was adapted being that two samples were taken:

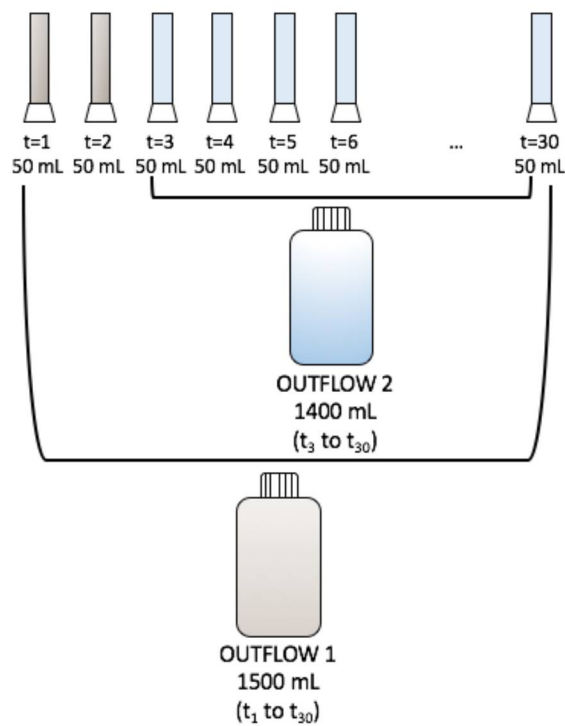
- Outflow 1, which is the mixing sample taking into consideration in the sampling the sludge;
- Outflow 2, which is the sampling without mixing the sludge.

A fixed volume of clear water was then withdrawn at fixed intervals and the individual samples were combined to form a mixing sample, in order to analyse a representative sample.

To making a mixed sample called Outflow 1, a sample of 50 mL was taken every 60 seconds from the outflow and combined to form a mixing sample, according to Figure 12, and the volume total of 1500 mL was the mixed sample resulting after 30 minutes of clear water discharge.

For the mixed sample Outflow 2, a sample of 50 mL was taken after 2 minutes of the start of the clear water discharge, in order to make a sample without sludge. A mixed sample volume of 1400 mL was obtained after 28 minutes.

FIGURE 11 – OUTFLOW 1 AND OUTFLOW 2 SAMPLING



SOURCE: Author

FIGURE 12 – INFLOW (LEFT) AND OUTFLOW 2 (RIGHT) SAMPLES



SOURCE: Author

Grab samples were taken twice or three times a week because the samples only could be taken during the clear water discharge, which took place usually once a day. The samples were transported and the analysis in duplicate were done in the Water and Wastewater Laboratory Technology at ISWA.

4.3.2 Chemical Oxygen Demand (COD)

The COD was determined by the laboratory of the working area Water and Wastewater Technology and the method utilised was in accordance with DIN 38409-41.

4.3.3 Nutrients

The nutrients analysed were nitrate, nitrite, ammonium, total nitrogen and phosphate. The samples were filtered in a cellulose membrane filter with a pore size of 0.45 μm and then followed the procedures according to the cuvette test from Hach (Table 11), and the measurements were made using the photometer HACH DR 3900.

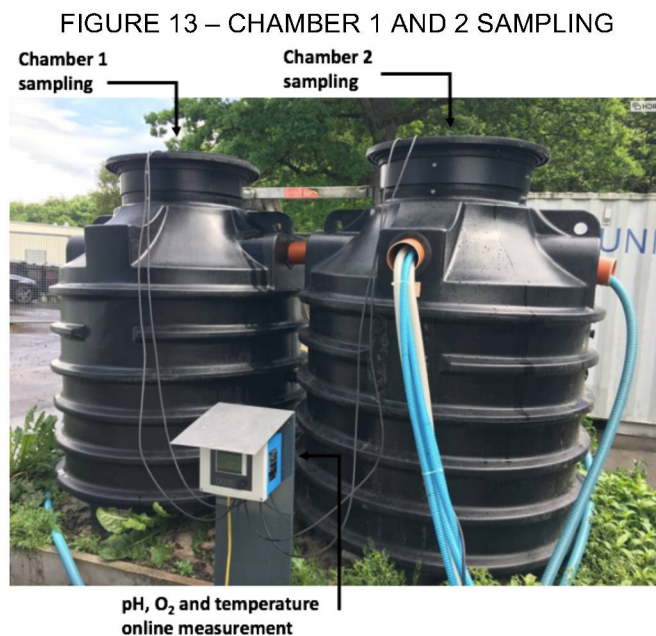
TABLE 11 – CUVETTE TESTS FOR NUTRIENTS

Parameter	Cuvette test	Range
Nitrate	LCK 339	1 – 60.0 mg/L NO ₃
Nitrite	LCK 341	0.05 – 2.0 mg/L NO ₂
Ammonium	LCK 303	2.5 – 60.0 mg/L NH ₄

4.3.4 Measurements in chamber one and chamber two

4.3.4.1 Sampling

The samples for settled sludge volume, solids content and sludge volume index were taken directly from both chambers during the aeration time between 10 to 13 a.m, according to FIGURE 13.



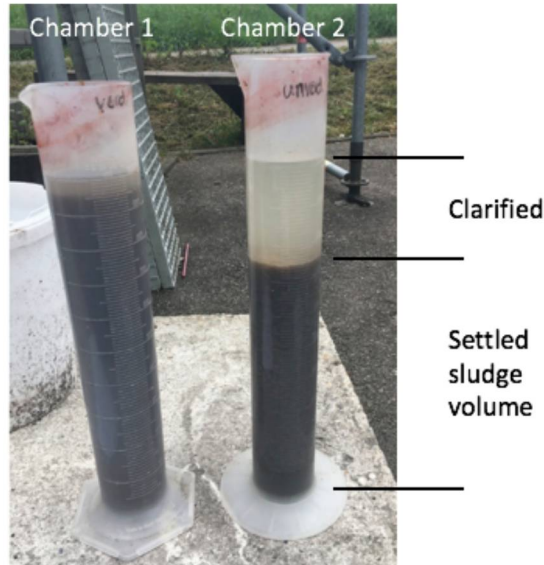
SOURCE: AUTHOR

4.3.4.2 Settled Sludge Volume (SSV)

The sludge volume was measured in accordance to DIN EN 14702-1 (2006), showed in Figure 14. A graduated measuring cylinder was filled with 1000 mL of mixed liquor sample and settled for 30 minutes. After this time period, the sludge volume was read in mL/L. If the sludge volume was higher than 250 mL/L, the sample was diluted

and the procedure was repeated in order to obtain a value smaller than 250 mL/L. After the dilution, the result was multiplied by the dilution factor.

FIGURE 14 – SETTLED SLUDGE VOLUME ANALYSIS



SOURCE: AUTHOR

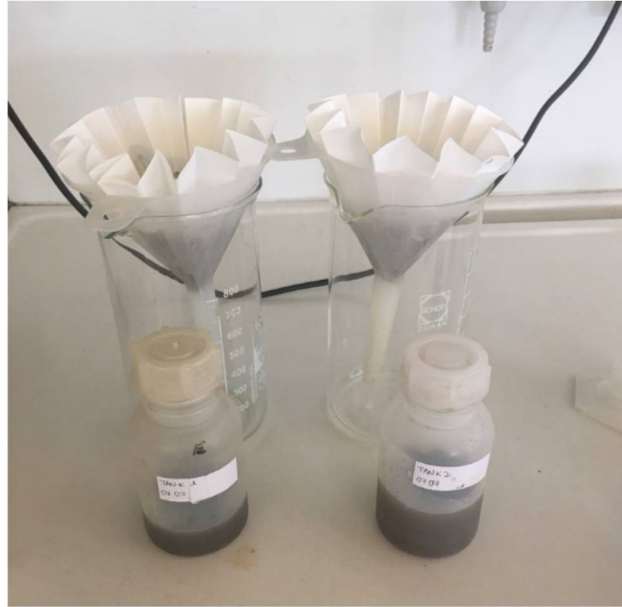
4.3.4.3 Solids Content (TS)

The TS is determined by 100 mL of mixed liquor filtered through a dried (at 104°C for 1 hour) and weighed filter (W_0) (Figure 15). The filter with sample is dried at 104°C for 24 hours, cooled down in a desiccator for 15 minutes and weighed (W_1). The difference between W_1 and W_0 is the TS in g/L, according to equation 1.

$$TS \left(\frac{g}{L} \right) = (W_1 - W_0) \cdot 100$$

Equation 3

FIGURE 15 – FILTRATION PROCESS TO DETERMINE SOLID CONTENT



SOURCE: Author

4.3.4.4 Sludge Volume Index (SVI)

The sludge volume index given in mL/g is calculated according to equation 4.

$$SVI \left(\frac{mL}{g} \right) = \frac{SSV}{TS} \cdot 1000 \quad \text{Equation 4}$$

4.3.4.5 pH, Oxygen (O₂) and Temperature

The measurements of pH-value, oxygen (O₂) and temperature were made online by the equipment Endress+Hauser CM444-1955/0 (Figure 16).

It was obtained pH-value, temperature and O₂ by online measurement from both chamber one and two. The measurements in chamber one were made during the aeration in chamber one, always between 10 a.m. to 1 p.m., according to the process, followed by the measurements in two following the same parameters. The measurements were registered three times a week.

The oxygen was always measured in the starting and end of the aeration process both in chamber one and two.

FIGURE 16 – ONLINE MEASUREMENT OF PH-VALUE, O₂ AND TEMPERATURE



SOURCE: Author

The local temperature data was recorded and provided by the weather station Lauchäcker of the Institute for Water and Environmental Systems Modelling of the University of Stuttgart.

4.3.4.6 Results Analysis

The average of the analysis results was calculated according to equation 5.

$$A = \frac{S}{N} \quad \text{Equation 5}$$

Where:

A is the average (or arithmetic mean);

N is the number of terms;

S is the sum of the numbers in the set interest.

The standard deviation of the analysis results was calculated according to equation 6.

$$\sigma = \sqrt{\frac{1}{N} \sum_{i=1}^N (x_i - u)^2}$$

Equation 6

Where:

σ is the standard deviation;

N is the number of terms;

x is a value from the population;

u is the average of population;

The removal efficiency of the analysis results was calculated according to equation 7.

$$efficiency (\%) = \frac{Inflow - Outflow}{Inflow} \cdot 100$$

Equation 7

4.3.4.7 Solar Panels Evaluation

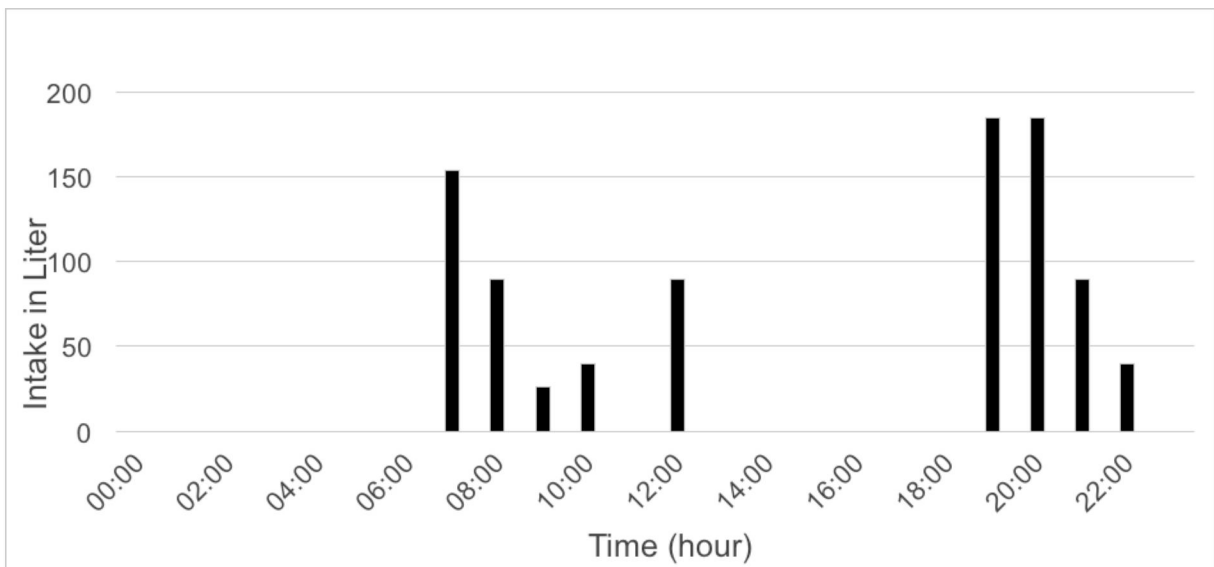
The data from global horizontal solar irradiation was registered in the Festo controller unit during the period of 1st July to 16th August 2017, as well the efficient of the photovoltaic panels.

5 RESULTS AND DISCUSSION

5.1 FEEDING TIME

The feeding pump was programmed to pump wastewater at peak intervals (FIGURE 17) during the day, simulating the times of the day in which there is a higher generation of wastewater in households, which means in the morning because it is when people usually get up, midday because of lunch and during the evening when people are back from work or school.

FIGURE 17 – PILOT PLANT'S FEEDING TIME FOR 6 PE



SOURCE: Author

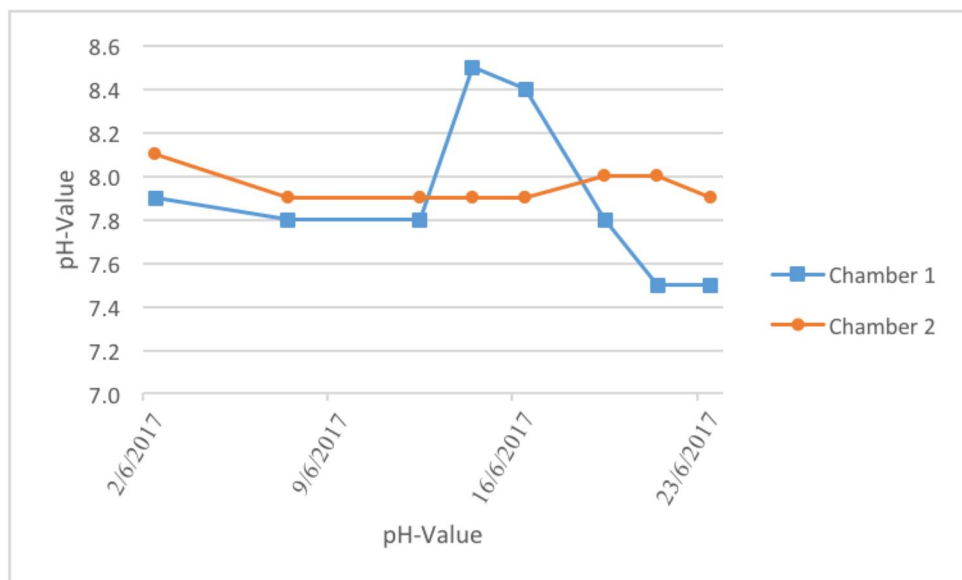
The daily load was set up to 6 PE considering the average household contains 3.34 people in Brazil, according to IBGE (2010), and as the plant was project to treat between 6 to 8 people, the set meets the criteria. The daily load for one person was considered 150 L, which is an average value for upper class and middle class in Brazil (Table 1), which implies a daily load of 900 L for the purposes of this study.

5.2 EVALUATION OF THE START UP PHASE

5.2.1 pH-value, Temperature and O₂

FIGURE 18 summarizes the pH-value during the start up phase in which it is possible to observe that the pH-value remained between 7.5 to 8.0. There were some variations in the pH values, as it is also related to the pH of the inflow. It is possible to observe that after 12th June there is a big peak in chamber 1, achieving pH 8,5 and after 10 days the pH achieves the lowest value (7,5). It explained by the "ammonia valley", which explains that when the nitrification starts in the process due to the aeration in the chamber, it consumes alkalinity because the ion H⁺ is released during the process resulting in a decreasing on pH. When the chamber is not aerating, the pH increase again (Ye *et al.*, 2009; Agathos and Reineke, 2003). The measurements showing results with low pH were made in the end of the aeration time and the results with the high pH-value were made in the beginning of the aeration

FIGURE 18 – PH-VALUE

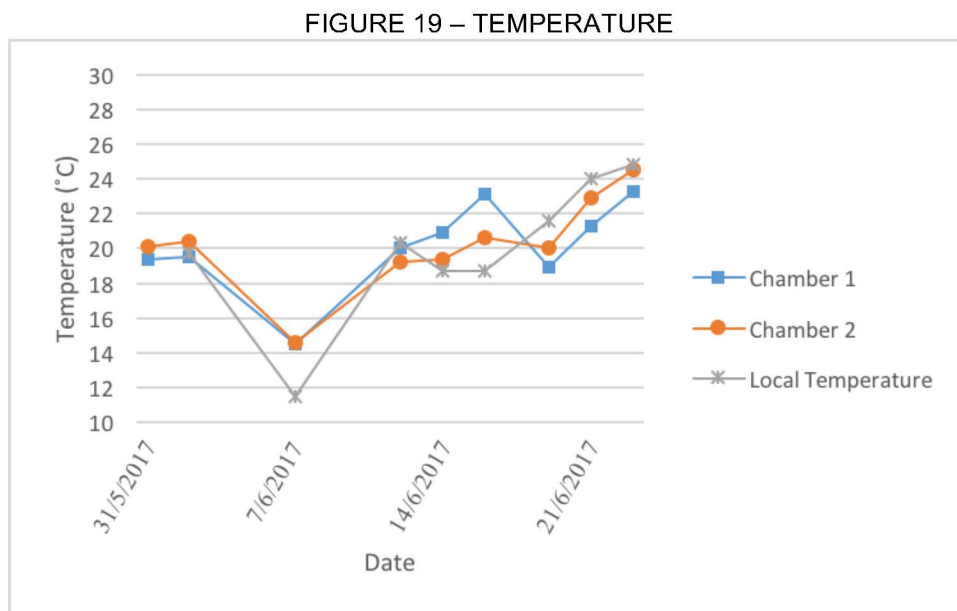


SOURCE: Author

The value average pH-value in chamber one is 7.9 ± 0.4 and in two is 8.0 ± 0.1 . pH-value remained between 7.5 to 8.1, which is a range that insure nitrification (5.8 – 8.5 for *Nitrosomonas* and 6.5 – 8.5 for *Nitrobacter*) and denitrification (6.5 – 8.5).

FIGURE 19 shows the temperature profile for chamber one and two and the local temperature. It is notable that the local temperature exerts high influence in the temperature in both chambers fact explained by the heat conduction. As chamber's volume (1.82 m^3) is too small in comparison to the environment where they are located, heat flows between the environment and the chambers to reach the same temperature in order to achieve a thermal equilibrium, as explained by thermodynamics.

The temperature remained between 18 to 25 °C except for one day in which the temperature was around 14.6 °C and the local temperature registered was 11.5 °C. Though, even the lower temperature registered the temperature required for nitrification and denitrification process is between 5 °C to 30 °C, which was in accordance during the period analysed. The average temperature in chamber one is 20.2 ± 2.8 °C and in chamber 2 is 20.2 ± 2.9 °C.



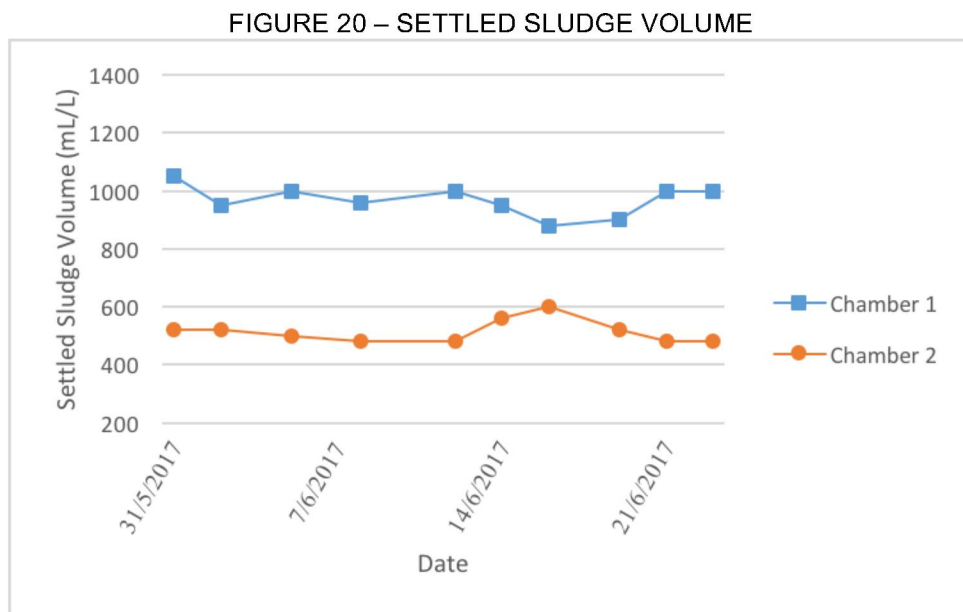
SOURCE: Author

5.2.2 Settled Sludge Volume

Figure 19 shows the settled sludge volume for chamber one and two. According to Ökoservice GmbH the settled sludge volume in chamber one is supposed to be between 800 to 1200 mL/L because this chamber is expected to have the activated sludge containing the microorganisms needed for the carbon, nitrogen and phosphor

degradation. The results demonstrated that the values meet the criteria, being that they remained between approximately 900 to 1000 mL/L.

Chamber two is not supposed to have as much sludge within it because it can affect the settlement of sludge during the clear water discharge, so the recommended amount is between 400 to 700 mL/L. The settled sludge volume in two had less fluctuations than the observed in one and the values remained between approximately 500 to 600 mL/L, as observed in figure 19, which meets the recommended. The clarified part of chamber two doesn't show floating solids indicating that the sludge settled-ability is good.



SOURCE: Author

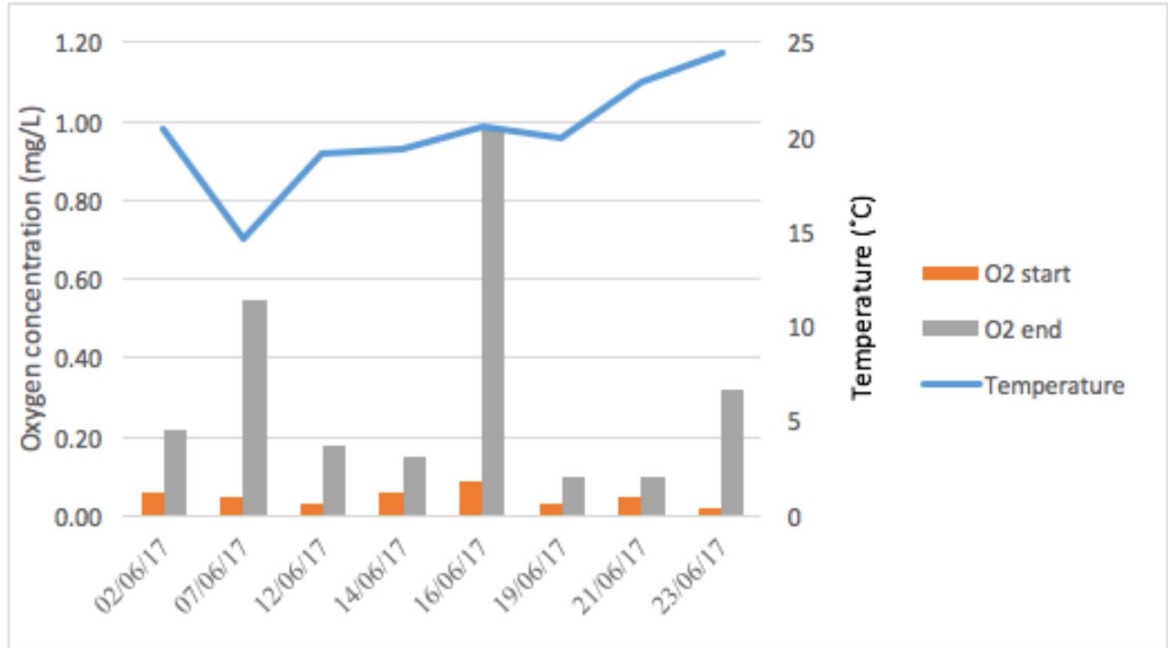
The settled sludge volume behaviour among time it is almost linear, showing that the plant is running in regime.

5.2.3 Oxygen

The measurements were made in the starting and end of the aeration process in both chambers. The oxygen in the beginning was almost zero due to the fact that the aeration starts after the pause in the process that is needed to ensure an anoxic environment for the denitrification process in chamber 1. At the end of the aeration, oxygen in chamber 1 was still low, as necessary for the nitrification process. In

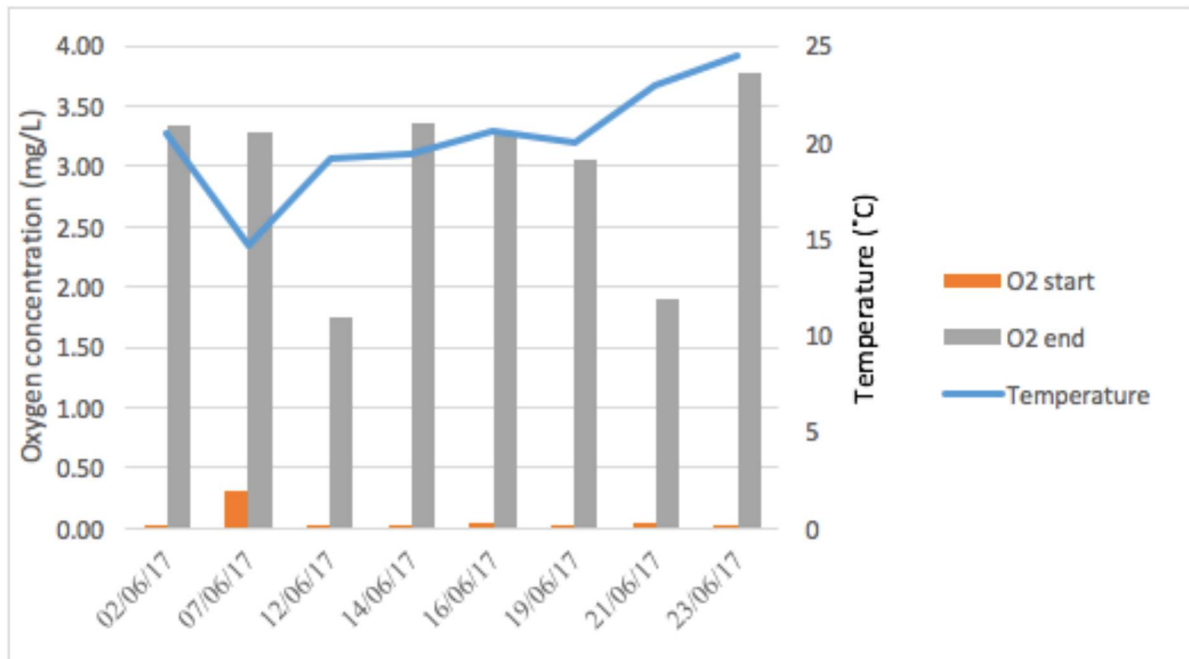
chamber 2 the value kept close to 3 mg/L which is necessary for the aerobic microorganisms responsible for nitrification. Figure 21 and 22 show the oxygen results.

FIGURE 21 – OXYGEN CONCENTRATION DURING AERATION IN CHAMBER ONE



SOURCE: Author

FIGURE 22 – OXYGEN CONCENTRATION DURING AERATION IN CHAMBER TWO



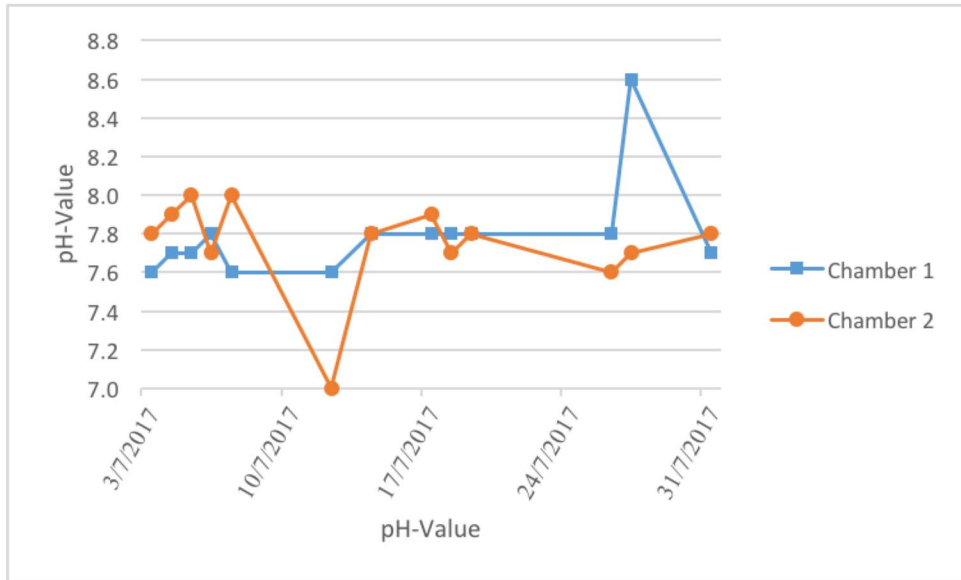
SOURCE: Author

The temperature in both chambers remained in the range to ensure nitrification and denitrification reactions. The settled sludge volume met the criteria recommend by Ökoservice GmbH, being that chamber one showed values between 900 to 1000 mL/L, which is the range necessary to confirm carbon, nitrogen and phosphor degradation, and chamber two showed values between 500 to 600 mL/L, which shows that the settlement of sludge is good to have a clarified wastewater after the treatment. Besides that, the behaviour of both chambers among time indicates regime. The low oxygen concentration after aeration in chamber one ensured an anoxic environment, which is necessary for denitrification reactions. While in chamber two, after aeration, the oxygen concentration ensured an aerobic environment that guaranteed nitrification reactions. During the start up phase, the compact WWTP showed to work without fails and the controlled parameters showed to be in accordance to the expected and ready to go to the next phase, the evaluation phase.

5.3 EVALUATION OF THE EFFICIENCY - EVALUATION PHASE

There were more fluctuations during this phase in the pH-value, mainly one peak in chamber one (8.6) and one smaller peak in two (7.0) due to the "ammonia valley", as explained in the item 5.2.1. The lowest peak on chamber two is due to the measurement has been made in the end of aeration, moment in which nitrification consumed the alkalinity. The opposite is observed on chamber one, in the highest peak, because the measurement was made in the beginning of the aeration. Despite this, the values remained between 7.5 to 8.0 which are acceptable values for nitrification (5.8 – 8.5 for *Nitrosomonas* and 6.5 – 8.5 for *Nitrobacter*) and denitrification (6.5 – 8.5), according to Wiesmann, Choi and Dombrowski (2007). Figure 23 shows the pH-value for the evaluation phase. The average pH-value in chamber one is 7.8 ± 0.3 and 7.7 ± 0.3 in two.

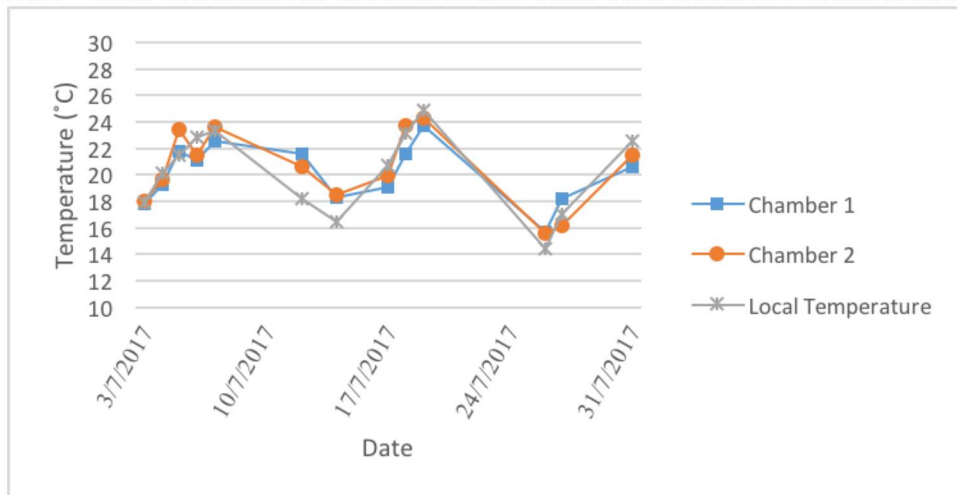
FIGURE 23 – PH-VALUE IN CHAMBER ONE AND TWO DURING EVALUATION PHASE



SOURCE: Author

In July, the temperature remained pretty similar to June, as showed in Figure 24. There were few days with lower temperatures, which had influence in both chambers but the studied parameters were still in between the range desired for nitrification (5 - 30°C for *Nitrosomonas* and 5 - 40°C for *Nitrobacter*), according to Wiesmann, Choi and Dombrowski (2007). The average temperature in chamber one was 20,1 °C.

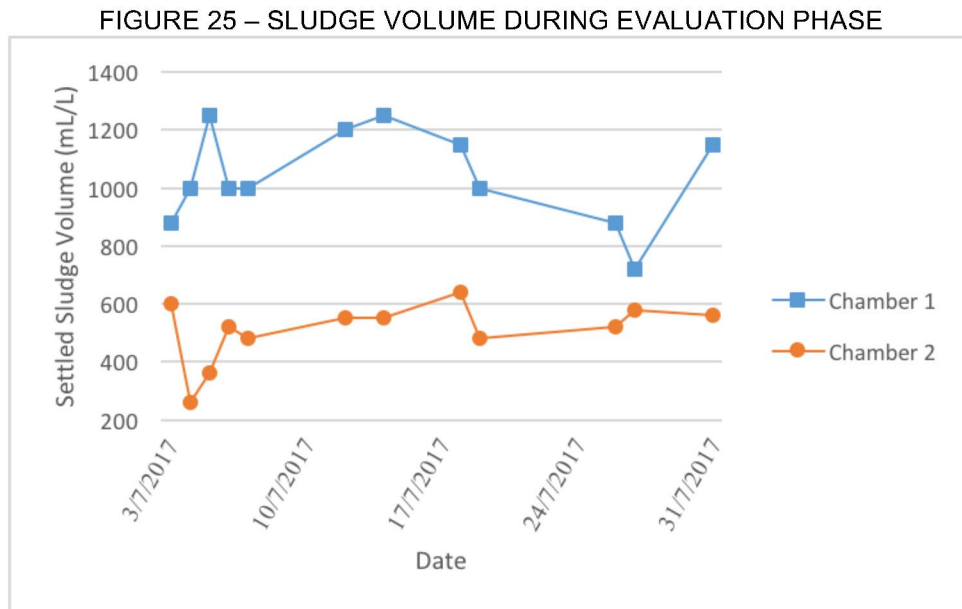
FIGURE 24 – TEMPERATURE IN CHAMBER ONE AND TWO DURING EVALUATION PHASE



SOURCE: Author

5.3.1 Sludge Parameters

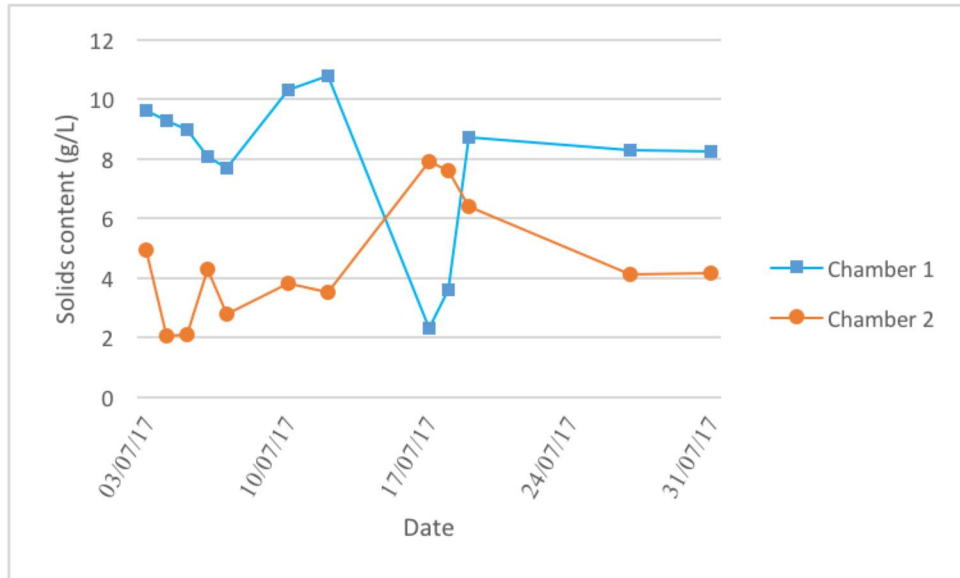
Figure 23 shows sludge volume during the evaluation phase. During this period, sludge volume showed more peaks in both chambers but chamber 1 still showed results between 800 to 1200 mL/L, which is the recommended by Ökoservice GmbH. Chamber 2 showed more stable results during the analysed month, the results were mainly between 500 to 600 mL/L.



SOURCE: Author

Sludge volume index is determined by calculation and it is a relation between settled sludge volume and solids content. FIGURE 26 shows the results for solids content.

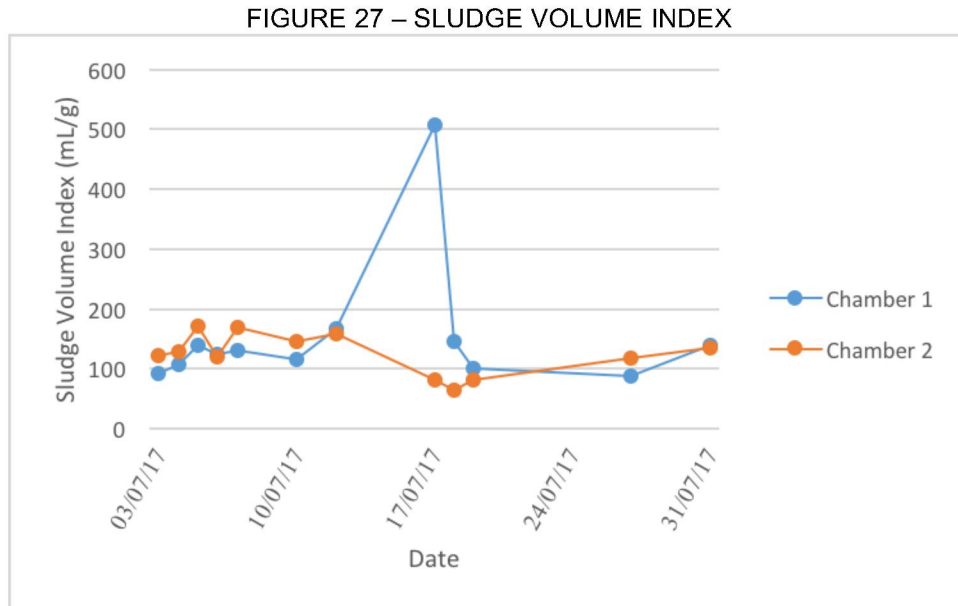
FIGURE 26 – SLUDGE SOLIDS CONTENT IN CHAMBER ONE AND TWO



SOURCE: Author

The sludge volume index for chambers one and two is showed in figure 27. The sludge volume index is one of the best parameters to evaluate the activated sludge process, as mentioned before in the item 3.2. A value of no more than 200 mL/L and no less than 40 mL/L is seen as ideal by most wastewater treatment plants which stay within these parameters accordingly (Van Haandel and Van der Lubbe, 2012). The recommended value from the manufacturer meanwhile is between 80 to 120 mL/L.

During the experiment the value remained between 100 to 160 mL/L. There was one big peak in chamber 1, in which the value was 506.61 mL/L. This can be explained by the fact that on 16th July the station was automatically switched off for safety due to a storm that made the wires wet. The station stayed switched off for one day and it was switched on on 17th July, day in which the peak is observed. A high SVI value indicates the sludge compacts poorly and settles very slowly, besides that it is observed light and fluffy solids, not dense. This high value can be explained by the fact that during the day the plant was switched off there was no aeration, which means the prevalence of anaerobic and facultative anaerobic organisms. When the plant was switched on, the aerobic organisms started forming the floc particles again, resulting in a high SVI and a low sludge solids content in chamber one. After two days, the situation was normalized.



SOURCE: Author

According to the sludge parameters, the process runs perfectly well with the new operational conditions presented in the item 4.2.

5.3.2 Chemical Parameters in The Clear Water

During the sampling of the clear water discharge it was identified the presence of sludge in the first 1-3 minutes of the discharge. The presence of sludge is due to the the project of the pipe and the way of pumping the water with an air lift pump because during the aeration time the mixing in the chamber two carries sludge to the pipe. The solution was an addition of a 45° elbow in the beginning of the pipe.

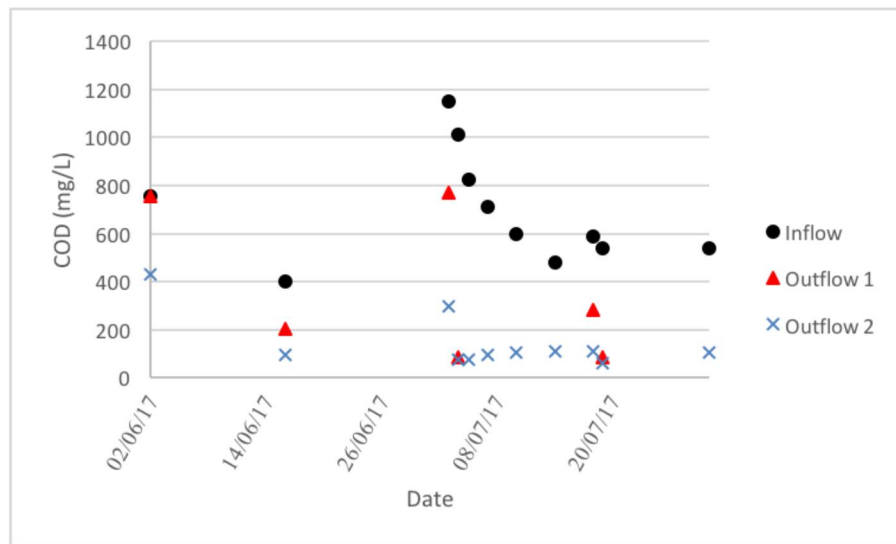
For the chemical parameters, it was analysed the inflow and the outflow, which was differentiated in two flows: outflow one for samples with presence of sludge and outflow two for samples without sludge, as explained in the item 4.3.1(p. 47).

5.3.2.1 COD

Figure 28 summarizes COD for the current phase. It is possible to observe that the inflow is very instable with values variation between 400 to almost 1200 mg/L, which means that the compact WWTP is loaded with big peaks of high organic loads.

The samples containing sludge with the clear water show results higher than the desired, which is more than 150 mg/L, the recommended by the manufacturer. In the first day the two highest values for outflow one and two were detected, however it was in the first day of the set up phase so the new parameters were recently changed. The average COD during this period is 142 mg/L with a standard deviation of 114 mg/L.

FIGURE 28 – COD DURING EVALUATION PHASE



SOURCE: Author

Table 12 shows the efficiency in the COD removal. The outflow 1 shows good efficiency in twice (92% and 84%), but in general the results are higher than 150 mg/L showing that the process runs with better efficiency without presence of sludge.

For outflow 2, the results are in average 83%, which is below than 90%, value expected for SBR compact wastewater treatment plants according to Abegglen, Ospelt and Siegrist (2008). This fact can be explained by the high fluctuations in the inflow, probably due to different activities in the hotel that feeds the plant with wastewater.

TABLE 12 – EFFICIENCY IN THE COD REMOVAL

Date	Inflow (mg/L)	Outflow 1 (mg/L)	Outflow 2 (mg/L)	Efficiency 1 (mg/L)	Efficiency 2 (mg/L)
02/06/17	756	756	431	0%	43%
16/06/17	402	205	96	49%	76%
03/07/17	1148	770	295	33%	74%
04/07/17	1012	84	75	92%	93%
05/07/17	823	-	76	-	91%
07/07/17	709	-	95	-	87%
10/07/17	600	-	107	-	82%
14/07/17	479	-	112	-	77%
18/07/17	586	283	110	52%	81%
19/07/17	540	86	63	84%	88%
30/07/17	539	-	104	-	81%

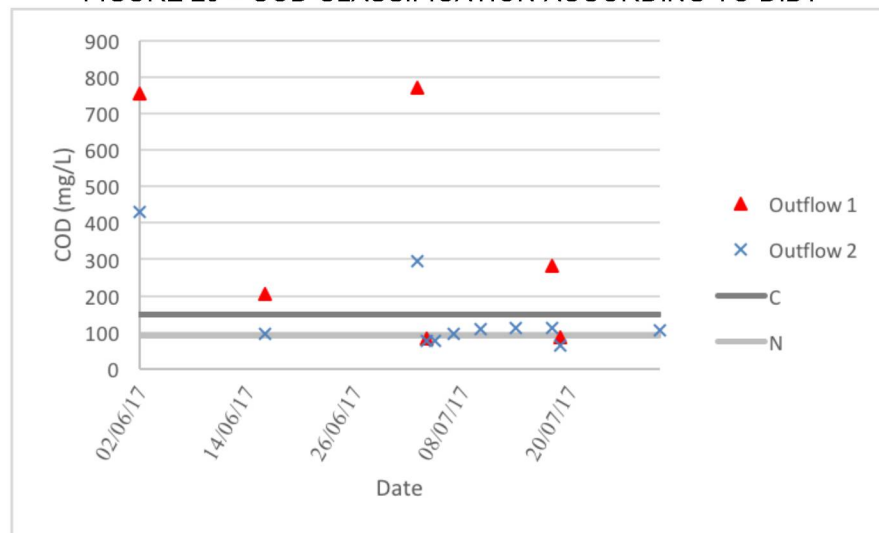
- No samples for outflow 1 because sludge was not detected in the clear water

SOURCE: Author

Figure 29 shows the comparison between the outflows and the classification according to DIBt. According to the classification showed in Table 4, the compact wastewater treatment plant are classified taking into consideration only the parameter COD as C if they show results for COD under 150 mg/L and N if they show results for COD under 90 mg/L. Outflow 1 exceeds the value accepted for class C in almost all of the detected cases due to the presence of sludge which compromises the process quality.

For the evaluation, only outflow 2 will be taken into consideration and it attends class C in almost all of the samples analysed being that the first point that exceeds the limit was in the day in which the changes in the process were made and the second one was in the same day in which was noticed a big peak in the sludge volume index (figure 25) and for COD it can also be explained as a consequence of the day in which the plant was switched off.

FIGURE 29 – COD CLASSIFICATION ACCORDING TO DIBT



SOURCE: Author

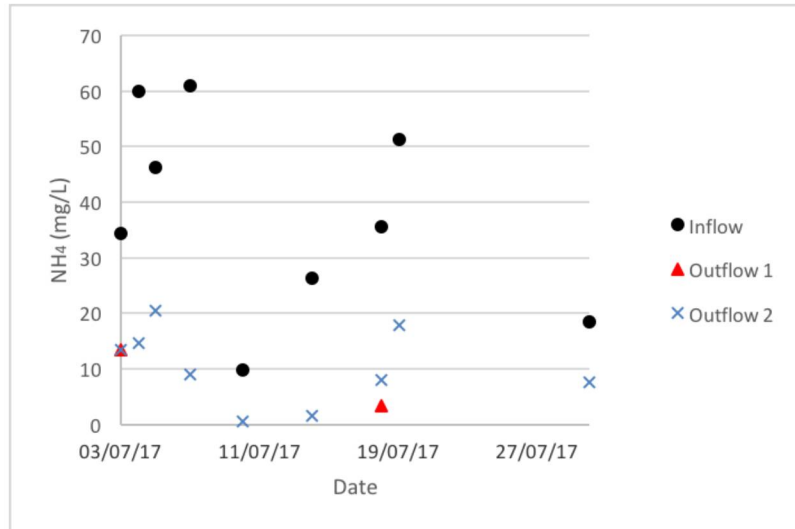
5.3.2.2 Estimated BOD

The BOD value can be estimated as it is known that in municipal wastewater normally presents a ratio between 0.4 to 0.6 of BOD/COD (Wiesmann, Choi and Dombrowski, 2007; Porto, 1991; Von Sperling, 2012). For the calculations, it was considered the average value (0.5). The results showed that the BOD removal was higher than 74%, being the average 85%. The results are meeting the criteria according to the Brazilian legislation CONAMA 430/11, which recommends the removal of 60% of BOD.

5.3.2.3 Ammonium, nitrite and nitrate

Figure 30, 31 and 32 show ammonium, nitrite and nitrate respectively. Ammonium shows values between 10 to 60 mg/L in the inflow and between 0.5 to 20 mg/L in the outflow. In all of the samples a good reduction in the ammonium content can be seen which shows that the first step of the nitrification process is working (ammonium is being oxidized to nitrite) and on average the efficiency of ammonium removal was 74%. The average for ammonium content is 12.8 mg/L with a standard deviation of 10.1 mg/L.

FIGURE 30 – AMMONIUM FOR EVALUATION PHASE

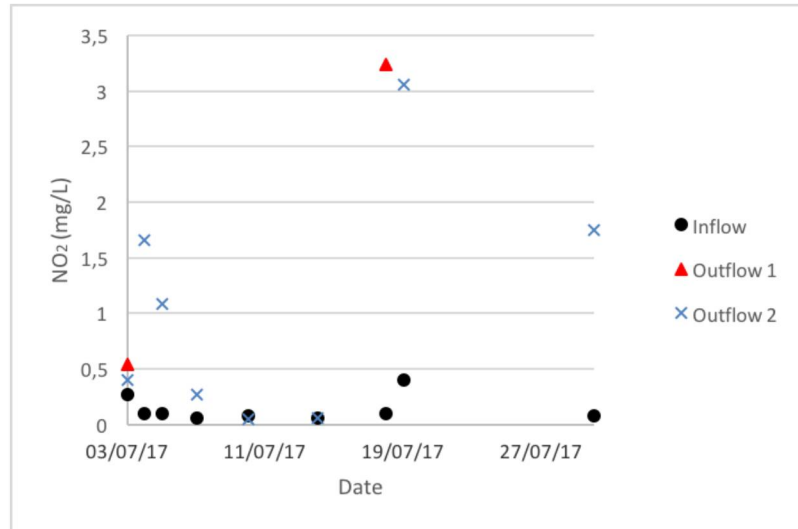


SOURCE: Author

The nitrite and nitrate content in the inflow were very low, which was expected because in the beginning of the process ammonium was not oxidized to nitrite and nitrite to nitrate. A big variance in the inflow values was also not detected. In the outflow, higher values for nitrite and nitrate were expected than in the inflow because at this point ammonium is oxidized to nitrite.

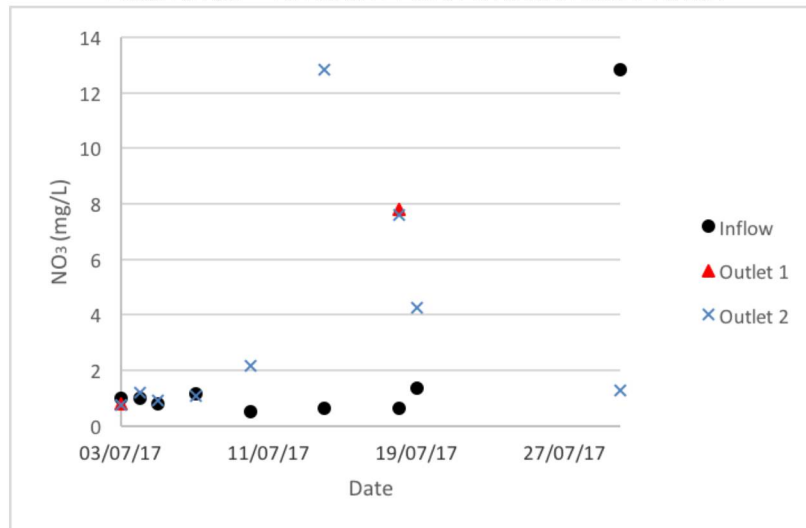
It is evident that both the nitrate and nitrite values of the outflow were above the values of the inflow which suggests that nitrification has occurred during the process, but denitrification has not been completed. Presence of oxygen in the system, inadequate conversion of the microbial respiration, low microbial activity, or inadequate return of nitrate and nitrite from chamber 2 to chamber 1 could be some of the reasons. Control of the denitrification is made by controlling the nitrification reaction and this controlling is possible by reducing the sludge age or by the addition of hydrogen peroxide in the second chamber.

FIGURE 31 – NITRITE FOR EVALUATION PHASE



SOURCE: Author

FIGURE 32 – NITRATE FOR EVALUATION PHASE



SOURCE: Author

The nitrite and nitrate average content are 1.04 and 3.55 mg/L, and the standard deviation are 1.0 and 4.0 mg/L, respectively.

According to DIBt, there is specification in the classes N and D for ammonium, but it is for the 24h mixing test which was not the one used in the current study. The specified value is 10 mg/L, which was achieved in 56% of the samples analysed for this parameter. There is no specification in the four classes for nitrite and nitrate, however for class D there is specification from inorganic nitrogen, which is the sum total of ammonium, nitrite and nitrate.

Table 13 shows the results for inorganic nitrogen where it is possible to observe that all of the samples could be classified as class D only taking into consideration this parameter. The efficiency of inorganic nitrogen removal was 62% in average, being that the expected for this reactor is between 10 to 70% of removal, according to Abegglen, Ospelt and Siegrist (2008), showing that the efficiency in nutrients removal for this reactor is the expected.

TABLE 13 – INORGANIC NITROGEN

Date	Ninorg. (mg/L)
03/07/17	14
04/07/17	18
05/07/17	22
07/07/17	10
10/07/17	3
14/07/17	14
18/07/17	16
19/07/17	25
30/07/17	11

During the evaluation phase the chamber showed to be easy to operate, no maintenance was required and the plant ran automatically, which means it is a good alternative for households where there is no qualified people to look after the treatment frequently.

The operational parameters, such as temperature, pH, oxygen concentration and settled sludge volume, as discussed before, meet the recommended by the manufacturer.

Comparing the results obtained for COD removal, the small-scale WWTP shows better results than septic tanks (20 - 30% of COD removal), according to Abegglen, Ospelt and Siegrist (2008). Regarding nitrogen removal, the results are better than the expected for septic tanks (0 – 10%), trickling filter (10 – 40 %) and sand filter (10 – 20%), being the results comparable to the ones for reed bed (10 – 90%) and normal scale WWTP (60%) (table 3). The small-scale WWTP showed to be a good alternative in terms of organic matter and nitrogen removal.

5.3.3 Establishment of the ideal operational parameters

During this phase, the first change was made by decreasing the aeration time in chamber two from 23 to 18 minutes. The results for COD with the new time was better than the showed before, in average the value was 81 mg/L with standard deviation of 30 mg/L. The minimum COD value was 56 mg/L and the maximum 123 mg/L, being that the efficiency of removal was in average 87%. These results show that the efficiency in COD removal was increased by this change. Regarding nitrogen removal, the efficiency in the ammonium removal was $78\pm 16\%$ and for organic nitrogen $72\pm 17\%$, better results than the evaluation phase.

The second change was made by increasing the pause in the process from 30 to 40 minutes. The COD removal efficiency in average for this period was $84\pm 9\%$, ammonium removal $90\pm 9\%$ and organic nitrogen removal $78\pm 8\%$.

Table 14 shows the comparison between the COD removal efficiency during evaluation phase, test 1 and 2. It is possible to observe that the better results in average are showed in test 2. However, the maximum efficiency is the same for all of them (93%) and the minimum efficiency is very close, 74%, 75% and 72% for evaluation phase, test 1 and 2, respectively.

TABLE 14 – COMPARISON BETWEEN COD REMOVAL EFFICIENCY

Phase	Maximum efficiency	Minimum efficiency	Average
Evaluation phase	93%	74%	$80\pm 8\%$
Test 1	93%	75%	$88\pm 7\%$
Test 2	93%	72%	$84\pm 9\%$

Table 15 shows the comparison between nitrogen removal efficiency between the three different phases. The results show a good improving between the evaluation phase and test 2, being that test 2 shows better results in ammonium and organic nitrogen removal efficiency.

TABLE 15 – COMPARISON BETWEEN NITROGEN REMOVAL EFFICIENCY

	Ammonium	Organic nitrogen
Phase	Average efficiency	Average efficiency
Evaluation phase	72±16%	63±12%
Test 1	78±16%	72±17%
Test 2	90±9%	78±8%

Analysing the results, it is possible to conclude that the decreasing in the time of the aeration improved the organic matter removal and the increasing in the time of the pause of the process improved nitrogen removal. However, tests 1 and 2 were analysed only 10 days each and for a better conclusion, it would be recommended to analyse the efficiency among time, at least for 5 weeks. It is also recommended to analyse a third test, which would be a combination of test 1 and 2, in order to evaluate if there is an improvement of organic matter and nitrogen removal at the same time. Though, the aim of test 1 and 2 was evaluate if in case of low global horizontal solar irradiation it would be possible to save energy by decreasing the time of aeration and the pause in the process without compromising the efficiency and the results shows that it is possible.

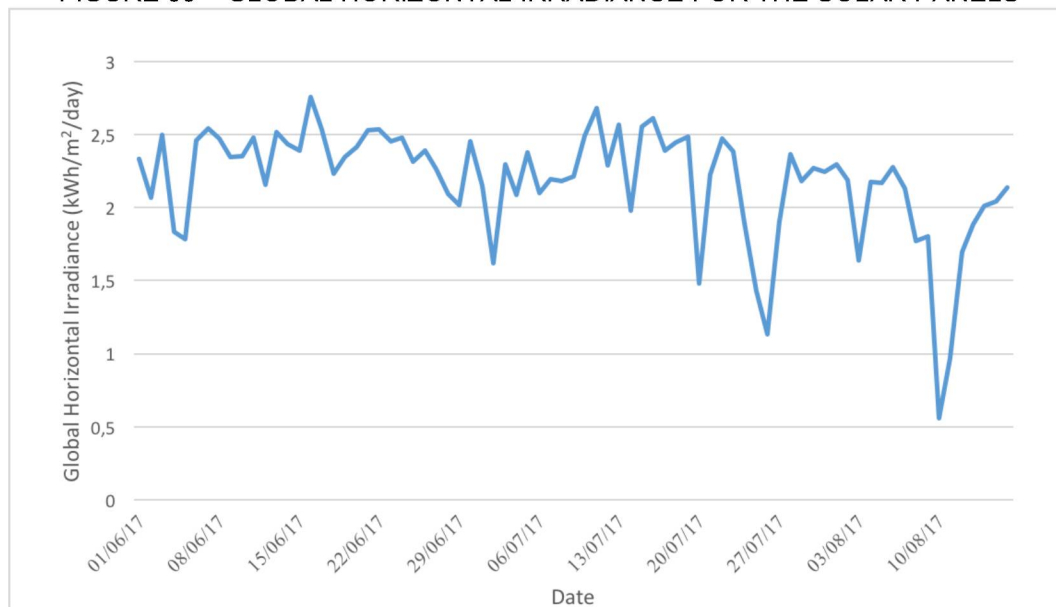
5.4 VERIFICATION OF THE SOLAR PANELS OPERATION

The plant ran during the period of this study with solar power and batteries as back up and showed that it is possible to run the process with this renewable energy source. The module showed an efficiency of 17% at standard test conditions, which means the laboratory conditions in which the photovoltaic modules were tested, and 15% at normal operating cell temperature. Comparing the theoretical value with the real one, it is possible to see that the panels worked according to the manufacturer instructions. The area of each solar panel is 1.6 m², totalizing 6,4 m² for the 4 panels.

Figure 33 shows the global horizontal irradiance for the solar panels during the period of 1st July to 16th August 2017. The average value during this period is 2.18±0.4 kWh/m²/day, the minimum value was 0.55 kWh/m²/day on 10th August and the maximum value registered was 2.76 kWh/m²/day on 16th July. Comparing the values registered with the ones for Brazil, showed in figure 2, it is possible to see that the values are comparable with the ones showed mainly in all of the regions in Brazil, with exception of part of South-West. However, in states such as Paraná, Santa Catarina,

Rio Grande do Sul, Amazonas, Acre and Pará it should work with more solar panels because in these states the horizontal solar irradiance is lower than the one showed in Stuttgart.

FIGURE 33 – GLOBAL HORIZONTAL IRRADIANCE FOR THE SOLAR PANELS



SOURCE: Author

5.5 ESTIMATED COSTS

The estimated costs for the compact wastewater treatment plant are showed in Table 16.

TABLE 16 – COMPACT WWTP ESTIMATED PRICE

Product	Estimated Price (€)
Wastewater treatment plant	1000.00
Solar panels (including mounting, cables and 19% tax)*	2104.48
Electrical cabinet (including 19% tax and commissioning)	14,064.50
Remote access (remote access via GPRS modem)	200.00**

*Estimated price for the 4 out 10 solar panels used.

**Price per year

The total price for the implementation of this plant would be approximately 17,169 € (approximately R\$68,676.00). This value could be considered cost effective for a hotel or a complex of houses, but it is not cost effective for a household in Brazil

if comparing this value with a SBR compact wastewater treatment plant for 6 to 10 PE that costs R\$ 25,000.00 (Tegeve Ambiental, 2017). The costs of the solar panels and electrical cabinet increase considerable the final price of the compact wastewater treatment plant.

6 CONCLUSION

The compact wastewater treatment plant shows itself to be a good alternative for households, restaurants, farms or hotels that are located in sites where municipal wastewater treatment is not available. It is also a better way of managing domestic wastewater in comparison to septic chambers.

The study showed that the plant is very simple to operate, it can run automatically without requirement of regular maintenance. During the period from June to August, 2017 no maintenance was required. It was also possible to evaluate the operation of the plant during European summer, where it was notable that the temperature values were enough to keep the nitrification and denitrification in the process and there was no need to pump wastewater into the plant every hour in order to prevent the pipes and pumps from freezing which happened during the winter.

One of the most important parameters in an activated sludge process is the sludge volume index. During the evaluation phase, the SVI remained between 100 to 160 mL/g except for one isolated day in which the plant was switched off due to a safety action caused by wet wiring during a storm. The SVI-value results demonstrate that during the evaluation phase the sludge could be considered to be from high quality.

The pH-value, temperature and oxygen were the required for the nitrification and denitrification process. pH-value and temperature showed some fluctuation. The pH-value fluctuations is because of the consumption of the ion H^+ during the nitrification process, which causes decreasing in the pH-value. However, the pH-value remained between 7,0 to 8,6 during all of the period. The temperature remained between 18 to 25°C for most of the time. It was notable that the local temperature exert high influence in the temperature of the process because the volume of the chamber is only 1,6 m³.

The efficiency of CODChamber 1 worked with anaerobic and anoxic phases, which are necessary for denitrification and carbon and phosphor degradation and chamber 2 worked well with the anoxic and aerobic phases for nitrification and carbon degradation. The inorganic nitrogen efficiency was 62% in average, which is compared with the literature that shows expected values between 10 to 70% for SBR and

compact reactors. However, the nitrification process is working better than denitrification process, showed by the ammonium removal efficiency of 74%. Control of the denitrification is made by controlling the nitrification reaction and this controlling is possible by reducing the sludge age or by the addition of hydrogen peroxide in the second chamber.

Fluctuations in the inflow content were observed, mainly in the chemical parameters, such as COD and ammonium, which puts it under more strain as the plant is loaded with high peaks of organic matter and nitrogen. It is recommended to run the plant for more tests in a household where the wastewater content is more linear.

The efficiency of the the organic matter removal was evaluated, analysed by measuring COD, was 83% in average, being that the lower COD value was 63 mg/L and the highest 431 mg/L. The fluctuations in the inflow content is one of the reasons why there is such difference between the COD content in the outflow because this small-scale wastewater treatment plant is very sensitive to the variations in wastewater and in the parameters that control the process. The positive effect is that the variations in the process can be easily notice in order to evaluate their effects or to improve the treatment, so when the variation is controlled in order to study the process it is good to have a sensitive process. On the other hand, the negative effect is that if the variation is caused by a fluctuation in the inflow, the efficiency of the process will be negative affected.

The presence of sludge in the clear water discharge is an issue of the small-scale wastewater treatment plant which was improved with the implementation of a 45° elbow helped and the presence of sludge was then only noticed in 45% of the samples. The manufacturer is working on a more effective solution for the next projects. As the presence of sludge is not due to the bad operation of the plant but due to an error in the project design, the outflow 1 is not being considered.

The tests 1 and 2 showed good results as an improvement for the small-scale treatment plant, as well. Test 1 showed to improve organic matter removal and test 2 improved nitrogen removal. However, each test was made only for one week and two validate those results it would be necessary to repeat the tests for at least 5 weeks.

Besides that, it would be interesting to have test 1 and 2 running together, to evaluate the consequence in organic matter and nitrogen removal.

According to the DIBt, the compact wastewater treatment plant can be classified as class C in 82% of the samples analysed. There is no specific regulation for compact plants in Brazil and to apply this project in the country it would be needed to require the environmental licensing.

The operation with solar energy was evaluated and showed to be possible, being that no problem was detected during the 3 months operation. The plant worked with 4 solar panels out of 10 and 6 batteries as back up. Comparing the average value of global horizontal solar irradiation obtained by the solar panels ($2,18 \pm 0,4$ kWh/m²/day) to the one in Brazil is possible to conclude that there is even better condition to run this plant in Brazil than in Germany. However, in states such as Paraná, Santa Catarina, Rio Grande do Sul, Amazonas, Acre and Pará it should work with more solar panels because in these states the horizontal solar irradiation is lower than the one showed in Stuttgart.

The total price for the implementation of this plant would be approximately 17,169 € (approximately R\$68,676.00). This value could be considered cost effective for a hotel or a complex of houses, but it is not cost effective for a household in Brazil. The costs of the solar panels and electrical cabinet increase considerable the final price of the compact wastewater treatment plant.

6.1 RECOMENDATIONS

In conclusion, it is recommended that:

- BOD analysis in the inflow, in order to compare the values with CONAMA 430/11 (Brazilian legislation).
- Pilot tests in a household in Brazil, to evaluate if there is high fluctuation in the inflow parameters as the showed in this study.

- Run test 1 and 2 together for at least 5 weeks to evaluate the efficiency in organic matter and nitrogen removal.
- Run the plant with less than 4 solar panels, to evaluate if it is possible to reduce the price of the implementation.

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ANEEL – RESOLUÇÃO NORMATIVA Nº 77/04 "Estabelece os procedimentos vinculados à redução das tarifas de uso dos sistemas elétricos de transmissão e de distribuição, para empreendimentos hidrelétricos e aqueles com base em fonte solar, eólica, biomassa ou cogeração qualificada".

ANEEL – RESOLUÇÃO NORMATIVA Nº 482/2012. "Estabelece as condições gerais para o acesso de microgeração e minigeração distribuída aos sistemas de distribuição de energia elétrica, o sistema de compensação de energia elétrica, e dá outras providências".

CAMEX - RESOLUÇÃO Nº 22/16. "Altera para 2% (dois por cento) as alíquotas do Imposto de Importação incidentes sobre Bens de Capital, na condição de Ex-tarifários, e dá outras providências".

CAMEX - RESOLUÇÃO Nº 64/17. " Altera para 0% (zero por cento) as alíquotas do Imposto de Importação incidentes sobre Bens de Capital, na condição de Ex-tarifários, e dá outras providências.".

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DECRETO Nº 1.745/79 – SEMARH/GO. "Aprova o Regulamento da Lei nº8544, de 17 de outubro de 1978, que dispõe sobre a prevenção e o controle da poluição do meio ambiente.". Goiás.

DECRETO Nº 6.200/95 – SEMARH/AL. "Estabelece medidas de proteção ambiental na área de implantação do Pólo Cloroquímico de Alagoas e dá outras providências". Alagoas.

DECRETO Nº 8.468/76. Regulamento da lei nº 997, de 31 de maio de 1976, que dispõe sobre a prevenção e o controle da poluição do meio ambiente.

DECRETO Nº 9.067/09. Dispõe sobre a Construção de Estações de Tratamento de Esgoto Sanitário em Edifícios e Condomínios e dá outras providências.

DECRETO Nº 14.250/81 – FATMA/SC. "Regulamenta dispositivos da Lei nº 5.793, de 15 de outubro de 1980, referentes à Proteção e a Melhoria da Qualidade Ambiental e no decreto nº 21.460/84 da FATMA (1984), altera a redação do artigo 19". Santa Catarina.

DECRETO Nº 14.250/81 – FATMA/SC. "Regulamenta dispositivos da Lei nº 5.793, de 15 de outubro de 1980, referentes à Proteção e a Melhoria da Qualidade Ambiental e no decreto nº 21.460/84 da FATMA (1984), altera a redação do artigo 19". Santa Catarina.

DECRETO Nº 7.212/10. "Regulamenta a cobrança, fiscalização, arrecadação e administração do Imposto sobre Produtos Industrializados - IPI". Distrito Federal.

DECRETO Nº 7.217/2010. " Regulamenta a Lei no 11.445, de 5 de janeiro de 2007, que estabelece diretrizes nacionais para o saneamento básico, e dá outras providências.". Distrito Federal.

DECRETO Nº 7.903/97 – SEDAM/RO. "Regulamenta a Lei nº 547, de 30 de dezembro de 1993, que dispõe sobre proteção, recuperação, controle, fiscalização e melhoria de qualidade do meio ambiente no Estado de Rondônia". Rondônia.

ICMS 101/97. "Concede isenção do ICMS nas operações com equipamentos e componentes para o aproveitamento das energias solar e eólica que especifica". Rio de Janeiro.

NT-202.R-10. "Critérios e padrões para lançamento de efluentes líquidos". Rio de Janeiro.

PORTARIA N.º 05/89 – SSMA/RS. "Aprova a Norma Técnica SSMA Nº 01/89 – DMA, que dispõe sobre critérios e padrões de efluentes líquidos a serem observados por todas as fontes poluidoras que lançam seus efluentes nos corpos d'água interiores do Estado do Rio Grande do Sul". Rio Grande do Sul.

RESOLUÇÃO Nº 001/07 – SEMA/PR. "Dispõe sobre licenciamento ambiental, estabelece condições e padrões ambientais e dá outras providências, para empreendimentos de saneamento." Paraná.

ATTACHMENTS

ATTACHMENT A – SOLAR PANELS

Sunmodule[®] Plus SW 260 – 280 mono



Produktion am Technologie-
Standort Deutschland



TÜV Power controlled:
Niedrigste Messtoleranz branchenweit



Sunmodule Plus:
Positive Leistungstoleranz



25 Jahre lineare Leistungsgarantie und
10 Jahre Produktgewährleistung



Die SolarWorld AG setzt bei der Produktion ihrer Solarmodule auf den Technologie-Standort Deutschland und sichert so die nachhaltige Qualität ihrer Produkte.

Das Prüfschild Power controlled des TÜV Rheinland garantiert, dass die ausgewiesene Nennleistung der Solarmodule in regelmäßigen Abständen überprüft wird und somit gewährleistet ist. Die Abweichung zum TÜV beträgt maximal 2 Prozent.

Die positive Leistungstoleranz garantiert höchste Anlageneffizienz. Es werden nur Solarmodule ausgeliefert, die nach den Leistungstests die ausgewiesene Nennleistung oder mehr erreichen. Die Leistungstoleranz liegt zwischen -0 Wp und +5 Wp.

Mit der linearen Leistungsgarantie über 25 Jahre garantiert SolarWorld eine maximale Leistungsdegression von 0,7% p.a. – ein deutlicher Mehrwert gegenüber branchenüblichen, zweistufigen Garantien. Das Service-Zertifikat ist somit eine langfristige und umfassende Investitionsabsicherung.

Sunmodule[®] Plus SW 260 – 280 mono

VERHALTEN BEI STANDARDTESTBEDINGUNGEN (STC)*

		SW 260	SW 265	SW 270	SW 275	SW 280
Maximalleistung	P_{max}	260 Wp	265 Wp	270 Wp	275 Wp	280 Wp
Leerlaufspannung	U_{oc}	38,5 V	39,0 V	39,2 V	39,4 V	39,5 V
Spannung bei Maximalleistung	U_{mp}	30,7 V	30,8 V	30,9 V	31,0 V	31,2 V
Kurzschlussstrom	I_{sc}	9,18 A	9,31 A	9,44 A	9,58 A	9,71 A
Strom bei Maximalleistung	I_{mp}	8,56 A	8,69 A	8,81 A	8,94 A	9,07 A

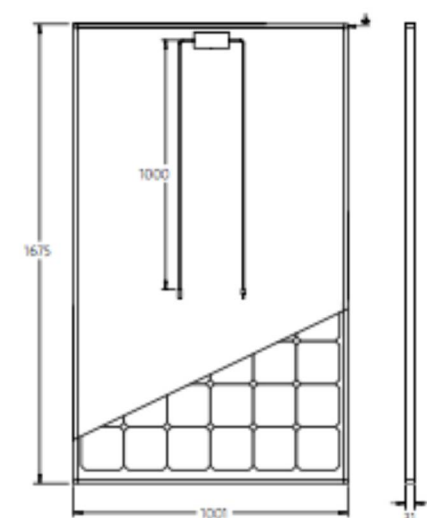
Mess toleranz (P_{max}) rückföhrbar auf TÜV Rheinland: +/- 2% (TÜV Power controlled)

*STC: 1000W/m², 25°C, AM 1,5

VERHALTEN BEI 800 W/m², NOCT, AM 1,5

		SW 260	SW 265	SW 270	SW 275	SW 280
Maximalleistung	P_{max}	194,2 Wp	197,8 Wp	201,3 Wp	205,0 Wp	209,2 Wp
Leerlaufspannung	U_{oc}	35,6 V	35,7 V	35,9 V	36,1 V	36,1 V
Spannung bei Maximalleistung	U_{mp}	28,1 V	28,2 V	28,3 V	28,4 V	28,5 V
Kurzschlussstrom	I_{sc}	7,42 A	7,53 A	7,63 A	7,75 A	7,85 A
Strom bei Maximalleistung	I_{mp}	6,92 A	7,02 A	7,12 A	7,22 A	7,33 A

Geringe Wirkungsgradreduktion im Teillastverhalten bei 25°C: bei 200 W/m² werden 100% (+/- 2%) des STC Wirkungsgrades (1000 W/m²) erreicht.



ABMESSUNG

Länge	1675 mm
Breite	1001 mm
Höhe	31 mm
Äußerung	silber eloxiertes Aluminium
Gewicht	21,2 kg

VERWENDETE MATERIALIEN

Zellen pro Modul	60
Zelltyp	Monokristallin
Zellabmessungen	156 mm x 156 mm
Vorderseite	4 mm gehärtetes Glas (EN 12150)

THERMISCHE KENNGRÖSSEN

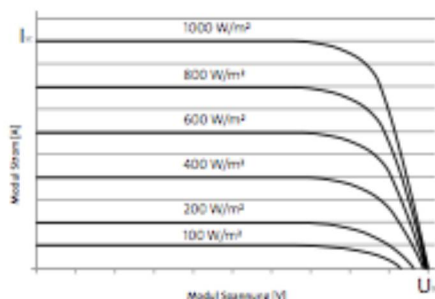
NOCT	46 °C
TK I_{sc}	0,040 %/K
TK U_{oc}	-0,30 %/K
TK P_{max}	-0,41 %/K

WEITERE ANGABEN

Leistungsortierung	-0 Wp / +5 Wp
Anschlussdose	IP65
Stecker	MCA / KSK4

KENNGRÖSSEN ZUR OPTIMALEN SYSTEMEINBINDUNG

Max. Systemspannung SK II	1000 V
Rückstrombelastbarkeit	16 A
Auflast / dyn. Last	5,4 / 2,4 kN/m ²
Anzahl Bypassdioden	3
zulässige Betriebstemperatur	-40°C bis +85°C



- Qualified, IEC 61215
- Safety tested, IEC 61738
- Periodic inspection
- Blowing sand resistant



Die SolarWorld AG behält sich Spezifikationsänderungen vor. Dieses Datenblatt entspricht den Vorgaben der EN 50380. Dieses Datenblatt ist auch als englische Fassung erhältlich.

ATTACHMENT B – BATTERIES

EFFEKTA®
Stromversorgungen

Batterien BTL



BTL 12-100



BTL 12-65



BTL 12-45



BTL 12-55



BTL 12-33

Die bevorzugten Anwendungsbereiche der BTL-Akkumulatoren sind

- Unterbrechungsfreie Stromversorgungen (USV)
- Telekommunikationssysteme
- Feueralarm- und Sicherheitssysteme
- Medizinische Geräte
- Photovoltaische Anwendungen
- Notbeleuchtungssysteme
- Leichte Elektrofahrzeuge

Leistungsmerkmale der BTL-Akkumulatoren:

- Absolut wartungsfreier Betrieb
- Hohe Rekombinationsfähigkeit im Zyklusbetrieb
- Ventilgeregelte Kunststoffkonstruktion als Schutz bei Überladung
- Exzellente Hochstromeigenschaften
- Kein Gefahrgut gemäß IATA
- Hohe Nutzungsdauer von bis zu zehn Jahren
- Hohe Zyklenfestigkeit (mehr als 500 Lade-/Entladezyklen bis zu 50% Entladetiefe)
- Robuster Aufbau
- Lageunabhängiger Betrieb