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Phytoremediation of industrial effluents using Lemna minor

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ABSTRACT

One of the great challenges for companies in recent years has been to implement sustainability in their industrial processes and thus adapt their production to the quality of the environment, thus avoiding major impacts that can harm nature. In this context, the concept of sustainable industry emerges, which aims to combine economic development with environmental care, preserving the conditions of the planet for future generations.

Keywords: Sustainability, Environmental management, Effluent treatment.

INTRODUCTION

One of the great challenges for companies in recent years has been to implement sustainability in their industrial processes and thus adapt their production to the quality of the environment, thus avoiding major impacts that can harm nature. In this context, the concept of sustainable industry emerges, which aims to combine economic development with environmental care, preserving the conditions of the planet for future generations.

According to MARQUES (2015), environmental management is fundamental for every organization, regardless of its field of activity. This is because the public and the market start to associate the company's name with environmental preservation, which favors its image before customers and competitors. Organizations that encourage the practice of this type of management can absorb several benefits, such as reducing expenses and costs by reducing water and energy waste through the reuse of materials.

According to SILVA (2019), around 1970, the industry seemed to be just a solution to make products cheaper through the mass production of machines, this logic ended up generating a series of unplanned developments, among them, the harmful impacts on the environment; However, if the processes that generate such impacts are recognized, it is possible to implement sustainable development practices.

Industries that use effluents to maintain their production must follow the instructions of the National Council for the Environment (CONAMA), which is the body responsible for regularizing the processes of capture and disposal of liquid waste, in compliance with the provisions of Resolution No.

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430/2011 (BRASIL, 2011). However, the major problem of liquid effluents that are produced during and after industrial processes is the adequacy of environmental parameters. This is a factor that causes excessive costs for industries, considering that traditional effluent treatments are characterized by the use of large quantities and concentrations of chemicals, which can cause enormous environmental impact (AMBIENTAL TERA, 2019).

The effluent generated in the industrialization process of soybean oil has a high concentration of chemical oxygen demand, total and dissolved suspended solids, oils and greases, among other organic components. Therefore, it can cause significant impacts if disposed of in its raw form into the environment (ALTHER, 2008; YANG, 2007). This is the reason for opting for an appropriate treatment system, in which the types and concentration of contaminants present in the effluent can be taken into account, the necessary quality of the effluent after treatment, the flow to be treated, the methods and options that have a cost/benefit analysis. Thus, it is necessary to analyze the production system associated with the treatment system (MORITA, 2022).

In this context, alternative methodologies for decontamination have been highlighted, including phytoremediation, which is characterized by the use of plants for the decontamination of environments impacted by organic or inorganic pollutants (PIRES et al., 2005), such plants can degrade, extract, contain or immobilize contaminants from soils and waters (ROCHA et al., 2000). The success of such a technique depends on the interaction of several physical, chemical and biological processes that occur between the plants and the surrounding environment and which has advantages such as simple applicability, does not require operators with deep qualification, low cost, and simple maintenance (TAVARES, 2013).

Therefore, phytoremediation with aquatic plants becomes an attraction for industrial plants, as it contributes to sustainability in addition to generating financial savings with the treatment of the environment. The processes are different for each contaminant involved, including phytoextraction, phytostabilization, phytovolatilization and phytodegradation; such processes may predominate according to the characteristics of the contaminant (MORITA, 2022).

Lemna minor is a floating aquatic plant that is part of the Araceae family, commonly known as "duckweed" and is found in water bodies around the world. These species are assiduous in lentic ecosystems such as lakes and brackish water bodies, most of which are contingent, are considered the smallest existing vascular plants and reproduce intensely (MEDEIROS, 2017). The use of Lemna minor in wastewater treatment has several advantages over conventional wastewater treatment methods, including low cost, high efficiency, and easy maintenance. However, it is important to note that plant efficiency can be influenced by a number of factors, including temperature, pH, pollutant concentration, and contact time.

Floating macrophytes of the genus Lemna are found in several continental regions with the exception of the Arctic and Antarctica (ALMEIDA, 2018). Divided into five genera and 37 species, they are the smallest angiosperms in the world and show exponential growth, and can, under ideal conditions of temperature and light intensity, double in two days or less (ALMEIDA, 2018).

In addition, this species has excellent adaptability, being tolerant to the stress of these mechanisms. This property is important for the treatment of effluents, removing nutrients and metals (ALMEIDA, 2018). Lemnas minor are monocotyledonous floating plants, composed of one or a few leaves and a single root or radicle without stem, with a length between 2 and 4 mm (EKPERUSI, 2019). It reproduces vegetatively by dividing to form separate individual plants (CORREL, 1972). It aggregates forming colonies in surface waters and its foliage doubling time is about 1.4 days. If grown in the laboratory, it can grow indefinitely if nutrients, light, and water are provided (EKPERUSI, 2019).

It is a species native to Africa, Asia, and Europe, but also found in Australia and South America (APPENROTH et al., 2015). Birds are responsible for their propagation to new sites (EKPERUSI, 2019). Its sporadic distribution and invasive nature, and the ability to reproduce in diverse habitats, have increased its potential to withstand harsh conditions, including polluted and degraded waters (SUKUMARAN, 2013). For this reason, among its various uses, the phytoremediation of various pollutants in aquatic environments, including metals, organic compounds, agricultural, pharmaceutical, and personal care products, nanomaterials, hydrocarbons from oil, and radioactive waste (EKPERUSI, 2019).

According to REGITANO-D'ARCE (2006), soybean oil is universally obtained by solvent extraction, a mixture of paraffinic fractions derived from petroleum refining, known as hexane. During extraction, non-triglyceride substances of non-polar nature are also solubilized by the solvent and drawn into the crude oil. The oil is contained within cell organelles called spherosomes or lipid bodies scattered throughout the endosperm. The bark contains less than 6% oil, which justifies its separation in some industrial plants. For the solvent process to be efficient, the grain goes through a sequence of steps that characterize the preparation. These are operations that aim to reduce the size (breakage) and thickness (lamination) of the grain, in order to expose the oil to the action of the solvent. This is followed by heating (conditioning) to increase the fluidity of the oil contained in the spherosomes, facilitating its dissolution in the solvent.

In Brazil, a complementary preparation process was developed – expansion – which, through the use of extrusion, makes the raw material porous and permeable to the solvent. The extraction takes place "hot", continuously, by immersion or percolation. From the extractor, saturated micelle and wet bran are obtained. Both must be conducted through watertight pipes to equipment in which the solvent will be evaporated, condensed and returned to the process. Desolventized oil is crude oil that, only after degumming, can be marketed or stored until the time of refining.

The effluent generated in the refining process is in the form of an emulsion, oil and water. Chemically stabilized oil droplets, according to Lelinski (1993), behave more like solid particles than physically stabilized ones, due to their high surface charge density and small size. Effluents contaminated with oils when disposed of in natura in rivers and in the sewage network and bring damage to health and the environment, and 1 liter of oil can contaminate about 20 thousand liters of water. The impacts of the discharge of oil effluents into water bodies occur due to the increase in the organic load, consuming the dissolved oxygen of the water and causing the asphyxiation of aquatic life, causing the formation of a floating film hindering gas exchange and oxygenation, soil waterproofing, clogging of storm drains and contaminating groundwater (RODRIGUES, 2019). Due to all these problems that effluents cause to the environment, it is necessary to routinely analyze the destination of effluents to the environment, and new means of treatment studied and developed in favor of environmental sustainability.

The organic matter of water is necessary for heterotrophic beings, in their nutrition, and for autotrophs, as a source of nutrient salts and carbon dioxide. In large quantities, however, they can cause some problems, such as color, odor, turbidity and consumption of dissolved oxygen by decomposing organisms. Oxygen consumption is one of the most serious problems of increasing organic matter content, as it causes ecological imbalances, which can cause the extinction of aerobic organisms. Generally, two indicators of organic matter content in water are used: Biochemical Oxygen Demand (BOD) and Chemical Oxygen Demand (COD) (BRASIL, 2014).

BOD and COD parameters are used to indicate the presence of organic matter in the water. It is known that organic matter is responsible for the main problem of water pollution, which is the reduction in the concentration of dissolved oxygen. This occurs as a consequence of the respiratory activity of the bacteria for the stabilization of organic matter. Therefore, the evaluation of the presence of organic matter in the water can be done by measuring oxygen consumption. These BOD and COD parameters indicate the oxygen consumption or demand necessary to stabilize the organic matter contained in the water sample. This demand is conventionally referred to a period of five days, since the complete stabilization of organic matter requires a longer time, and at a temperature of 20ºC (BRASIL, 2014)

The difference between BOD and COD lies in the type of stabilized organic matter; while BOD refers exclusively to organic matter mineralized by the activity of microorganisms, COD also encompasses the stabilization of organic matter occurring by chemical processes. Therefore, the COD value is always higher than that of BOD. Furthermore, the relationship between COD and BOD values indicates the portion of organic matter that can be stabilized by biological means. Both BOD and COD are expressed in mg $^{L-1}$. The average concentration of BOD – which is, between the two, the most commonly used parameter – in domestic sewage is in the order of 300 mg $^{L-1}$, which indicates that 300 milligrams of oxygen are needed to stabilize, in a period of five days and at 20 ºC, the amount of biodegradable organic matter contained in 1 liter of the sample. Some effluents from industries that process organic matter have BOD values in the order of magnitude of tens or even hundreds of grams per liter. In unpolluted natural environments, the concentration of BOD is low (1 mg $^{L-1}$ to 10 mg $^{L-1}$), and can reach much higher values in water bodies subject to organic pollution, generally resulting from the receipt of domestic sewage or animal husbandry (BRASIL, 2014).

As for acidity and alkalinity, they are extremely important parameters for anaerobic digestion. The volatile fatty acids must be in balance with the alkalinity of the system. Inhibition of the anaerobic process by volatile fatty acids is associated with pH. Low pH values are usually related to high concentrations of volatile fatty acids, and consequently to process failure (Kus and Wismann, 1995). For the vast majority of bacteria, the optimal pH of growth is between 6.5 and 7.5. The maximum and minimum variations, for most of them, are between pH 4 and 9. However, if grown in a medium adjusted to a given pH, it is likely that this pH will change, as a result of the metabolites produced, which can be both acidic and alkaline (Campos et al., 2006).

In anaerobic treatment processes, an attempt is made to accelerate the digestion reactions of organic matter, creating favorable conditions for the growth and maintenance of microorganisms in the reactor (Campos et al., 2005a).

A study conducted by HU (2019), evaluated the ability of Lemna minor to remove organic and inorganic pollutants in an effluent treatment system. The results showed that the plant was able to remove up to 97% of organic matter and 99% of phosphorus from the effluent. In addition, the plant has been shown to be efficient in removing heavy metals such as lead and zinc, with removal efficiency of up to 88% to 96%, respectively.

Another study conducted by Kivaisi (2001) investigated the ability of Lemna minor to remove organic matter from effluents from a paper mill. The results showed that the plant was able to remove up to 88% of organic matter from the effluent. In addition, the plant was also efficient in removing nitrogen and phosphorus, with removal efficiency of up to 98% to 92%, respectively.

Khan et al. (2002) evaluated the ability of Lemna minor to remove pesticides from the effluent of a pesticide plant. The results showed that the plant was able to remove up to 97% of the pesticides present in the effluent.

The ecological study on the cultivation and management of aquatic macrophytes in the treatment of effluents has been increasingly approached by researchers due to the promising results they demonstrate. The insertion of this vegetation helps in the removal of nutrients and presents good efficiency in reducing biochemical oxygen demand and oxygen chemical demand. In addition, this method is very attractive due to the low costs of implementation, operation, and maintenance when compared to other conventional treatment technologies (TIMM, 2015; LEMES et al., 2008).

OBJECTIVE

Considering the above, this article addresses the use of phytoremediation, applying Lemna minor, to control the levels of COD, BOD and pH of effluents of a soybean oil extraction company, thus aiming to align the economy of resources with environmental care.

METHODOLOGY

The investigation of the impact of phytoremediation was carried out in the effluent of the Coopertadição industry, located in the city of Clevelândia, in the State of Paraná. The company has three lagoons, the first of which is characterized as anaerobic, due to the lack of dissolved oxygen in the water. This creates an environment conducive to the growth of anaerobic bacteria, which are able to break down organic matter in wastewater in the absence of oxygen. The second pond is considered a stabilization pond, capable of removing organic matter, suspended solids, nutrients (such as nitrogen and phosphorus) and pathogens (disease-causing microorganisms). And the third maturation pond that is used for final polishing, pathogen removal and improvement of the aesthetic quality of the treated water. They have an inlet flow of 10 to 12 m3 per hour, with a final outlet from the third pond of 8m3 hours.

The treatment through Lemnas occurred with the use of approximately 2kg of the macrophyte lemna in the second lagoon that is characterized by a stabilization lagoon in 2019. As the macrophyte has a high proliferation content, in approximately 2 years, the second and third lagoons were already 100% covered with lemnas, the second lagoon has an area of 4,505 m2 and the third one totaling an area of 1,098 m2.

Normally, to control the COD, BOD and pH levels, the company used the conventional treatment with NaOH and H2SO4, until the physicochemical parameters were maintained according to the normative instructions. Collections were carried out bimonthly in the months of February, May, August and November from the year 2020 from surface water.

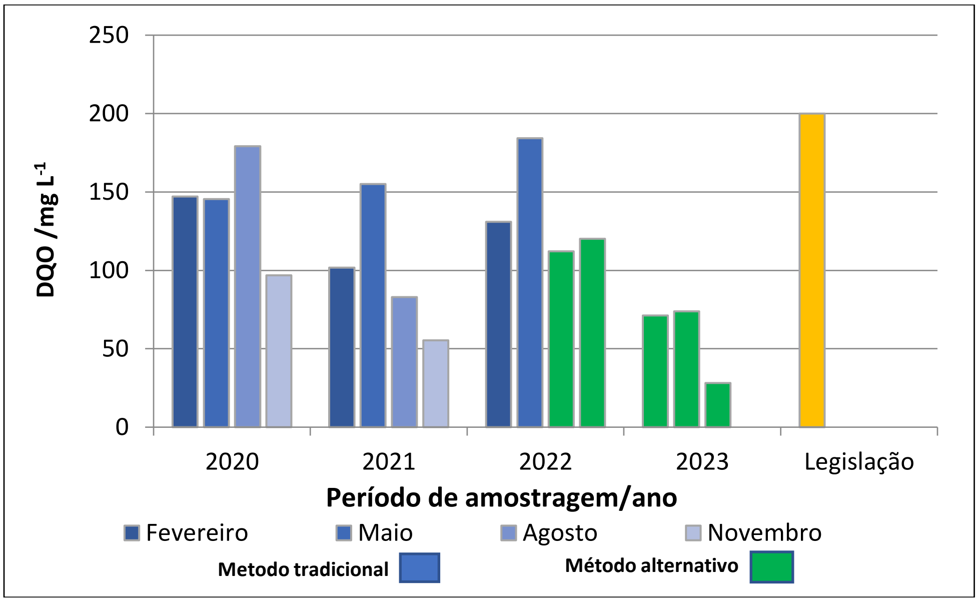
Water pH was determined in situ and COD and BOD were determined in partner laboratories. For COD determination, the technique used was PE FQ 015, for BOD technique used APHA, AWWA, WEF - Standard Methods for the Examination of Water and Wastewater, 23rd ed. 2017.

DEVELOPMENT

Resolution 357/05 of CONAMA (BRASIL, 2005) amended by Resolution No. 430/2011 (BRASIL, 2011) does not refer to COD in the classification of water bodies and in the discharge patterns of liquid effluents, but requests values of the BOD parameter. It is related to the amount of oxygen consumed by microorganisms present in a given sample of an effluent. It is the most used parameter to measure the level of water pollution since these microorganisms perform the decomposition of organic matter in the aquatic environment through oxidative processes, especially by respiration.

Graph 1 shows the levels of COD with traditional treatment and during the phytoremediation process. Until August 2022, COD levels were stabilized using the traditional methodology with the use of chemical agents that assist in the treatment by performing the sedimentation of the activated sludge. It is observed that in all situations the concentrations were lower than 200 mg $^{L-1}$ stipulated by Ordinance 256/2013, which is an extension of Resolution 357/2005 changed to Resolution 430/2011, but always with the aid of chemical reagents. After this period, these products were no longer used, leaving only the action of phytoremediation by lemnas. It is possible to observe that after August 2022, when 100% of the lagoons were covered by macrophytes, it was possible to obtain extremely satisfactory levels, reaching 110 mg $^{L-1}$. However, in 2023 these levels dropped even further, reaching 30 mg $^{L-1}$. Thus, it is proven that the action of phytoremediation using lemnas provided the reduction of organic matter present in the environment.

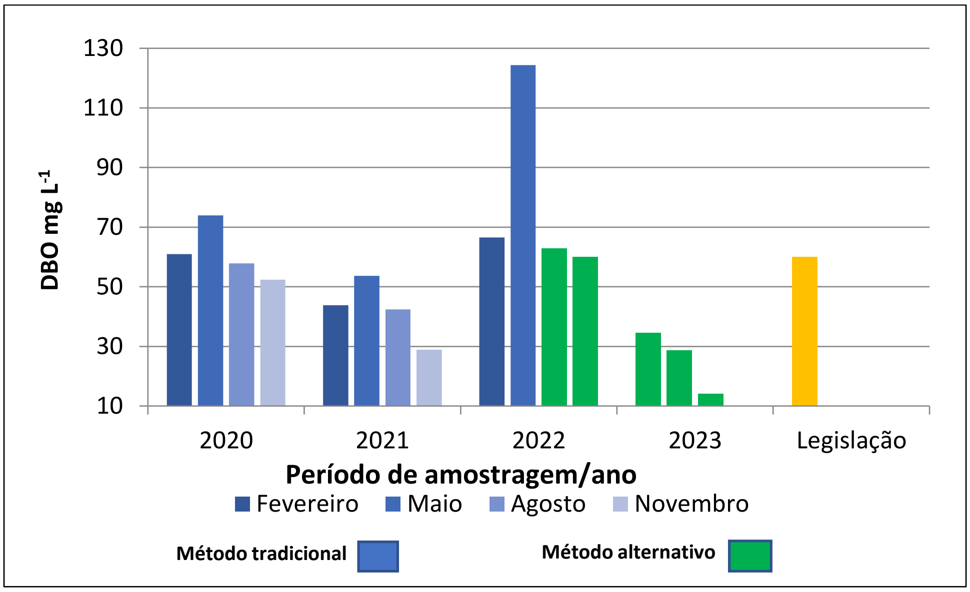
Graph 1. Levels of chemical oxygen demand in soybean oil industry effluent after traditional treatment and during phytoremediation treatment



Graph 2 describes the monitoring of BOD levels before and during the phytoremediation process. Until August 2022, the traditional methodology was used to maintain these levels; with phytoremediation, very satisfactory levels were obtained, perfectly complying with Ordinance 256/2013, which is an extension of Resolution 357/2005 amended to Resolution 430/2011, which stipulates BOD indices lower than 60 mg $^{L-1}$ according to the final flow of effluent discharge into receiving bodies.

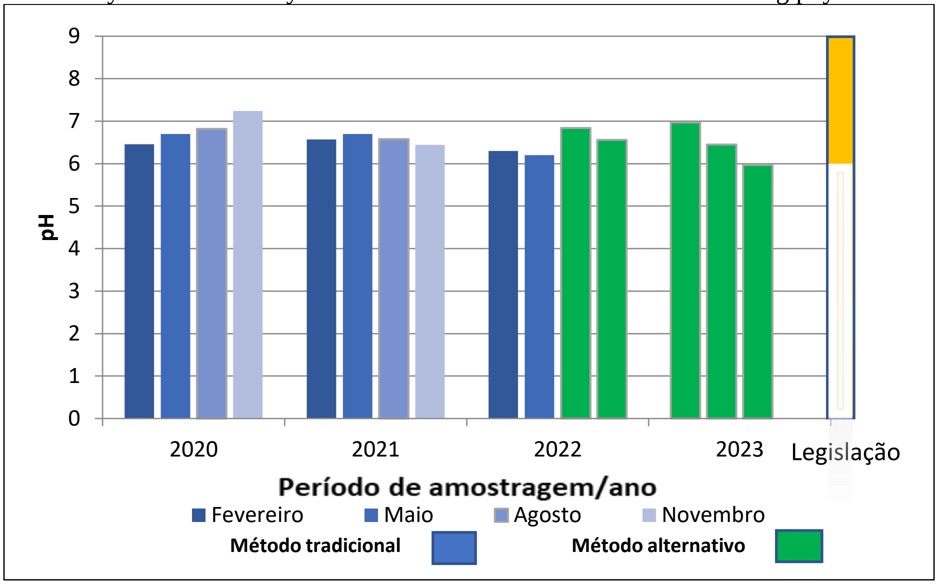
However, in 2023 these levels dropped even further, reaching 14.18 mg $^{L-1}$. The best index in recent years, therefore, it is proven that the action of phytoremediation using lemnas provided the reduction of organic matter present in the environment, considerably improving the quality of effluent treatment.

Graph 2. Levels of biochemical oxygen demand in soybean oil industry effluent after traditional treatment and during phytoremediation treatment



Graph 3 shows the pH levels before and during the phytoremediation process. Chemical agents were used as a way to stabilize pH levels until the year 2022 to comply with resolution No. 430/2011 of the National Council for the Environment (CONAMA), which stipulates pH indices between 6 and 9. With the use of phytoremediation, it was noted that there was a stabilization of pH levels, and the use of chemical agents was no longer necessary.

Graph 3. pH levels in soybean oil industry effluent after traditional treatment and during phytoremediation treatment



Until 2022, the industry treated its effluent through the traditional method with the addition of chemical products, whether biodegradable or non-biodegradable, with an average annual cost in products of R$ 71,736.00 to obtain the decantation of activated sludge. However, this method, in addition to demanding a financial cost for the company due to the acquisition of chemical products, also required an employee to remove the supernadam, this step consists of separating the solid (sludge-liquid) (raw effluent) through the sedimentation of solid particles.

At this stage, the sludge was manually removed from the lagoons and deposited in specific boxes for later collection by a certified company accredited to properly dispose of the waste generated by the lagoons.

However, this disposal process generated a high cost for the company, as disposal was invoiced per m3 collected and this value was stipulated at R$ 500 per m3, so in February 2021 a cost of approximately R$ 90,000 was generated in the disposal of organic waste from the lagoons.

FINAL CONSIDERATIONS

The results obtained from the application of Lemna minor in the treatment of effluents from a soybean oil production industry demonstrated that phytoremediation is capable of removing a large amount of pollutants present in the water, since the COD, BOD and pH levels were maintained within the established by the current legislation without the use of chemical products. Lemmas have a high potential in reducing oxidizable organic matter, so they can, in addition to reducing the pollutant load of organic effluents, and also mitigate the cost of effluent treatments.

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