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Study and treatment proposal for an effluent generated in a slaughterhouse

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ABSTRACT
The treatment of slaughterhouse effluent is extremely important due to the large organic and inorganic load that the wastewater carries after all the productive process developed in this industry segment. In its production, a large amount of water is used for the process of slaughter, cleaning of carcasses and sanitization, which generates a huge volume of effluent. The consumption of beef grows year by year in Brazil and in the world, so organizing an effective form of effluent treatment undoubtedly contributes to environmental preservation with regard to receiving bodies, such as rivers. The objective of this study was to elaborate a proposal for a treatment system based on the characterization of the effluent generated by the slaughterhouse. For this, it was necessary to collect data in relation to the production process, productive organization and forwarding of the waste generated. Based on the characterization of the raw effluent, an effluent treatment was proposed, taking into account the available literature, including preliminary treatment, with static and rotary sieve, primary treatment, with coagulation and flotation processes with organic coagulant, and secondary treatment using anaerobic, facultative ponds and, finally, a polishing pond playing the role of tertiary treatment.

Keywords: Slaughterhouse, effluent treatment, treatment ponds, environmental preservation, effluent characterization, methods of treatment.

1 INTRODUCTION

In Brazil, cattle production slaughtered more than 22 million head of cattle by the third quarter of 2022 (IBGE, 2022). According to ABIEC (2022) and MAPA (2022), Brazil is the largest exporter of beef in the world, which reinforces the importance of establishing adequate effluent treatment practices to minimize the environmental impacts resulting from this activity.

The treatment of effluents generated in cattle slaughterhouses is a critical issue that affects both the environment and public health. According to Legner (2019), these effluents can be classified as water pollution agents and a great threat to public health, as they cause a significant impact on the water quality of water bodies if they are not properly treated prior to their release (USEPA, 2017).

The treatment of this type of wastewater is important not only for the preservation of the quality of our water resources, but also for environmental protection as a whole.

Wastewater treatment refers to the removal of contaminants from wastewater before it is released into the environment. Among the methods that can be used for the treatment of effluents we can mention the physical, chemical and biological methods.

Physical methods, such as sedimentation and filtration, make it possible to separate solid particles from the effluent.

Chemical methods, such as coagulation and flocculation, use chemicals to change the properties of pollutants in wastewater, making them easier to remove. Biological methods, such as aerobic and anaerobic treatment, depend on microorganisms to decompose organic matter in wastewater (DEZOTTI, 2008; VON SPERLING, 2014).

Despite the availability of these methods, the treatment of effluents from slaughterhouses remains a challenging task. Since, this present high complexity due to their characteristics and variability.

In addition, the treatment process must be cost-effective and efficient, while meeting stringent regulatory requirements for wastewater discharge. This highlights the importance of the effluent treatment process in the cattle meatpacking industry, both from an industrial and academic scientific point of view.

The industrial sector is constantly looking for economical and efficient solutions for the treatment of effluents. While the academic scientific sector is focused on the development of new technologies to improve the effluent treatment process (VON SPERLING, 2014; TCHOBANOGLOUS, 2013).

In this context, the present work aimed to perform the physicochemical characterization of the raw effluent generated by the production process of a slaughterhouse located in the north of Paraná.

Thus, based on these data and the environmental legislation in force in the locality, a treatment system is proposed that can be applied to its disposal, taking into account the operational conditions of the study site.

2 CHARACTERISTICS OF EFFLUENTS FROM SLAUGHTERHOUSE

Effluents from slaughterhouses are considered harmful worldwide due to their complex composition of fats, proteins and fibers, as well as the presence of inorganic compounds, nutrients, pathogenic and non-pathogenic microorganisms, detergents and disinfectants used for cleaning activities and pharmaceutical products (ZIARA, 2018).

These are generated from the various slaughter operations. In addition, the physicochemical characteristics of the slaughterhouse effluent varies from region to region and depends on the size of the industry, water consumption and, mainly, the recovery of useful by-products (PACHECO, 2008).

The effluents from slaughterhouses are evaluated in relation to the normative parameters of the environmental agency of the region. Taking into account the quantity and species of animals slaughtered and the associated pollutant loads. Although there may be variations, these effluents generally have high concentrations of total phosphorus (TF), total nitrogen (NT), total organic carbon (TOC), chemical oxygen demand (COD), total suspended solids (TSS), biochemical oxygen demand (BOD), color, and turbidity (BUSTILLO-LECOMPTE; MEHRVAR, 2015).

When compared with sanitary sewage, the average characteristics of the effluent from the slaughterhouse can be 3.9 times higher for TOC, 6.3 times higher for BOD, 9.8 times higher for COD, 10.7 times higher for NT, 5.5 times higher for TSS, and 7.1 times higher for FT, which evidences its need for treatment for its disposal in the environment (NG *et al*., 2022).

2.1 EFFLUENT TREATMENT CHARACTERISTICS OF SLAUGHTERHOUSES

The characteristics of meat-packing effluents depend on the internal operations of meat processing. The slaughterhouse can carry out a pre-treatment process before sending the raw effluent to the effluent treatment facilities. Figure 1 shows the treatment sequence commonly used for effluents from slaughterhouses. Treatment methods include biological, physico-chemical, and advanced oxidation processes operating individually or together (NG *et al*., 2022).

Figure 1 - General scheme of treatment of effluent from slaughterhouse

Source: Adapted from NG *et al*. (2022).

2.1.1 Primary and Primary Treatment

Preliminary effluent treatments aim to remove coarse solids, sand and fats. While primary treatments aim at the removal of sedimentable, suspended solids and part of the organic matter diluted in the liquid medium (VON SPERLING, 2014).

According to Von Sperling (2005), an equipment widely used in effluents that have coarse solids are the rotary sieves, which remove these larger particles and floating materials from the wastewater.

The principle of operation is based on the passage of water through a rotating screen, which retains the solids larger than the spacing between the bars of the screen. The retained solids are collected and disposed of in a bucket or transported for proper treatment.

The rotary sieves can be sized according to the diameter, spacing of the screen bars, rotation speed and the flow of water to be treated. It is also important to consider the need to clean the screen, which can be done by water jets or by automatic scrapers.

In the primary treatment, the removal of suspended solids can be potentiated by the use of coagulants and flocculants.

Coagulants are substances that promote the formation of clots, facilitating the removal of particles by sedimentation or flotation.

Flocculants are responsible for agglutinating the clots formed, increasing their size and facilitating their removal. Among the coagulants most commonly used in the primary treatment are aluminum sulfate, ferric chloride and aluminum polychloride. The most common flocculants are anionic and cationic polymers (VON SPERLING, 1996).

The slaughterhouse effluent goes through a grating pre-treatment and fat separation. Subsequently, it may be subjected to physical sedimentation treatment or other physicochemical treatments, such as dissolved air flotation or coagulation/flocculation. Only after these processes is the effluent sent for secondary treatment (BUSTILLO-LECOMPTE; MEHRVAR, 2015).

2.1.2 Secondary Treatment

Primary and primary treatments are not sufficient to completely remove the soluble organic compounds present in the slaughterhouse effluent in order to meet legal release standards.

Therefore, secondary treatment is a crucial step for the effective removal of these compounds. This process may involve different technologies, such as activated sludge, anaerobic reactors and biological filters, which are designed to remove the residual organic load from the effluent (BUSTILLO-LECOMPTE; MEHRVAR, 2015).

According to Von Sperling (1996), the biological treatment of effluents consists of using microorganisms to remove organic and inorganic pollutants from the effluent.

These microorganisms can be aerobic or anaerobic, depending on the oxygen conditions in the system. Stabilization ponds are treatment systems that use natural processes of oxidation and decomposition of organic matter to remove pollutants from the effluent.

These systems consist of large ponds, with varying depths, that allow the effluent to come into contact with the atmosphere and sunlight, creating a favorable environment for the growth of bacteria and organisms that degrade organic matter.

Anaerobic ponds are a type of stabilization pond that use anaerobic biological processes for the removal of organic matter and nutrients from effluents.

In the dynamics of nutrient removal, anaerobic ponds present limitations in the extraction of nitrogen and phosphorus, which can be removed by complementary processes, such as facultative ponds and polishing systems.

The average dimensions of anaerobic ponds vary according to the flow and organic load to be treated. It can have depths ranging from 1.5 to 5 meters and hydraulic detention time of 10 to 30 days. (VON SPERLING, 2005).

During this time, the anaerobic bacteria present in the pond degrade organic matter, generating biogas and other organic compounds.

This degradation can be explained through four distinct phases. In the first, the hydrolysis of complex organic compounds into simpler compounds, such as amino acids and sugars, occurs.

In the second, called acidogenesis, the fermentation of these compounds into short-chain organic acids, such as acetic, butyric and propionic acid, occurs. In the third, called acetogenesis, the conversion of these organic acids into acetic acid, hydrogen and carbon dioxide occurs.

Finally, in the last phase, methanogenesis occurs, in which methanogenic bacteria convert acetic acid and hydrogen into methane and carbon dioxide (VON SPERLING, 1996).

Despite presenting limitations in the removal of nutrients, anaerobic ponds are a low-cost and efficient treatment option in the removal of organic matter. Especially in regions with high temperatures. However, it is important to note that the operation and maintenance of these systems require specific care to avoid odor problems and sludge accumulation at the bottom of the pond (VON SPERLING, 2014).

Aerobic ponds are effluent treatment systems that use aerobic microorganisms to remove pollutants from the effluent. In these systems, the effluent is stirred and aerated to provide oxygen to aerobic microorganisms, which degrade the organic matter present in the effluent.

The dynamics of nutrient removal and organic load in aerobic ponds occur in different zones within the pond.

In the aeration zone, the oxidation of organic matter and the removal of nutrients, such as nitrogen and phosphorus, occurs through nitrification and denitrification. In the sedimentation zone, sedimentation of solids and the formation of sludge occurs, which is periodically removed (VON SPERLING, 2014).

The average dimensions of the aerobic ponds vary according to the flow and the characteristics of the effluent to be treated.

The hydraulic detention time can also vary depending on the organic load to be removed and the degree of treatment required. Some of the benefits of aerobic ponds include the efficient removal of organic matter and nutrients. In addition, they offer the possibility of treating effluents of high organic load and the ability to adapt to different temperature and flow conditions.

However, these systems may have higher construction and maintenance costs compared to simpler systems such as anaerobic ponds (VON SPERLING, 2014).

Nutrient removal can be understood based on the nitrogen and phosphorus cycle. According to Ternus (2007), in the ammonification stage, the bacteria convert the nitrogenous organic compounds present in the effluent into ammonia (NH_3) and ammonium ions (NH_4^+). The nitrifying bacteria then convert the ammonium ion to nitrite (NO_2^-) and then to nitrate (NO_3^-) in the nitrification step. In the denitrification step, bacteria use nitrate as a source of oxygen to oxidize organic compounds and produce nitrogen (N_2) gas, which is released into the atmosphere. Thus, the aerobic pond completes the nitrogen cycle by removing nitrogenous compounds from the effluent.

Von Sperling (2005) addresses that the phosphorus cycle in ponds is a process that involves the transfer of phosphorus from the liquid medium to the solids present at the bottom of the ponds, where it is adsorbed and stored. It can be later removed from the system by extracting biological sludge from the ponds.

The removal of phosphorus from the ponds can be carried out through biological processes, such as absorption by microorganisms and can be increased through the aeration of the ponds, favoring the growth of phosphorus-absorbing beings.

Von Sperling (2014) highlights the importance of phosphorus removal for the protection of receiving water bodies.

Since excess phosphorus can cause eutrophication which is the excessive enrichment of nutrients in a body of water, leading to an increase in algae reproduction and a reduction in the amount of dissolved oxygen available.

Therefore, the phosphorus cycle in ponds can be influenced by several factors, such as the presence of microorganisms, aeration, type of effluent and removal processes.

In addition, the process of degradation of organic matter in these systems depends on several factors, including the carbon/nitrogen (C/N) ratio of the effluent.

The C/N ratio is important because it affects the microbial growth rate and therefore the efficiency of the treatment process. A proper C/N ratio can increase the efficiency of organic matter removal, while an inadequate ratio can lead to problems such as the release of unpleasant-smelling gases.

The ideal C/N ratio for stabilization ponds is generally considered to be in the range of 20:1 to 30:1. However, this can vary depending on the specific conditions of the system, such as temperature, pH, and effluent load (VON SPERLING, 2005).

Secondary treatment may involve a variety of combined processes, such as anaerobic, aerobic, facultative ponds, and biological filters, which are selected based on the specific characteristics of the effluent to be treated. These processes are complementary to each other (TCHOBANOGLOUS; BURTON; STENSEL, 2014).

2.1.2.1 Other types of anaerobic treatment systems

According to Von Sperling (2005), anaerobic biological treatment systems are used to treat sewage and other liquid effluents, through biological processes that occur in the absence of oxygen. These systems can be classified into several types, among which the following stand out:

a. Upstream anaerobic reactors (UASB): are reactors with upward flow of wastewater, in which biomass is retained at the bottom of the reactor by means of a blanket of sludge, which acts as a filter. This system is indicated to treat sewage with a high organic load, and can be combined with other biological processes to remove nutrients such as nitrogen and phosphorus.
b. Upflow anaerobic reactors and sludge blanket (UASB + anaerobic filter): This system combines the UASB reactor with an anaerobic filter, which removes the remaining organic matter and other compounds such as sulfate and nitrate.
c. Compartmentalized anaerobic reactor (RAC): is a system that divides the reactor into compartments, to control the different stages of the decomposition of organic matter and increase the efficiency of the process. The RAC is indicated for sewage treatment with high organic load and nutrients.

It should be noted that the higher associated space-time yield contributes considerably to the economic viability of anaerobic treatment plants (TRITT; Schuchardt, 1992). Thus, the combination of anaerobic systems is a potential alternative to conventional methods in order to satisfy current effluent discharge standards (BUSTILLO-LECOMPTE *et al*., 2014).

2.1.2.2 Other types of aerobic treatment systems

According to Von Sperling (2005), aerobic biological treatment systems are used to treat liquid effluents through biological processes that occur in the presence of oxygen. Some types of systems stand out:

a. Activated sludge: these are systems that use a reactor with continuous aeration to allow the growth of microorganisms that consume the organic matter present in the sewage. The system consists of an aeration chamber and a secondary decanter for sludge separation.
b. Aerobic biofilm: is a system that uses a support medium (such as plastic material) to allow microorganisms to form a layer adhered to the surface. Air is inflated at the base of the reactor to maintain aeration and the treatment process. This system is indicated for effluents with a high organic load and can be used as a pre-treatment for other treatment systems.

c. Aerated membrane systems: is a system that combines aeration and membranes to separate the treated effluent from the activated sludge. This system is suitable for effluents with high organic load and suspended solids.

As seen, in aerobic systems, aerobic bacteria are responsible for removing organic materials in the presence of oxygen. The treatment time and the amount of oxygen required suddenly increase as the organic load of the effluent from the slaughterhouse increases.

The aerobic treatment is usually used for final decontamination and removal of nutrients after the use of physicochemical or anaerobic techniques (CHERNICHARO, 2006).

2.1.3 Tertiary Treatment

Although, the removal of organic matter and nutrients can be efficient in primary and secondary treatments.

Treated effluents from slaughterhouses usually need to undergo a tertiary treatment in order to meet the quality standards necessary to be discharged into water bodies or be reused in the production process of the slaughter industry.

This additional step is necessary to ensure that the effluent complies with the environmental standards in force (BUSTILLO-LECOMPTE; MEHRVAR, 2015).

According to Von Sperling (2005), polishing ponds are used in the tertiary wastewater treatment process to more completely remove nutrients, heavy metals and other contaminants.

This may be necessary in situations where water quality standards are more stringent, such as in areas where treated water is reused for agricultural, industrial purposes, or even as a source of drinking water.

In addition, in some cases, polishing ponds can be followed by additional treatment processes. Such as filtration in sand, membranes or disinfection with chlorine, ozone or ultraviolet, ensuring that the treated water meets the required quality standards.

It is important to emphasize that the use of polishing ponds as a tertiary process depends on local conditions, the type of effluent to be treated and the specific regulatory requirements of each region.

The most widely used tertiary treatment technologies today are membrane separation processes and advanced oxidative processes (AOP).

These processes are employed as post-treatment after conventional treatment of effluents, with the aim of removing refractory and recalcitrant compounds, such as organic microcontaminants and pathogens, which are not completely removed by traditional processes (MORAES, 2010).

One of the most common AOPs is heterogeneous photocatalysis, which is a chemical process that uses the energy of light to accelerate oxidation or reduction reactions in a solid catalyst. This process occurs on the surface of the catalyst, which absorbs light and promotes electrons from the valence band to the conduction band.

Forming pairs of electrons and electronic gaps that have oxidizing character and produce unpaired radicals that react with the compounds present in the solution, promoting the oxidation or reduction of these compounds. Titanium dioxide (TiO_2) is the most common catalyst used in heterogeneous photocatalysis, which is a semiconductor material that has photocatalytic properties when exposed to ultraviolet (UV) light. When UV light is absorbed by TiO_2, it generates electron pairs and electronic gaps, which can react with water or oxygen molecules to produce highly oxidizing free radicals, such as the hydroxyl radical (-OH) (MORAES, 2010).

Another AOP studied for the treatment of dairy effluents is the photo-fenton process, which also aims to remove organic compounds and reduce the chemical oxygen demand (COD). The process is based on the addition of hydrogen peroxide and iron to the effluent and exposure to ultraviolet (UV) light, which generates highly oxidizing free radicals, such as the hydroxyl radical (-OH), which can oxidize the organic compounds present in the solution. Da Silva and Dias (2019) conducted bench-scale experiments, evaluating the influence of operational parameters, such as hydrogen peroxide concentration and the molar relationship between peroxide and iron, on process efficiency.

Finally, Garcia *et al*. (2018) evaluated the efficiency of UV/H_2O_2 application in the removal of organic compounds present in effluents from textile industries. The process was carried out in a batch reactor, with the addition of hydrogen peroxide (H_2O_2) and exposure to ultraviolet (UV) radiation.

The operating dynamics consisted of the variation of the concentration of H_2O_2 and the time of exposure to UV radiation, in order to evaluate the influence of these parameters on the efficiency of the process of removal of organic compounds.

The results obtained indicated that the UV/H_2O_2 process presented high efficiency in the removal of organic compounds present in effluents from slaughterhouses. The average removal of organic matter was 93%, indicating that the process can be a viable alternative for the treatment of effluents from slaughterhouses.

In addition, the authors observed that the concentration of H_2O_2 and the time of exposure to UV radiation had a significant influence on the efficiency of the process. The application of the UV/H_2O_2 technique can be an effective and promising alternative for the removal of organic compounds in industrial effluents.

The selection of a treatment system depends mainly on the characteristics of the effluent to be treated, as well as the quality standards necessary to comply with the regulations in force, under different political jurisdictions, for the release or reuse of this effluent (PACHECO, 2008).

2.1.4 Legislation for Effluent Emission

In Brazil, there are guidelines that regulate environmental management, such as the standards for the discharge of effluents into water bodies and the quality standards of these water bodies.

They are established by CONAMA Resolution No. 357 of 2005, which classifies the types of water in Brazil (fresh, brackish and saline) according to their quality and use.

The resolution is also directly related to the complementary resolution CONAMA No. 430 of 2011, which establishes the standards for the discharge of effluent.

It is important that both standards are met simultaneously, that is, both the effluent and the quality of the water body which will receive the effluent, to ensure the preservation and quality of water bodies (BRAZIL, 2005; BRAZIL, 2011).

Two situations deserve to be highlighted according to CONAMA Resolutions No. 357/2005 and 430/2011. In the first, when the receiving body has a good dilution and assimilation capacity, the effluent may not meet the release standards established by law, but it can still be accepted by the receiving body without causing damage to the environment. In this case, the environmental agency may grant an authorization for the discharge of the effluent, with specific conditions and limits of quantity and quality.

In the second situation, when the receiving body has a poor dilution and assimilation capacity, the effluent must meet the quality standards of the receiving body, which are stricter than the release standards established by law. This is because, if the effluent is released in these conditions, it can cause serious environmental impacts and harm aquatic life, in addition to compromising public health (BRASIL, 2005; BRAZIL, 2011).

It is important to highlight that national legislation does not always establish the only effluent discharge standards to be followed, since each state and municipality of the federation may have its own laws regarding environmental management.

Thus, these laws can be stricter than the national ones, defining specific parameters for the discharge of effluents that are not contemplated in CONAMA resolution 357/2005. In this sense, state and municipal laws should be considered as a reference to ensure that local standards are met and environmental preservation is effective (VON SPERLING, 2005).

For the state of Paraná, there are two other current legislations, one linked to the Water and Land Institute (IAT) of the state and the other to a technical standard established by the Paraná Sanitation Company (Sanepar).

The CEMA 70 technical standard is specific for the release of effluents into Sanepar's sewage collection networks, which establishes quality criteria and specific procedures for the release of effluents into these networks based on the industry segment, such as maximum permissible values of pH, temperature, turbidity, among others (SANEPAR, 2002).

Resolution No. 40/2013 of the IAT establishes the quality standards and conditions required for the release of liquid effluents into surface and underground water bodies in the state, limiting maximum concentration values for various substances present in the effluents.

In addition to requiring monitoring of the quality of the effluents released, procedures for the licensing and supervision of the activities that generate effluents.

Therefore, each of these standards applies to a specific type of effluent discharge establishing different criteria and requirements.

It is important that companies and enterprises that carry out the release of effluents in the state of Paraná know and meet the specific standards applicable to their situation, in order to ensure compliance with legal requirements and the preservation of the environment (PARANÁ, 2013).

2.1.5 Criteria for the Establishment of a Treatment System

Industrial effluents present significant variations in their quantitative and qualitative characteristics. What makes it important to perform preliminary and primary treatments to contain the presence of coarse solids amenable to grating and suspended solids susceptible to sedimentation, as well as insoluble material such as fats or chemically stable suspended particles that can cause turbidity and require physicochemical processes for removal (DEZOTTI, 2008).

In relation to biological treatment, it is essential to consider some criteria such as the biodegradability of the effluent, the treatability, the concentration of biodegradable organic matter (BOD), the availability of nutrients (balance between C:N:P) and the toxicity of the wastewater.

The presence of toxic compounds or inhibitors that may make biological treatment unfeasible should be considered (VON SPERLING, 2014).

In this context, it is essential to obtain specific data of the enterprise, related to water consumption and the generation of effluents. Parameters such as the total water consumption and the volume consumed in each step of the process, internal recirculations, the origin of the water (public supply, wells, etc.), the possible presence of an internal water treatment plant (WTP), the production of dumps, the total flow (per day or per month), the number of launch points (with the process step associated with each point), are required, the release regime (continuous or intermittent, duration and frequency) of each launch point, the emission points (collector network, watercourse) and the eventual mixing of effluents with domestic sewage and rainwater (VON SPERLING, 2014).

According to the authors Moraes Pinto *et al* (2015) and Cremonini, Nedel and Higarishi (2018), the raw effluent of a slaughterhouse can present several problems due to the large amount of organic matter present in the waste, as well as the presence of chemical substances such as fatty acids, proteins, ammonium salts, chlorides and other compounds. The main problems are:

a. Organic load: the effluent can present a high concentration of organic matter, mainly from the blood, feces and fat of the slaughtered animals. High concentration of suspended solids: the presence of solid particles in suspension in the effluent can cause clogging problems in pipes and equipment, in addition to contributing to the obstruction of irrigation channels and siltation of water bodies.
b. Nutrients: The effluent can contain high concentrations of nutrients, such as nitrogen and phosphorus, from the feces and urine of animals. Presence of pathogens: The effluent may contain pathogens that pose risks to human and animal health, such as bacteria, viruses, and parasites.
c. pH: the effluent may have a high pH, due to the presence of alkaline substances, such as sodium hydroxide used in the cleaning of equipment.
d. Temperature: the effluent may present high temperature, due to the heating of the water used in the process of cleaning the equipment and in the slaughter of the animals.

Therefore, for the establishment of an effluent treatment system it is necessary to evaluate the quantitative and qualitative characteristics of the effluent, through analysis of the quality parameters, as well as the predicted characteristics of the receiving body that will receive it.

For this it is necessary to analyze which are the contaminants that should be removed and the level of removal necessary for the framing of the effluent in the legislation of release into water bodies or reuse.

However, in view of these needs, the processes and the area available for treatment should be analyzed. Finally, one should choose a technology that is economically and technically feasible (VON SPERLING, 2014).

3 METHODOLOGIES

3.1 DESCRIPTION OF THE PRODUCTION PROCESS, RECOGNITION AND COLLECTION OF THE OBJECT OF STUDY

The study was developed in three stages: visit to the slaughterhouse, collection and characterization of the effluent, as well as study of suggestions for improvements in the treatment system of the slaughterhouse, which are described in the following sections.

First, a technical visit was made to a slaughterhouse located in the city of Paiçandu (PR), highway PR 323, km 3, lot 348A/1-1 (-23.45°, -52.01°), in order to know the entire process of generation and treatment of effluents of the same, from the slaughter of the animals to the discharge of the effluent treated in the Ribeirão Paiçandu. To this end, the visit was guided by the engineer responsible for the treatment of effluents of the company and by the veterinarian responsible for the quality sector.

After a visit to the cattle slaughter sector and the effluent treatment plant, the tailings from the mixture of the red and green lines were collected in duplicate in the morning.

On the red line, we have water with blood, which comes out of the washing of the parts of the animal after skinning. In the green line, we have the water containing manure and rumen, coming from the bushing and triparia.

For sample collection, a 5 L beaker was used, which was positioned directly at the end of the effluent discharge pipe in the first treatment pond (anaerobic).

Two samples were collected at different times, and the temperature of the samples collected at both times was measured. Then, the collections were stored in two plastic gallons of 5 L and taken to the Laboratory of Management, Control and Environmental Preservation (LGCPA) of the State University of Maringá (UEM).

The samples were mixed and homogenized prior to storage. The conservation of the effluent until its complete characterization was done under refrigeration at 4ºC, following the recommendations of *the Standard Methods for the Examination of Water and Wastewater* (APHA, 1998).

3.2 METHODS USED TO CHARACTERIZE THE EFFLUENT

The physicochemical analyses performed for the characterization of the effluent were: temperature *(in loco*), pH, alkalinity, apparent color, true color, turbidity, chemical oxygen demand (COD), biochemical oxygen demand after five days (BOD5), total Kjeldahl nitrogen (NTK), total ammonia nitrogen (NAT), nitrite (N-NO2-) and nitrate (N-NO3-), total solids (TSS), total suspended solids (TSS), total dissolved solids (TDS), total fixed solids (STF), total volatile solids (STV), fixed suspended solids (SSF) and volatile suspended solids (SSV). The analytical techniques and equipment that were used throughout the analyses are specified in Table 1.

3.3 ESTABLISHMENT OF SUGGESTIONS FOR EFFLUENT TREATMENT AND IMPROVEMENTS

In order to establish a proposal for treatment and improvement in the treatment system already existing in the slaughterhouse, bibliographic research was carried out, as presented in Section 2.

Based on the knowledge about effluent treatment, characteristics and quality standards of the same. CONAMA Resolutions No. 357/2005, 430/2011 and CEMA No. 70/2009, Annex VI, were used.

Frame 1- Analytical techniques for characterization of the effluent of the red line of beef slaughterhouse.

Parameter	**Unit**	**Analytical Technique**	**Method**	**Reference**	**Equipment**
Temperature	°C	Termomêtria	Method 2500	APHA, 1998	Thermometer
pH	-	Potenciometria	Method 4500-H+ B	APHA, 1998	pH-meter Digimed model DM/20
Alkalinity	mg $CaCO_3$ $^{L-1}$	Titulometria	Method 2320B	APHA, 1998	
Apparent color	mg PtCo $^{L-1}$	Platinum-cobalt method (λ = 455 nm)	Method 8025	HACH, 1996	HACH spectrophotometer, model DR-2010
True color	mg PtCo $^{L-1}$	Platinum-cobalt method (λ = 455 nm)	Method 8025	HACH, 1996	HACH spectrophotometer, model DR-2010
Turbidity	NTU	Nephelometric method	Method 2130 B	APHA, 1998	Digimed Turbidimeter, model DM-TU
DQO	mg O_3 $^{L-1}$	Colorimetria	Method 5220 D	APHA, 1998	HACH spectrophotometer, model DR-2010
DBO5	mg O_3 $^{L-1}$	Respirometria	Method 5210 D	APHA, 1998	BODTrakTM II HACH
Nitrite	mg N-NO_3-$^{L-1}$	Reduction with ferrous sulfate	Method 8153	HACH, 1996	HACH spectrophotometer, model DR-2010
Nitrate	mg N-NO_3-$^{L-1}$	Cadmium reduction	Method 8039	HACH, 1996	HACH Spectrophotometer, model DR-2011
NTK	mg N-NTK L^{-1}	Digestion in blocks	Adapted from Method 4500-NorgD	APHA, 1998	-
NAT	mg N-NH_4+ L^{-1}	Acidimetric distillation and titration	Methods 4500-NH3 C	APHA, 1998	Multiparameter meter Thermo Scientific,model Orion Star 4
Phosphorus	mg P $^{L-1}$ mg PO_4^{3-} $^{L-1}$ mg P_2O_5 $^{L-1}$	Digestion by persulfate acid	Method 8190 and Method 4500 I	HACH, 2007	HACH spectrophotometer, model DR 2800
Series of solids	mg $^{L-1}$	Gravimetry	Method 5520C and 2540E	APHA, 1998	Greenhouse Quimis,model Q-317B112

Note: APHA = *American Public Health Association*; ABNT = Brazilian Association of Technical Standards.; HACH = *Hach Company*

4 RESULTS AND DISCUSSION

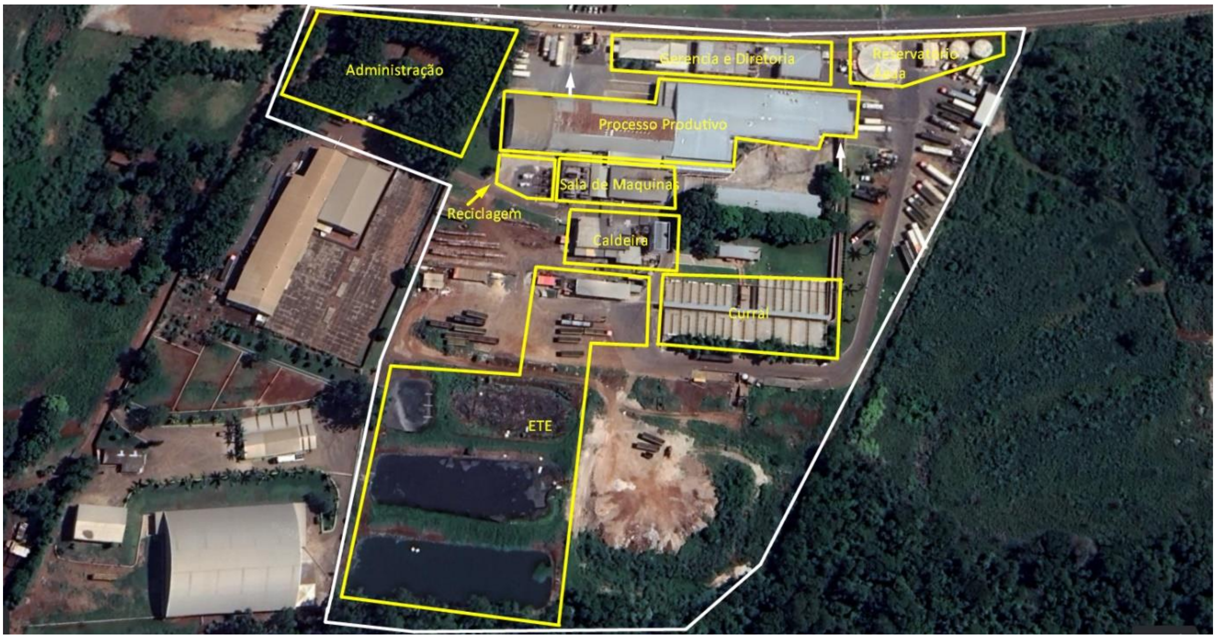
In the sections that follow are presented the results and discussion of each of the stages developed in the work.

4.1 IDENTIFICATION OF THE STUDY AREA

The place of study of this work is in the city of Paiçandu (PR). The slaughterhouse plant has a maximum daily slaughter capacity of 800 cattle, with a daily average of 300 to 500 animals. The production process requires around 1800 liters of water for each cattle slaughtered. The generation of effluent is proportional to the number of animals slaughtered on the day; therefore, the estimated average of daily effluent generation is around 7 to 8 L $^{s-1}$.

To have a better dimension of the slaughterhouse, Figure 2 presents an image with a superior view, showing each section of the slaughterhouse.

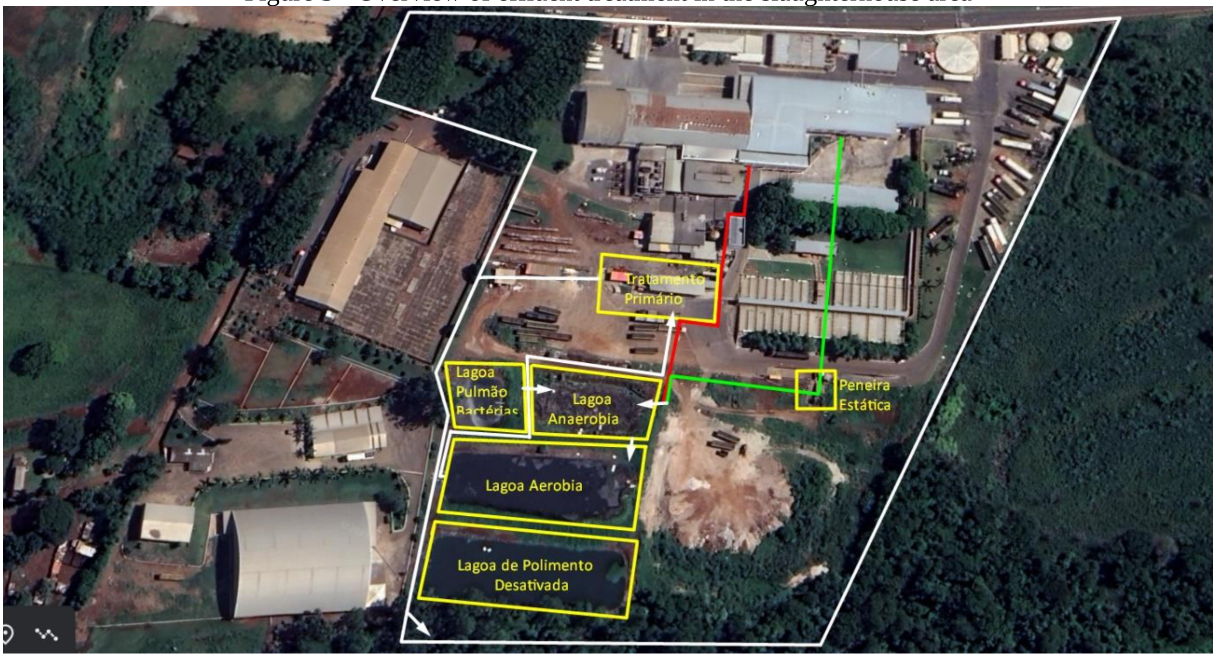
Figure 2 - Overview of the slaughterhouse.



Source: Authors (2023).

Complementing the previous image, with the arrivals of the green and red lines in the WWTP, Figure 3 presents an image specifying each section of effluent treatment in the refrigeration area.

Figure 3 - Overview of effluent treatment in the slaughterhouse area



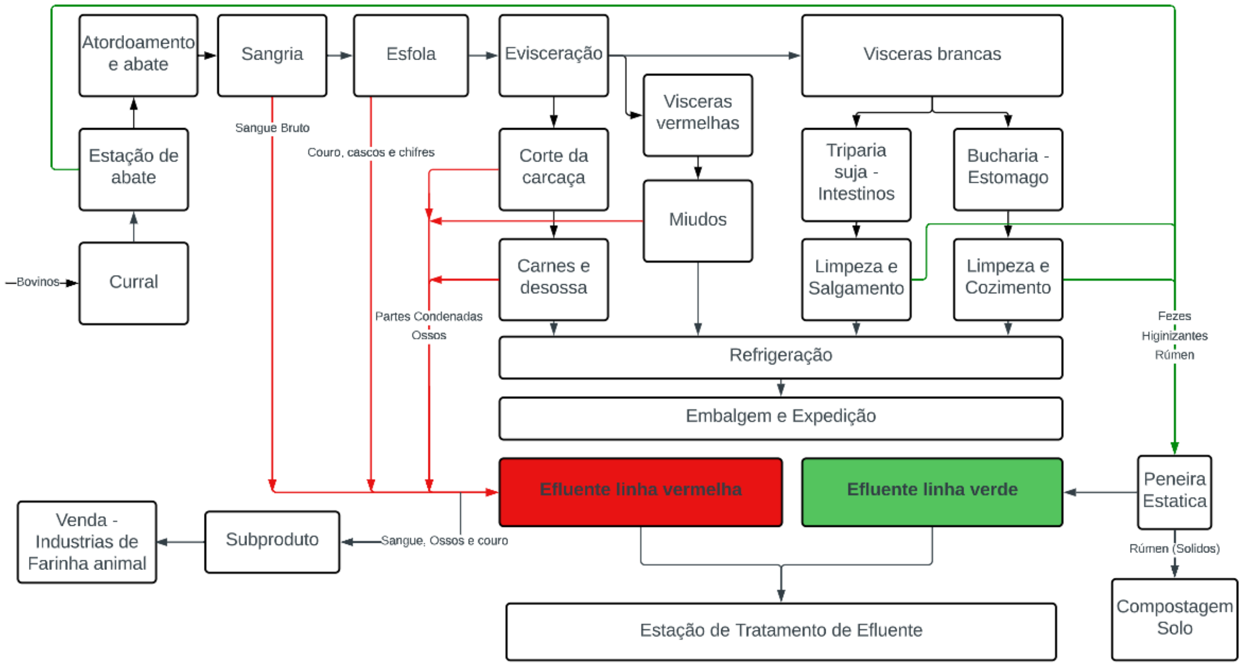
Source: Authors (2023).

4.2 IDENTIFICATION OF THE PRODUCTION PROCESS OF THE SLAUGHTERHOUSE

The production process of the slaughterhouse can be seen in Figure 4. The slaughter process begins in the corral by bathing the animals with disinfectant and leaving them fasting for 24 hours to clean the gastrointestinal tract. Then they are sent to the slaughter room where they are stunned, so that they do not suffer, they are hoisted by one leg, beheaded and transported in the same position over a vomiting channel (bleeding), so that all the blood is collected and stored in tanks for later sale to the animal feed industries.

After bleeding, the cattle go to the production chain in which several strategic cuts are made for skinning, a step responsible for removing all the leather from the animal, followed by the removal of hooves, horns, head and termite. After that, there is a strict protocol to verify possible contamination of the meats, if it is found, the carcass is selected for subsequent disposal following the current protocols. If the carcass of the cattle passes all the sanitary requirements to follow in the production chain, the evisceration process begins in which the carcass is sawn in half and all internal organs are removed, which also have sanitary protocols to confirm the viability of production.

Figure 4 - Flowchart of the slaughter process



Source: Authors (2023).

Subsequently, the production chain is divided into three sectors, the cutting and boning sector, the red viscera sector and the white viscera sector.

The section of cuts and boning gives rise to cuts of meat, while the section of red viscera gives rise to the offal, that is, heart, lung, liver, tongue and other viscera.

The last stage, that of white viscera, gives rise to the production of stomachs and intestines of cattle. Especially in the latter, the stomachs are sent to part of the bushing and the intestines to the dirty triparia, in which they are cleaned and subsequently undergo a process of cooking and salting, respectively.

After all the processes reported, the products of each section are separated, refrigerated, packed and sent to stock for later shipment. In addition, in order to optimize profits, the slaughterhouse separates the blood, bones and leather and disposes of them for sale to the animal feed industries.

4.3 IDENTIFICATION OF THE EFFLUENT TREATMENT PROCESS OF THE SLAUGHTERHOUSE

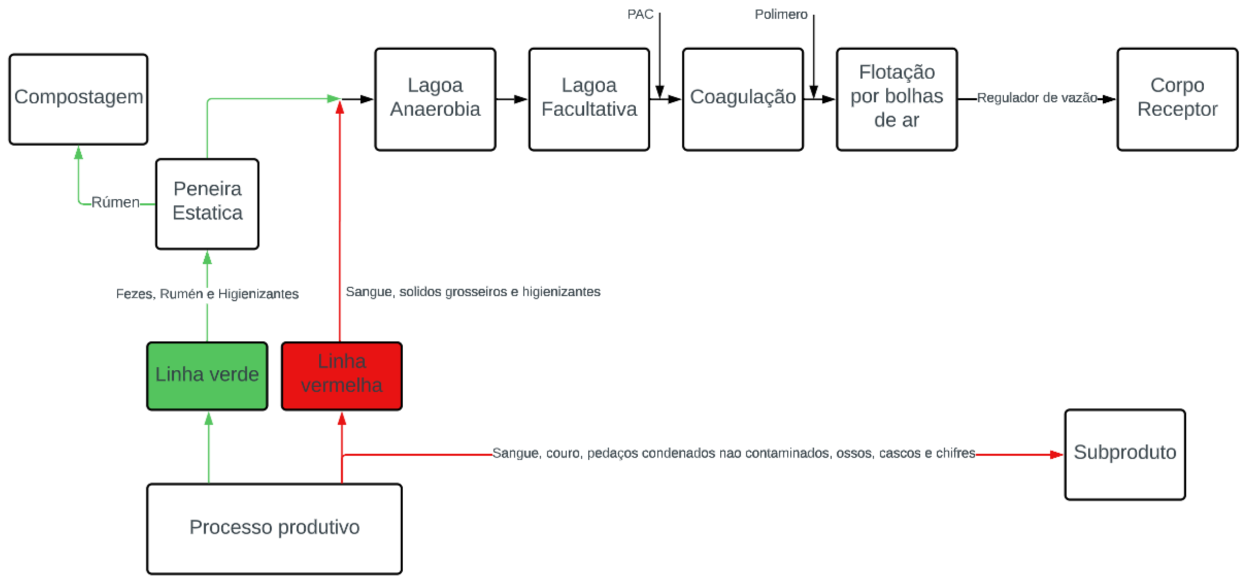
The effluents generated are divided into red line and green line. In the red line all the effluents derived are collected, mainly from the process of bleeding, skinning, red viscera and carcass cuts, being an effluent very rich in blood, meat remains and beef tallow. In the green line, in turn, the effluent generated from the processes of white viscera is collected. In this section we use a static sieve responsible for separating the raw effluent from suspended solids that contain high biological value such as feces and rumen (stomach contents of the bovine bush). The rumen separated in the static sieve in the green effluent line is destined for disposal in soil, serving as natural fertilizer.

The effluent lines come together in a mixing box becoming a single line, which is then dumped into the anaerobic pond that has a residence time of approximately three days. Then, the effluent is sent to an optional pond that has a hydraulic detention time of approximately 20 days.

The effluent lines come together in a mixing box becoming a single line, which is then dumped into the anaerobic pond that has a residence time of approximately three days. Then, the effluent is sent to an optional pond that has a hydraulic detention time of approximately 20 days.

Subsequently, the waste is sent for physicochemical treatment. Firstly, by going through a coagulation process, by addition of aluminum polychloride and lastly, by the flotation step, to which a coagulating polymer is added. The flotator has the aid of dissolved air bubbles, to then be forwarded to the receiving body Ribeirão Paiçandu river. Figure 5 shows the flowchart of the slaughterhouse WWTP.

Figure 5 - Flowchart of the slaughterhouse WWTP



Source: Authors (2023).

4.4 CHARACTERIZATION OF THE EFFLUENT

To perform the characterization of the effluent, two samples (duplicate) were collected at different times (half-hour interval) in September 2022. Both samples were mixed and homogenized prior to physicochemical characterization. All analyses were performed in triplicate. The results obtained are shown in Table 1.

Table 1 - Physicochemical characteristics of beef slaughterhouse effluent collected in September 2022

Parameter	**Unit**	**Average of analyses**	**Sample**			**Release Limit**
			A	**B**	**C**	
Temperature	°C	32	32	32	32	< 40 °Cb
pH	-	7,4	7,4	7,4	7,4	5,0 – 9,0 [b]
Alkalinity	mg $CaCO_3$ L^{-1}	552,7 ± 10,2	545,4	545,4	567,2	-
Apparent color	mg PtCo $^{L-1}$	13875	13875	13875	13875	-
True color	mg PtCo $^{L-1}$	1344	1344	1344	1344	75 [a]
Turbidity	NTU	1760	1760	1760	1760	100 [a]
DQO	mg O^2 $^{L-1}$	4174,6 ± 40,0	4230,7	4139,6	4153,6	-
DBO5	mg O^2 $^{L-1}$	1260 ± 134,3	1205	1445	1130	5,0 [a]
DQO/DBO5		3,35 ± 0,3	3,511	2,865	3,676	-
Nitrite	mg N-NO^2 L^{-1}	20	20	20	-	1,0 [a]
Nitrate	mg N-NO^3 L^{-1}	62 ± 4,0	58	66	-	10,0 [a]
NTK	mg N-NTK L^{-1}	856,1 ± 65,3	943,4	786,2	838,6	-
NAT	mg N-NH_4^+ L^{-1}	0	0	0	-	20 [b]
P total	mg P L^{-1}	36,5 ± 0,5	37,0	36,0	-	0,05 [b]
Total phosphate	mg PO_4^{3-} $^{L-1}$	112,5 ± 0,5	113,0	112,0	-	-
Ortofosfato total	mg P_2O_5 $^{L-1}$	84,5 ± 0,5	85,0	84,0	-	-
ST	mg $^{L-1}$	2419,3 ± 115,5	2496,0	2256,0	2506,0	-
STV	mg $^{L-1}$	2016,7 ± 106,5	2104,0	1866,0	2080,0	-
STF	mg $^{L-1}$	402 ± 16,5	392,0	390,0	426,0	-
SST	mg $^{L-1}$	295,2 ± 13,2	290,2	282,0	313,3	-
SSV	mg $^{L-1}$	246 ± 10,9	244,7	233,2	260,0	-
SSF	mg $^{L-1}$	49,2 ± 3,2	45,6	48,7	53,3	-
TSP	mg $^{L-1}$	2124,2 ± 106,3	2205,8	1974,0	2192,8	500 [a]

Note: (a) CONAMA Resolution 357/2005 (BRAZIL, 2005); (b) CONAMA Resolution 430/2011 (BRAZIL, 2011); (c) Resolution CEMA 70/2009, Annex VI (PARANÁ, 2009).

Table 2 - Parameters found in the literature for effluent from beef slaughterhouse.

Parameter	Range of values	Unit
pH	4,9-8,1	-
Turbidity	200-300	NTU
DQO	500-15900	mg O_2 $^{L-1}$
DBO5	150-4635	mg O_2 $^{L-1}$
NTK	50-841	mg N-NTK. L^{-1}
P total	25-200	mg P L^{-1}
Total phosphate	20-100	mg $PO_4^{3-\ L-1}$
SST	270-6400	mg $^{L-1}$

Source: Bustillo-Lecompte *et al.* (2014).

4.5 ANALYSIS OF THE PHYSICO-CHEMICAL CHARACTERISTICS OF THE EFFLUENT

4.5.1 pH

The pH interferes in all chemical and biochemical reactions, as well as influences aquatic life. Low pH values make water corrosive. In contrast, waters with high pH tend to form scales in the pipes, as exposed by Dezotti (2008).

For the effluent analyzed (Table 1), the verified pH value is close to neutral, but slightly basic (7.4), which corroborates the values found in the literature for bovine slaughter effluents (Table 2).

This value can also be justified by the majority contribution of bovine blood in the effluent, which, according to Gianesella et al. (2010) and Salles et al. (2012), has an average pH of 7.4 as well. In addition, based on CONAMA Resolution 430/2011, for the discharge of effluent into water bodies, the pH value is already within the release limit.

4.5.2 Alkalinity

Alkalinity is caused by alkaline salts, mainly sodium and calcium. This parameter measures the ability of water to neutralize acids. The main constituents of alkalinity are carbonate (CO_3^{-2}), bicarbonate (HCO^{3-}) and hydroxide (OH-) ions, as exposed by Andrade and Macêdo (1994). The found value of alkalinity (552.7 mg $CaCO_3$ L^{-1}) can be explained, according to Ziara (2018), by the addition of organic acids and cleaning chemicals. Also, according to Von Sperling (2014), alkalinity is an important determination in the control of water treatment, being related to coagulation, hardness reduction and prevention of corrosion in pipes.

Thus, alkalinity can interfere with biological treatment in several ways, including inhibition of microbial activity, pH imbalance, reduced effectiveness of nitrification and denitrification processes, among other factors. In wastewater treatment systems, careful control of alkalinity is important to ensure the stability and efficiency of the biological process (CHERNICHARO, 2007; GRADY et al. 2011).

Some studies indicate that the average values of alkalinity in raw effluents from cattle slaughterhouses may be in the range of 560-680 mg/L of calcium carbonate (CaCO3) (MADEIRA *et al.*, 2022). Therefore, knowing that the average of values found for the alkalinity of the effluent studied was 552.7 mg/L of CaCO3, it can be affirmed that they are values within the standards, and can be explained due to the detergents from the cleaning of the slaughter and green line processes.

4.5.3 Color

According to Von Sperling (2014), often the color can come from metals such as iron or manganese, from the decomposition of organic matter in water, or even from the presence of dissolved solids in the aqueous matrix. The constituents that generate the color in the effluent, when of natural origin, in general, do not present health risks. On the other hand, when they come from industrial processes, they may or may not present toxicity, as exposed by Branco (1978). Many factors can influence the color of the effluent, for example, the amount of water used throughout the process and the previous system of treatment of the effluent before the point of collection, which increase or decrease the amount of waste in the raw effluent.

While the apparent color is the reading of the color of the effluent, with the presence of suspended solids and turbidity in the aqueous medium, the true color, performed only after filtration of the sample in a 0.45 µm membrane, concerns the actual color of the effluent.

Since the sample collected presented apparent and true color concentration of 13875 and 1344 mg. L^{-1}, respectively. It is possible to infer that, although the effluent does indeed have a high color (reddish brown), the effluent also had a high contribution of turbidity and solids, which was confirmed by the analysis of these parameters.

Thus, it is understood that the true color of the effluent has a majority contribution of the large portion of blood that makes up the effluent.

The results also show that the suspended portion accounted for in the apparent color comes from sebum and small solid particles, such as micro pieces of meat or rumen, since the effluent collected was the mixture of green and red lines.

Based on CONAMA Resolution 357/2005, for the discharge of effluent into water bodies, the limit value for true color is 75 mg PtCo/L. The value obtained from the sample collected was 1344 mg PtCo/L, a high value compared to the limit, so a good flocculation/coagulation treatment will be necessary in order to reduce this parameter to fit it within the allowed.

4.5.4 Turbidity

Turbidity is the condition of water with excessive number of suspended particles. The presence of these particles affects the propagation of light through water and, in this way, causes a lack of transparency in the water resource, which is essential to living organisms. According to Dezotti (2008), the main causes of turbidity in an effluent are: presence of solid material in suspension (such as silt, clay, silica), finely divided organic and inorganic material (which may be associated with a colloidal material of dimensions from 10-6 to 10-3 mm), microorganisms and algae.

Compared to the values obtained in the literature and presented in Table 2, the raw effluent analyzed has high turbidity values (1760 NTU), thus, some factors that contribute to these turbidity values can be indicated. The first would be the presence of organic matter in suspension, since the processing of meats in slaughterhouses can generate a large amount of organic waste, such as fat and protein.

According to Spellman (2013), the presence of fat in carcass washing water can significantly increase turbidity levels. Another factor would be microbiological contamination, as one of the main factors that contribute to high turbidity values in slaughterhouse effluents. In addition, the presence of solid particles of animal origin also contributes to turbidity in effluents from slaughterhouses (ECKENFELDER *et al*., 2009).

According to CONAMA Resolution 357/2005, for the discharge of effluent into water bodies, the limit value for turbidity is 100 NTU, the result obtained through the sample collected was well above that stipulated by the resolution. As well as to reduce the apparent color values of the effluent, the coagulation/flocculation treatment must be satisfactory, if the treatment is not sufficient, a sand filtration treatment can be added prior to this step.

4.5.5 Chemical Oxygen Demand (COD) and Biochemical Oxygen Demand (BOD)

According to Legner (2019), several sources contribute to the organic loads in wastewater from slaughterhouses including manure, bushing materials, blood, fats, proteins, and organic acids used in antimicrobial interventions. The average values of BOD5 and COD in a raw effluent of beef slaughterhouse can vary widely, depending on several factors, such as the slaughter process, the amount of water used in the washing of equipment and facilities, the volume of blood and other solid waste present in the effluent, among other factors (DEZOTTI, 2008; VON SPERLING, 2014).

Comparing the values obtained with the values suggested in the literature (Table 2), for COD there are high values (4174.6 mg O_2 $L^{-1)}$ although below the limit found in the literature (15900 mg O_2 $L^{-1).}$ The same goes for the value of BOD5 (1260 mg O_2 L^{-1}) that was within the range found in the literature ($^{150\text{-}4635\ mg\ O2}$ L^{-1}). It is important to emphasize that effluents with high concentrations of organic matter should be treated prior to release into receiving bodies so as not to cause a drop in dissolved oxygen in the waters, in order to avoid the death of the aquatic biota.

According to CEMA Resolution 70/2009, for the discharge of effluent into water bodies, the limit values for COD and BOD5 are 200 mg/L and 60 mg/L, respectively. From the samples collected, there are mean values of 4174.6 mg/L for COD and 1260 mg/L for BOD, so the values obtained are far from the limits established by the resolution. In order to frame the effluent according to the mentioned resolution, a satisfactory physico-chemical process will be necessary, which may be a coagulation/flocculation, then a biological process, which may be a stabilization pond or activated sludge. If these treatments are insufficient, an advanced treatment could be added, including an ultrafiltration membrane or an advanced oxidative process (AOP).

4.5.6 COD/BOD ratio

The COD/BOD ratio provides indications on the biodegradability of an effluent. According to Dezotti (2008) and Von Sperling (2014), values in the range of 1.5 to 2.5 suggest that the pollutants present in the effluent are mostly biodegradable, being indicated in these cases, biological treatments for removal of organic matter. Values higher than 5.0 suggest the presence of non-biodegradable pollutants, and for these cases physicochemical treatment is indicated for the removal of recalcitrant organic matter. For the effluent studied, the COD/BOD ratio obtained was 3.35. This value indicates that, although the effluent is partially constituted by biodegradable organic matter and can be removed by secondary (biological) treatment, it also presents recalcitrant organic matter that, in order to be removed, requires a tertiary physico-chemical treatment.

4.5.7 Total Nitrogen

Total nitrogen includes organic nitrogen, ammonia, nitrite, and nitrate. It is an indispensable nutrient for the development of microorganisms in biological treatment, as portrayed by Von Sperling (2014).

4.5.7.1 Total Kjedahl Nitrogen (Organic Nitrogen and NAT)

According to Von Sperling (2014), organic nitrogen and ammonia comprise the so-called Kjeldahl total nitrogen (NTK). While NTK is the nitrogen found in the form of proteins, amino acids, and urea, total ammonia nitrogen (NAT) corresponds to the nitrogen produced in the first stage of organic nitrogen decomposition. The literature (Table 2) indicates that the range of NTK ranges from 50 to 841 mg NTK L^{-1} and the result obtained for the collected effluent was 851 mg N-NTK L^{-1}.

This value can be explained due to the large amount of organic nitrogen that the effluent has, since it is derived from animal meat, which has a high number of amino acids and nitrogen. Regarding total ammonia nitrogen (NAT), all the analyses performed showed that there is no NAT in the collected effluent, soon admitted as zero in the analyses.

As justification for this value, a large portion of organic nitrogen had not been degraded and the portion degraded to NAT had already undergone nitrification process, being transformed into nitrite and nitrate, in this respective order.

4.5.7.2 Nitrite and Nitrate

The nitrogen present in nitrite and nitrate correspond to the intermediate and final products of ammonia oxidation, respectively, according to Von Sperling (2014). The analyses performed in duplicate with the collected effluent demonstrate an average of 20 mg $N\text{-}NO^{2-}$ L-1 and 62 mg N-NO3-. L-1 indicating that the effluent was already in the process of natural degradation.

Some factors may be responsible for increasing the amounts of nitrite and nitrate in the effluent. For example, the presence of organic residues, which can provide substrate for nitrifying bacteria, the use of chemicals containing nitrate and nitrite, which are common in meat preservation processes. Finally, the lack of proper treatment of the effluent generated may allow nitrogen compounds to accumulate in the effluent (VON SPERLING, 2014; DEZOTTI, 2008).

Based on CONAMA Resolution 357/2005, for the discharge of effluent into water bodies, the limit values of nitrite and nitrate are 1.0 mg/L and 10.0 mg/L, respectively. Thus, it will be necessary to use efficient treatments in order to achieve the parameters defined by the resolution.

Physicochemical treatments such as coagulation/flocculation followed by biological processes such as nitrification and denitrification by means of bacteria are used. If the limit values are not yet reached, more advanced methods such as membrane systems may be employed.

4.5.8 Total Phosphorus

According to Dezotti (2008) and Von Sperling (2014), phosphorus is found in water in the forms of orthophosphate, polyphosphate and organic phosphorus being an indispensable nutrient in biological treatment. According to Dezotti (2008), phosphate is an important nutrient for microbial growth, being one of the main limiting nutrients in the biological treatment of effluents. However, in excess the concentration of phosphate can cause overpopulation of microorganisms, leading to excess sludge and loss of treatment efficiency.

Von Sperling (2018) states that in effluents from slaughterhouses, the presence of phosphates may be a limiting factor for the nitrification process that is responsible for the conversion of ammonia into nitrate. This is because, at high concentrations, phosphate can compete with ammonia for fixation sites in microorganisms, thereby reducing the nitrification rate.

In addition, Dezotti (2008) points out that excess phosphate can favor the growth of algae and other forms of aquatic life, causing eutrophication problems in water bodies receiving treated effluents.

Therefore, it is important to control the concentration of phosphate in the treatment of effluents from slaughterhouses to ensure the efficiency of the process and avoid environmental problems.

Based on the literature (Table 2), it can be stated that the values obtained in the analyses indicate that the phosphorus present is in accordance with the expected standards for the raw effluent, since the limit proposed in the reference suggests that it is from 25 to 200 mg P $^{L-1}$. The results obtained indicate that the average total phosphorus is 36.5 mg P $^{L-1}$.

According to CONAMA Resolution 430/2011, for the discharge of effluent into water bodies, the limit value for phosphorus concentration is 0.05 mg/L. Thus, it will be necessary to use efficient treatments in order to achieve the parameters defined by the resolution.

Physico-chemical treatments such as precipitation or flotation followed by biological processes such as activated sludge, biological filters or anaerobic reactors are used.

4.5.8.1 Phosphate and Orthophosphates

Phosphorus derivatives occur, in raw wastewater, in the form of soluble polyphosphates or, after hydrolysis, in the form of orthophosphates, according to Von Sperling (2014). In addition to being a natural source, such as blood, phosphorus and its derivatives are also present in detergent agents that are used to sanitize the boots and hands of employees, who enter the clean areas of the slaughterhouse.

According to Dezotti (2008), the presence of phosphate in effluents can affect the efficiency of biological treatment processes due to its ability to limit microbial growth. This occurs because phosphate is an essential nutrient for the growth of microorganisms, but the excess can cause the selection of microorganisms that are not effective in removing pollutants.

Von Sperling (2014) points out that the presence of orthophosphate in effluents can cause fouling problems in treatment systems due to the formation of calcium and magnesium phosphates, which can be deposited in equipment and pipes. These deposits can reduce treatment efficiency, increase energy consumption, and affect equipment life.

The analyses performed indicate that the average of the values obtained, of 112.5 mg PO_4^{3-} L^{-1}, are above the limits that the literature suggests, from 20 to 100 mg $PO_4^{3-\ L-1}$, which may indicate the use of detergents used in the cleaning processes dissolved in the collected effluent.

4.5.9 Total Solids (TS)

The total solids in a slaughterhouse effluent are the sum of all solids present in the effluent, including suspended solids, dissolved solids, and volatile solids. These solids can be composed of proteins, fats, sugars, minerals and other components (TCHOBANOGLOUS *et al*. 2003). According to Mittal (2004), several sources contribute to the concentration of solids in the effluent of slaughterhouses, including bushing materials, solids stuck to the skins of animals, fats and proteins from livestock processing operations. The values of total solids in a beef slaughterhouse effluent can vary depending on several factors, such as the size of the plant, the production process and the technology used in the treatment of effluents.

Some studies provide a general idea of the mean values found. A study conducted in meat-packing plants in Quebec and Ontario found total solids values ranging from 2244 mg/L to 5748 mg/L (MASSÉ, L.; MASSÉ, D.I, 2000). Another study, conducted at a beef processing plant in Ontario, found average total solids values of 15694 mg/L in the plant's effluent (MITTAL; WU, 2012). Thus, it can be stated that the amounts of solids found in the raw effluent are within the standards expected for a slaughterhouse.

4.5.9.1 Total Volatile Solids (STV)

Total volatile solids refer to the portion of total solids that is lost after calcination of the sample for 2 hours in the muffle at 550°C. This parameter presents an estimate of the organic matter in the solids. The values of total volatile solids in a beef slaughterhouse effluent before treatment can vary widely, depending on the characteristics of the effluent and the management and treatment practices used by the slaughterhouse.

According to a study by Massé *et al*. (2000) in slaughterhouses located in Quebec and Ontario, the values of total volatile solids in samples of raw effluents ranged between 1204 mg/L and 4458 mg/L. Thus, the amounts of total volatile solids found in the raw effluent are in accordance with the standards expected for a slaughterhouse.

In addition, the results show that most of the total solids are composed of volatile solids (approximately 83%). Therefore, most solids come from organic matter.

4.5.9.2 Total Fixed Solids (STF)

The portion of the total solids that does not volatilize after calcination process, that is, what remains, are the fixed total solids.

The values of fixed total solids in a beef slaughterhouse effluent can vary significantly depending on the production process and the type of effluent treatment adopted by the industry.

A study by Massé *et al*. (2000) evaluated the quality of effluent generated by slaughterhouses in Quebec and Ontario, and found a concentration of STF in the range of 594 to 1887 mg/L.

Therefore, values of fixed total solids were obtained below the values found in the literature, this can be explained by the size of the operation and the static sieve on the green line. In addition, the values obtained are relatively low compared to total solids (approximately 17%), which may indicate that a small part of the solids come from inorganic matter, such as salts and bones.

4.5.10 Total Suspended Solids (TSS)

Portion of the total solids that is retained in a filter that provides the retention of particles of diameter greater than or equal to 1.2 μm. Also called non-filterable waste (PIVELI, 2013). The values of total suspended solids in a raw effluent of a beef slaughterhouse can vary according to several factors, such as the size of the slaughterhouse, the type of meat processing and the efficiency of the effluent treatment system.

The average values of total suspended solids in a raw effluent from a beef slaughterhouse may vary depending on the type of operation of the slaughterhouse and the wastewater treatment processes used. However, according to a study by Massé *et al*. (2000), the values of total suspended solids in a raw effluent from a slaughterhouse were found in the range of 736 to 2099 mg/L.

Thus, the values obtained are low compared to those obtained in the literature. The use of the static sieve, in the green line, retaining much of the suspended solids, may be the explanation of the large number of organic solids and low number of inorganic solids, as previously presented.

4.5.10.1 Volatile Suspended Solids (SSV)

After filtering the effluent and drying the filter for 12 hours in the greenhouse, the filter goes to the muffle for 2 hours, also for calcination. The mass lost after this period is the volatile suspended solids. The average values of volatile suspended solids (SSV) in raw effluents of beef slaughterhouses can vary widely, depending on a number of factors, such as the size of the operation, the production process, the degree of effluent treatment and the quality of the raw material.

A study conducted by Massé et al. (2000) evaluated the quality of the effluent generated by slaughterhouses in Quebec and Ontario, finding a concentration of SSV in the range of 594 to 1887 mg/L. Therefore, the amounts of SSV obtained are below the values found in the literature, which can be explained by the size of the daily operation of the slaughterhouse. As expected, the results obtained are analogous to those of total solids, about 83% are volatile solids, which defines the large amount of organic matter in the effluent.

4.5.10.2 Fixed Suspended Solids (SSF)

After passing through the greenhouse, the filter is calcined for 2 hours in the muffle at 550 °C, and what remains are the fixed suspended solids. The values of fixed suspended solids in crude effluents from cattle slaughterhouses can vary significantly depending on several factors, such as the type of meat processing and the effectiveness of effluent treatment. A study by de Massé *et al*. (2000) in slaughterhouses in Quebec and Ontario found values of fixed suspended solids in the range of 156 to 282 mg/L.

Thus, the amounts of SSF found are below the values found in the literature, which can be explained by the static sieve used in the green line. And as expected, the results obtained are analogous to those of the total fixed solids, confirming that little part of the suspended solids come from inorganic matter.

4.5.11 Total Dissolved Solids (TDS)

The total dissolved solids (TDS) of an effluent refers to the total amount of solids that are suspended and dissolved in water, so it is the result of the mathematical difference between the total solids and the total suspended solids. Based on CONAMA Resolution 430/2011, the effluent discharge into water bodies has a limit value for the concentration of dissolved solids of 500 mg/L.

The average value of the samples collected was 2124.2 mg/L. For this, an efficient treatment system is necessary in order to lower the concentration of solids to fit the effluent within the limit established by the resolution. A pre-treatment system may be used, e.g., sand filter or static sieve, followed by a physico-chemical process such as coagulation.

4.6 PROPOSED IMPROVEMENTS IN THE TREATMENT SYSTEM

Based on the results obtained in the analysis of the samples collected in the slaughterhouse, it was identified that most of the inorganic and organic parameters presented high concentrations. These values are above the release standards, but according to the expected for this class of effluent, according to the data presented in the literary references.

It was verified both visually and through the analysis of the physical parameters of TS and TSS that the effluent collected at the site presented the presence of suspended solids, which consisted of residues of bushing of the green line (rumen that was not retained in the static sieve) and pieces of meat, tallow or fat from the cutting sectors of the red line. It is important to note that there is no physical separation of these wastes before they are mixed with the green line.

In view of this, as a first (preliminary) step it is proposed to keep the static sieve at the exit of the green line of the factory for the separation of the rumen intended for disposal on the ground. However, it is suggested to increase the retention area of the sieve and decrease the opening of the grid to improve the separation of the solid material.

Then, after the green and red line effluent mixing box, the raw effluent must first undergo a preliminary treatment for retention of the solids of the red line composed of a rotary sieve. These preliminary steps are intended not only to considerably remove the number of coarse solids, but also the fat suspended in the effluent. In addition, this will contribute to the decrease of SST, NTK, DBO and COD.

After that, the effluent must undergo a primary coagulation/flotation treatment. This phase is important to remove suspended and/or floating solids, which were not removed efficiently in the preliminary treatment. Coagulation is done by the continuous and rapid addition of coagulant, which aims to perform the physicochemical destabilization of colloidal particles, present in aqueous medium. This process happens from the neutralization of the surface loads that keep them separated from each other and in suspension. This allows the matter to coalesce on the surface, facilitating the formation of flakes in the flotation step.

The subsequent step to the coagulation process is flotation, which aims at the agglomeration of particles in the previous step in order to produce larger conglomerates. Unlike the previous phase, flotation requires a low current speed to prevent the breakage of the flakes formed by the polymer. In addition, this process must be accompanied by an air microbubble generator system to optimize the step. The flakes must be removed by a surface scraping system.

The coagulant/flocculant recommended for use is Tanfloc *SG®* which is an organic and biodegradable polymer (WHITE; ZORZIN, 2016). Although the sludge generated is amenable to biodigestion according to Cruz *et al* (2005), the amount of fat that the effluent presents does not allow this sludge to be biodigested directly. First, one must go through the primary process, the oils and greases tend to be suspended on the surface along with the flotated impurities. Thus, according to Ferreira *et al* (2018), after scraping the surface material, the float should be sent to a sludge storage tank with heating and agitation structure that allows heating the sludge up to 95°C. Then the heated sludge must be routed through pumps to a tridecanter centrifuge. Which will separate by means of rotation, the sludge in three phases: crude oil, clarified and dehydrated sludge.

The crude oil must be piped to an oil packaging tank that will go through a process of decantation of the oil water to later be marketed as a by-product. The clarified returns to the beginning of treatment, as a form of recycling. Dehydrated sludge should be routed to dumpsters and subsequent composting. According to Krebs et al. (2012), heating the oil-water mixture before decantation is a common technique used to improve the efficiency of the separation process.

When the mixture is heated, the density of the oil decreases and its viscosity decreases, which facilitates separation by decantation. In addition, heating can also help reduce the surface tension between oil and water, making it even easier to separate. It is important to note that the ideal temperature for the separation of the mixture can vary depending on several factors, such as the specific composition of the mixture and the amount of oil present. It is necessary to experimentally determine the ideal temperature for each specific case in order to obtain the best separation efficiency.

To remove some of the remaining BOD after primary treatment and allow the removal of nutrients such as nitrogen and phosphorus, it is essential to refer the treated effluent into the flotator for secondary treatment. This process begins in an anaerobic-type stabilization pond. The anoxia unit has a hydraulic detention time of approximately seven days and its main function is the digestion of organic matter, which remains dissolved in the effluent.

After this period, the effluent must be sent to a facultative pond, which has a residence time of approximately three days, in which the facultative bacteria present will digest organic matter in the presence of oxygen as well as in its absence. In the secondary treatment, part of the removed BOD is converted into biomass, which generates a biological sludge that must be removed as needed (VON

SPERLING, 2005). Bathymetry is a method that consists of measuring the depth of water bodies by means of specific equipment, such as sonar. From these measurements, it is possible to calculate the volume of water and sediments accumulated at the bottom of the lagoons (PROSAB, 1999).

According to CONAMA Resolution No. 375/2006, decanted sludge in treatment ponds can be sent for composting. Since the flocculant used to carry out the primary treatment of the effluent is of plant origin and does not generate hazardous waste. Thus, the sludge resulting from the treatment process can be considered as an organic material rich in nutrients, which can be used as fertilizer in agricultural areas or as a component in the production of organic fertilizers.

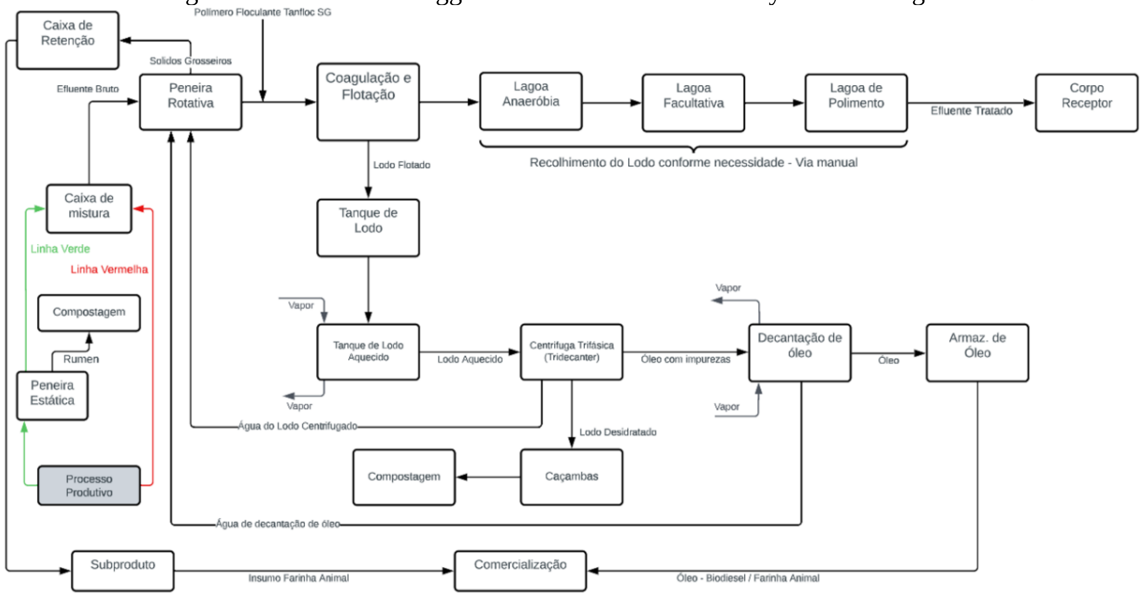
However, it is important to note that before sending the sludge for composting, it is necessary to carry out quality tests to ensure that it does not present high levels of contaminants, such as pathogens and heavy metals, which can harm human health and the environment. In addition, it is essential that the composting process is carried out properly, following the applicable standards and regulations, in order to ensure the safety and efficiency of the process.

Finally, so that the receiving body does not receive wastewater loaded with pathogenic and non-pathogenic microorganisms, such as algae and microalgae. The effluent must undergo a tertiary treatment using polishing ponds, which aims to remove BOD and nutrients remaining in the effluent. In addition, the high exposure to UV radiation and dissolved oxygen favors the cell lysis of microorganisms (VON SPERLING, 2005). It is worth mentioning that the effluent has a high rate of NTK (organic nitrogen + ammonia) that must be assimilated by the algae present in the facultative and polishing ponds. Which have great capacity for photosynthesis, which contributes directly to the assimilation of nitrogen and phosphorus, promoting denitrification and phosphorization.

In addition, as an alternative so that the receiving body does not suffer damage caused by excess algae in the final effluent of the process. It is possible to use intermittent filters of small stones and sand to retain most of the algae. It is important to perform periodic cleaning of the filters to ensure their efficiency in removing impurities, as described in the study by Mara et al. (1992).

Figure 6 shows the flowchart of the proposed treatment system for the effluent studied, which is composed of preliminary, primary, secondary and tertiary treatment. With the application of the same it is believed to be possible to adapt the effluent to the release standards required by the current environmental resolutions.

Figure 6- Flowchart of suggestion of effluent treatment system of slaughterhouse.



Source: Authors (2023)

5 CONCLUSIONS

In this study, the characterization of a raw effluent from bovine slaughterhouse was performed by physicochemical methods. From the results obtained, it can be seen that there are many variations in the values of the parameters, compared to those of the different studies published in the same area.

Therefore, it is important to emphasize that the main aspect for any effluent is in its proper treatment, because regardless of the values obtained from its parameters before treatment, it is essential that the treated effluent is in accordance with the environmental standards in force in the region, for its correct discharge into water bodies. Based on the results obtained in the characterization of the effluent, a treatment system was proposed, which may be efficient for the current structure of the slaughterhouse. According to Rodrigues (2016), the removal efficiency with the use of organic polymer for COD is approximately 68% with a deviation of around 5%. According to Silva Filho (2007), the proposed sequence of ponds shows that they have the capacity to remove 65% to 80% of COD remaining in the effluent, as well as the removal of nitrogen and total phosphorus, making it possible to remove up to 60% of NT and 35% of FT.

In conclusion, the treatment of effluents generated in cattle slaughterhouses is a complex and challenging task, which requires a multidisciplinary approach. The cattle slaughter industry is a critical component of the global economy and it is essential that this segment invests in the development and implementation of effective technologies for the treatment of effluents ensuring a sustainable future for our water resources.

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