Briquettes From Sludge in Sewage Treatment Plant: Calorific Power

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Abstract

Due to the large volume of sewage generated every day, there is a high demand for its treatment. The by-product (called sludge) generated after the treatment process has caused problems in terms of its final disposal. Since the typical end off for this waste is landfills, it is mandatory reducing the landfill amount and the risk of soil contamination. The present work explored an adequate final disposal of the sludge as a sustainable alternative. For this purpose, briquettes were produced using dry sludge from the Sewage Treatment Plant of the Minas Gerais (Brazil) Sanitation Company and vegetable oil used to thicken the briquettes. These briquettes were compared to eucalyptus charcoal in terms of their calorific potential, through immediate analysis, since Brazil has a high demand for primary energy, especially in the industrial sphere. The calorific potential of charcoal reached 16.66 MJ/kg, while that of briquette reached 12.94 MJ/kg. However, briquettes had a density much higher than charcoal, so it takes a smaller volume of briquettes to achieve the same burning capacity as a large volume of charcoal.

Keywords: biomass; briquettes; charcoal; sludge; sustainability.

1. Introduction

With the increase in urbanization in the world, the need to conserve natural resources and the environment has become fundamental for people's quality of life. Thus, the treatment of sanitary sewage is worldwide a problem and it is essential to maintain the quality of water in watercourses (Di Iaconi et al. 2010; Khursheed and Kazmi 2011; Qian et al. 2016; Kacprzak et al. 2017; Lazzari 2018). The sewage generated after the consumption of potable water, whether for residential or industrial use, when released in nature into watercourse, causes significant changes in the aquatic environment, affecting chemical, physical and biological characteristics. The damage caused by sewage to water rivers is due to the large presence of organic matter present in the sewage. Thus, the treatment of wastewater has as its main objective to remove organic matter before it is released into watercourses (Di Iaconi et al. 2010; Carrère et al. 2010; Batista 2015).

A by-product generated from sewage treatment, called sewage sludge, has generated problems regarding its final disposal, since it is produced in large quantities and has toxic characteristics (Jamali et al. 2009; He et al. 2010; Fijalkowski et al. 2017). In Brazil, between 150 and 220 thousand tons of dry matter is produced per year.

Currently, the main forms of final disposal of sludge are landfills, incineration, and agricultural use. However, with the large volume generated and the great potential for pollution of sewage sludge, new ways of using the waste have been studied (Okuno et al. 2004; Vieira 2011; Eliche-Quesada et al. 2011; Paris et al. 2016; Geissdoerfer et al. 2017).

The expression "sludge" has been used to describe the tailing generated in the sewage treatment process. However, after biological processes, there is a conversion of part of the organic matter that is absorbed, forming sludge, also known as bio-solid, since it is basically composed of biological solids (Andreoli et al. 2001; Lv et al. 2007; Gueri 2014).

The production and collection of sewage begins in buildings, which can be commercial, residential or industrial, which are the responsibility of the owner. The sewage is conducted to collection systems, which are distinguished by: trunk collector, also known as main collector, receives secondary collectors; the interceptor, which is a network that receives the main collectors and; the emissary, which does not receive any contribution along its route and aims to reach a destination, which may be a lift, final launch or treatment station (COPASA 2022a).

The treatment of sanitary sewage has been increasing due to the population growth, the demand for greater service for the population and the investment in new sewage treatment plants (Pedroza 2010; Kacprzak et al. 2017). Thus, even with the emergence of new treatment technologies, the production of sewage sludge will also increase (Andreoli 2006; Kartal et al. 2010; Carrère et al. 2010; Jing et al. 2012; Gu et al. 2017).

When the sewage arrives at the treatment plant, sequential procedures are carried out to remove the undesirable substances or make them acceptable for use or final disposal. The treatments have four levels, namely: the preliminary, which is a physical process, which removes coarse solids and sand; the primary, also of a physical nature, removing floating and suspended solids, such as oils, greases and part of the organic matter; the secondary, biological, removing nutrients such as nitrogen and phosphorus, and mainly organic matter and, finally; the tertiary, which can be a complement to the secondary or remove specific substances (COPASA 2022b).

The Sanitation Company of Minas Gerais (COPASA) is among the largest sanitation companies in Brazil and is the concessionaire responsible for water supply and sanitary sewage in the city of Montes Claros. Regarding the sewage treatment processes carried out by the company, it is important to know each one of them. Anaerobic Systems is the treatment performed by bacteria that do not require oxygen for respiration, highlighting the Septic Tank, the Anaerobic Filter and the UASB Reactor (Upflow Anaerobic Sludge Blanket). Stabilization Ponds are treatment systems in which the aerobic oxidation or photosynthetic reduction of algae is carried out to stabilize organic matter. Aerobic Reactors with Biofilms, on the other hand, aim to stabilize organic matter by bacteria that develop on a plastic or stone support. It can also be mentioned the disposal in the soil, the surface runoff in the soil, the additive sludge, flotation, ultraviolet and the disposal of the sludge through the generated by-products (COPASA 2022b).

In Brazil, the most common way to dispose of sewage sludge is in landfills. There are two ways to dispose of this waste in landfills: (i) the first is to manage the sewage sludge together with the collection of urban solid waste, and (ii) the second is the construction of a sanitary landfill for the sludge. In most cases, the sludge is disposed of together with urban solid waste (Vieira 2011).

Landfills are considered the cheapest method to dispose of sewage sludge. However, it can cause several problems, such as: leaching, groundwater pollution, soil contamination and methane gas emissions. In addition to the environmental risks involved in disposing of sewage sludge in landfills, it is difficult to find areas to receive new landfills. There is a concern with the useful life of active landfills, since sewage sludge demands a large volume for its management (Silvério 2004; Qian et al. 2016; Kacprzak et al. 2017; Gherghel et al. 2019).

In some sewage treatment plants the incineration process is adopted, wherein the thermal destruction of the waste takes place by exposing the sludge to temperatures higher than 1000 °C. The result of this process is an ash, with reduced volume in relation to sewage sludge. This ash must be disposed of in appropriate landfills and the gases that must be treated, for instance, being used as a source of energy (Massanet-Nicolau et al. 2010; Kargbo 2010; Vieira 2011; Cao and Pawłowski 2012; Pastore et al. 2013; Gong et al. 2014; Cano et al. 2015; Gianico et al. 2015; Carlsson et al. 2016).

In the incineration process, the mass of sewage sludge is reduced by up to 5 times, leaving only fixed solids, called ash. This alternative is used when there are no areas available to handle the waste in landfills or the sludge contamination is very high. However, sludge incineration requires a large amount of energy and is potentially polluting for the atmosphere, therefore, a high investment in filters to retain the toxic gases produced is needed (Andreoli et al. 2001). One of the ways to equate the high investment to incinerate sewage sludge is the possibility of reusing the calorific potential of the sludge generated in the sewage treatment plant (Vieira 2011).

Among the conventional alternatives for the final disposal of sewage sludge, the most economically and environmentally viable is agricultural use, since the sludge is rich in nutrients and organic matter (Andreoli 2006). Besides being an important source of organic matter, when applied to the soil, the sludge provides an increase in productivity, a decrease in the use of fertilizers, increases soil resistance and increases its water retention capacity (Vieira 2011).

However, the presence of heavy metals and pathogenic organisms can make the use of sewage sludge in agriculture unfeasible (Jamali et al. 2009; He et al. 2010; Vieira 2011; Fijalkowski et al. 2017). Depending on the origin of the sewage, the type of treatment and efficiency, the presence of heavy metals and pathogenic organisms can vary from low or non-existent to very high, so it is necessary to evaluate all these aspects for the use of sludge in agriculture (Andreoli et al. 2001).

Due to the high-risk potential shown by the contaminants that can be identified in sewage sludge, the Brazilian National Council for the Environment (CONAMA) has drawn up a resolution governing the use of sewage sludge as fertilizer (Vieira 2011). The Brazilian Resolution No. 375, of August 29, 2006, “defines criteria and procedures for the agricultural use of sewage sludge generated in sanitary sewage treatment stations and its by-products (ABNT)”. The resolution brings aspects related to the quality parameters of the sewage sludge, the characteristics of the application sites, among others.

In addition, another important point to ensure the well-being of the population, availability of natural resources with the quality and quantity needed for future generations, it is necessary to create new renewable energy sources (Di Maria et al. 2016; Geissdoerfer et al. 2017; Gherghel et al. 2019). Since, Brazil has a great challenge about energy issues. During the 20th century there was an intense economic development in Brazil, which was reflected in a greater demand for primary energy, that is, energy from renewable sources (Tolmasquim et al. 2007).

Due to the large volume of sludge produced daily and considering population growth, the traditional way of disposing of this waste will become unfeasible, both environmentally and economically (Kelessidis and Stasinakis 2012). In addition, the large-scale production of industries that demand thermal energy coming mainly from the burning of charcoal causes an increase in illegal deforestation of Brazilian forests. Thus, producing energy with residual biomass from effluent treatment plants is a viable alternative, since there is a large supply of this residue worldwide (Kargbo 2010; Cao and Pawłowski 2012; Manara and Zabaniotou 2012; Pastore et al. 2013; Gong et al. 2014; Cano et al. 2015; Carlsson et al. 2016; Lazzari 2018).

The use of sludge as an alternative energy at low cost is verified in a study carried out with distillery sludge, in which different combinations between sludge and coal were proposed, in the proportions of 25%, 40%, 50% and 75% by weight. The best combination found was 40% sludge with 60% charcoal, with a calorific potential of 4659 kcal/kg (Dhote et al. 2020). Therefore, in addition to promoting low-cost energy, it also reduces the release of this effluent into the environment.

Others recent studies have also evaluated the calorific potential of materials such as chestnut shells (Jiang et al. 2018), residual vegetable oil (Dey et al. 2021) and empty bunches of palm oil (Yan et al. 2019). As the chestnut shells have cellulose, hemicellulose and lignin with low calorific value, a methodology to produce a biochar by catalytic pre-oxidation and pyrolysis with sulfuric acid and urea was proposed. The changes in the structure promoted the production of a high-quality coal with high calorific value (Jiang et al. 2018).

An optimized model that contained a mixture of fuel with residual vegetable oil was compared with diesel. The results showed this mixture has a calorific value and density comparable to diesel, in addition to a cleaner emission during engine operation (Dey et al. 2021).

Therefore, the objective of this study is to explore and contribute for an adequate destination for the sludge as a sustainable alternative, producing and analyzing briquettes, having as raw material the sludge from the sewage treatment plant, to be used as heat sources, totally or partially replacing vegetable coal. At the end of this work, it was hoped to find a viable alternative to dispose of sewage sludge, in addition to increasing the useful life of sanitary landfills, reducing the risk of soil contamination and the use of charcoal in the industrial scope.

2. Material and methods

For the present work, the sludge specimens were collected, as described in the Brazilian standard NBR 10007 – Sampling of solid waste (ABNT 2004), in the sewage treatment station of the Sanitation Company of Minas Gerais (COPASA) which handles all sewage generated in the city of Montes Claros. For the charcoal specimens, eucalyptus charcoal was used. After the production of sewage sludge briquettes and purchase of charcoal, the calorific value of the specimens was calculated, and its bulk density was determined.

2.1. Briquette production

The dry sewage sludge specimens were collected after the thermal drying process (Fig. 1), therefore, the specimens were homogeneous.

Fig. 1. Collection of specimens in the thermal dryer.

Sewage Treatment Station, in Montes Claros, Minas Gerais, performs the dehydration and desiccation of the sludge through thermal drying. The equipment used is a rotating drum that performs mixed drying, which is a combination of direct drying, called convection, and indirect drying, known as conduction (LOBATO 2011).

Direct drying involves the passage of hot air over the sludge (SANIN et al. 2010). The advantage of its use is greater heat exchange, as there is direct contact between the drying medium and the sludge (DAVID 2002). In this study, the rotary dryer has an inclined rotating cylindrical shell, which causes the sludge and drying medium to move to the end of the drum, while the rotation mixes them.

In indirect drying, the dryers do not come into contact with the sludge, causing heat transfer by conduction (DAVID 2002). The main advantage is the low production of dust and almost no air pollution, but it has a lower drying efficiency when compared to direct drying, recommending the use of a combination of both (SANIN et al. 2010).

The liquid sludge is discharged from the Upflow Anaerobic Reactors (UAR), containing a solids content of 3% and dehydrated in a centrifuge, concentrating approximately 25% of solids. After that, it is sent to the thermal dryer, with temperatures of 350°C in a period of 30 minutes, transforming it into a sterilized granular material (COMPANHIA DE SANEAMENTO DE MINAS GERAIS (COPASA) 2011). Briquettes with different proportions of residue/binder were prepared, as shown in Fig. 2, in order to find the best agglutination composition for the briquettes. Wasted vegetable oil was used as a binder.

Fig. 2. On the left, the briquettes on the molding day, and on the right, after drying.

For each individual briquette, 200 g of dry sludge and 30 ml of vegetable oil were mixed. The specimens were placed in cylindrical molds with 100 mm of diameter and 50 mm height and pressed with a compaction hammer, thus the final height being approximately 25 mm. Then, they were unmolded with a specimen extractor and exposed to laboratory conditions for 48 hours (wherein the temperature was about 25 °C and the relative humidity about 60%). Fig. 3 shows the sequence of processes used to obtain sludge briquettes:

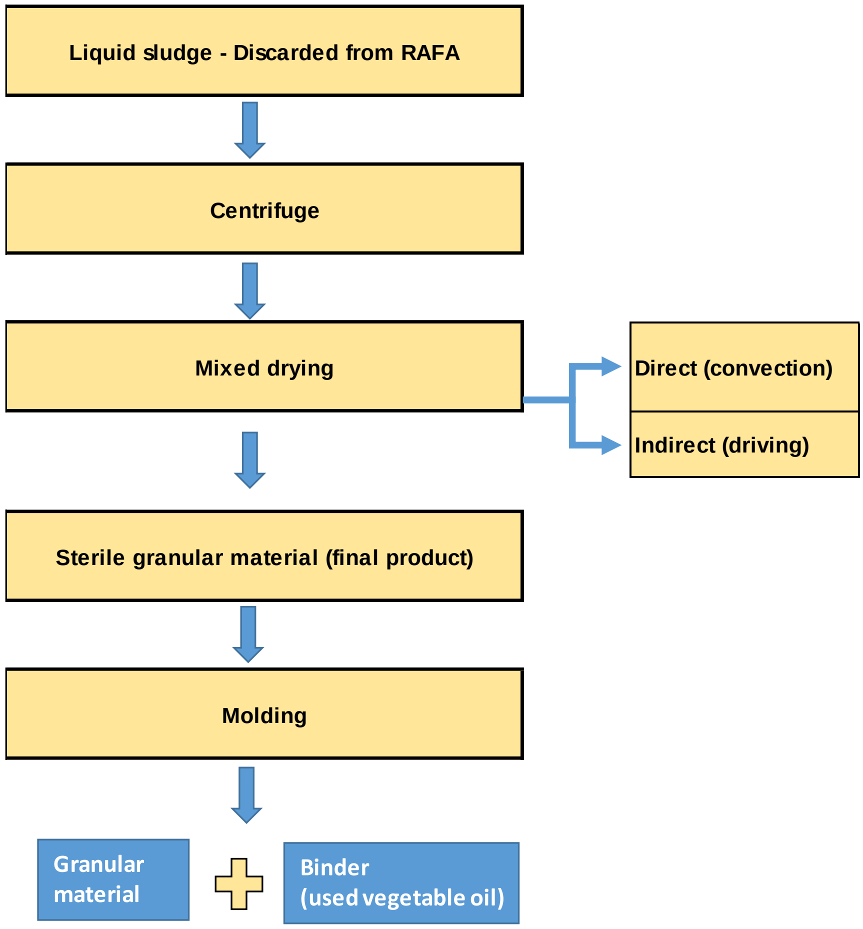

Fig. 3. Sequence of processes used to obtain sludge briquettes.

2.2. Immediate analysis

The sludge analysis was carried out according to the Brazilian standards: NBR 8112 – Charcoal: Immediate analysis (ABNT 1986), SANS 5924 - Moisture content of coal specimens intended for general analysis (Standard 2009) and ISO 562 – Hard coal and coke - Determination of volatile matter (International organization for standardization 2010), which applies to the determination of moisture content, ash, volatile materials, and fixed carbon.

To determine the calorific value, the equation developed in Ref. (Parikh et al. 2005) was used, which correlates the fixed carbon content, the content of volatile materials and the ash content to determine the calorific value in MJ/kg with absolute error of 3.74%.

2.3. Moisture content

According to the Brazilian standards NBR 8112 (ABNT 1986) and SANS 5924 (Standard 2009), the determination of the moisture content was done as follows: between 1 to 2 g of the sludge briquette specimen was collected with the aid of a balance. Then, the sample was taken to an oven previously heated to 105 ºC where it remained for 90 minutes. At the end of the process, the specimens were taken to the desiccator to cool and avoid humidity. After cooling, the final mass was determined. Thus, the moisture content could be determined from Equation 1.

$$\%H = \frac{m1-m2}{m1} \times 100 \quad (1)$$

Where:

%H is the moisture content, in percentage;

m1 is the initial mass of the sample, in grams;

m2 is the final mass of the sample, in grams.

According to the standard, three specimens of each material were analyzed to determine the moisture content.

2.4. Volatile material content

According to NBR 8112 (ABNT 1986) and ISO 562 (International organization for standardization 2010), the percentage of volatile material was determined from previously dried briquette specimens. A dry specimen with ~1 g was taken to a muffle with a maximum temperature of 950 °C following the steps (Table 1):

Table 1. Step-by-step determination of volatile material content (Source: ISO 562, 2010)

Procedure	Time	Temperature (°C)
Crucible at the door	Two minutes	300
Crucible inside the muffle with the door open	Three minutes	500
Crucible inside the muffle with the door closed	Six minutes	950

Therefore, the percentage of volatile material could be determined from Equation 2.

$$VM = \frac{m2-m3}{m2} \times 100 \quad (2)$$

Where:

VM is the percentage of volatile materials;

m2 is the mass of the dry sample before place in the muffle, in grams;

m3 is the mass of the dry sample after cooling, in grams.

According to the standard, three samples of each material were analyzed for the determination of volatile materials.

2.5. Ash content

According to NBR 8112 (ABNT 1986), the determination of the ash content was found by following the steps: ~1 g of a dry specimens was placed in a crucible. The set was placed in a muffle previously heated to 700 ºC and remained for one hour. After this process, the specimen was taken to the desiccator to cool and avoid humidity. After cooling, the final mass of the set was determined.

Thus, the determination of ash content could be determined from Equation 3.

$$AC = \frac{m1-m0}{m} \times 100 \quad (3)$$

Where:

AC is the ash content, in percentage;

m1 is the mass of the set crucible with sample ash after cooling, in grams;

m0 is the mass of the crucible, in grams;

m is the initial dry mass of the sample before place in the muffle, in grams.

According to the standard, three specimens of each material were analyzed to determine the ash content.

2.6. Fixed carbon content

According to NBR 8112 (ABNT 1986) the fixed carbon content was obtained through the difference of Equation 4.

$$FC = 100 - (AC + VM) \tag{4}$$

Where:

FC is the fixed carbon content, in percentage;

AC is the ash content, in percentage;

VM is the volatile materials, in percentage.

2.7. Determination of calorific power

The determination of the calorific value was carried out from the correlation of the immediate analysis developed (Parikh et al. 2005).

$$CP = (0.3536 * FC) + (0.1559 * VM) + (0.0078 * AC) \tag{5}$$

Where:

CP is the calorific power, in megajoule per kilogram;

FC is fixed carbon content, in percentage;

AC is the ash content, in percentage;

VM is the percentage of volatile materials.

2.8. Apparent density

To calculate the bulk density, a balance was used to define the briquette mass. The briquette volume was calculated based on its dimensions with the aid of a caliper. With that, Equation 6 is used to define the bulk density:

$$D = \frac{m}{v} \tag{6}$$

Where:

D is the bulk density, in kilograms per cubic meter;

m is the mass of the briquette, in kilograms;

v is the external volume of the briquette, in cubic meters.

3. Discussion

After molding and visual analyze the briquettes with varying proportions of residue/adhesive, the best consistency was achieved when 200 g dry sludge were mixed with 30 ml of waste vegetable oil. Table 2 shows the results of the immediate analysis applied to the specimens of sludge and charcoal briquettes. The average of the results obtained in the tests in three specimens was considered.

Table 2. Comparison of immediate analysis on specimens.

Specimens	**Moisture (%)**		**Volatile Materials (%)**		**Ash content (%)**		**Fixed Carbon** (%)**
	M_i	Average	VM_i	Average	AC_i	Average	Average
(A) Sludge Briquettes	3.0 3.5 3.9	3.5	57.5 47.8 42.8	49.3	38.3 31.5 40.1	36.6	14.0
(B) Charcoal	2.0 3.4 1.8	2.4	63.1 62.6 54.9	60.2	20.2 -16.8* 19.0	19.6	20.1

* This value was considered an outlier, probably there was an error during recording the initial mass.
** Fixed Carbon was determined using the average values of the volatile materials and the ash content.

As shown in Table 2, the sludge briquette specimens had higher moisture and ash content but lower volatile materials and fixed carbon content than the charcoal. The excess moisture in the biomass reduces the burning capacity, as the calorific value decreases, thus increasing the consumption of matter (Vieira 2011). The fixed carbon content has a direct influence on the calorific value, as the higher the fixed carbon, the greater the material's burning potential (Filho 2013).

Ash is the inorganic material remaining after burning a fuel (Filho 2013). The high concentration of ash reduces the calorific power of the material, since the ash does not participate in combustion (Vieira 2012). After testing the ash content, it was possible to identify that charcoal loses approximately 80% of its mass after burning and that briquettes lose 63%, leaving a considerable volume of inorganic material after burning (Fig. 4).

Fig. 4. On the left, ashes derived from burning specimens of coal. On the right, ashes obtained burning sludge derived briquettes.

Volatile materials are the fraction that vaporizes when the material is heated under certain conditions. Table 3 presents the results of the calorific value and density of the specimens.

Table 3. Comparison of calorific value and bulk density.

Sample	Calorific Value (MJ/kg)	Apparent Density (kg/m³)
(A) Sludge Briquettes	12.9	1157.3
(B) Charcoal	16.7	190.0

To assess the energy potential of a combustible material, the most important property is the calorific power (Filho 2013). Specimens of charcoal and sludge briquettes showed distinct values of calorific power, with the charcoal being 29% greater than that of sludge briquettes. However, the apparent density of specimens from sludge briquettes (when tightly packed) is about six times greater than that of the charcoal. Therefore, in terms of volume storage, sludge briquettes have an advantage when compared with the charcoal.

The calorific value of vegetable oil according to national manufacturers is 34.13 MJ/l (8,125 kcal/l). The density of a refined vegetable oil is 0.918 g/ml, whereas for used oil it is 0.908 g/mL (FROEHNER, S.; LEIRHOLD, J.; LIMA JÚNIOR 2007). Therefore, considering that each sludge briquette was composed by 30 ml (~27.2 g) of used vegetable oil and 200.0 g was sludge (i.e. the mass of the used vegetable oil was 12.0% of total the mass of the briquette) the calorific capacity of a used vegetable oil contributes with almost 35% of the total calorific capacity of the sludge briquette. Consequently, the calorific value of sewage sludge is estimated in 9.58 MJ/kg. This value agrees with the ones found in Durdević et al. (2019), but they are lower than the ones reported in Ostojski (2018) or in Gueri (2014) – wherein it was reported 17.89 MJ/kg for the sludge with 20% moisture.

It is worth mentioning that vegetable oil is widely used in Brazil and around the world. However, its incorrect disposal causes a lower availability of this material for reuse as fuel and as a binder, which is what is proposed in this discussion. The Conama Resolution n°. 362/2005 (CONAMA 2005) prohibits any disposal of used or contaminated oils in soils, subsoils, inland waters. It is important to create adequate policies that favor the efficient collection and disposal of this material.

From the legislative aspect in Brazil, the regulation for the emission of pollutants is the CONAMA 436/2011

(CONAMA 2011) which establishes the emission limits of waste by type of pollutant and type of source, according to its annexes present. The environmental inspection and licensing agency must consider the local conditions of the polluting source and its area of influence, determining emission limits and air quality management, if necessary. There is no current resolution for briquettes with sewage sludge, however, Annex III and Annex IV present in this resolution can serve as a reference, since they are biomass. The Annex III establishes emission limits for air pollutants from heat generation processes from the combustion of sugarcane biomass and Annex IV deals with emission limits for air pollutants from heat generation processes at from the external combustion of wood derivatives. These annexes establish the regulated pollutants, the rated power ranges, and the emission limit concentration of particulate matter.

4. Conclusions

Through the analysis and determination of the calorific potential of the sewage sludge and charcoal briquettes, it is concluded that the briquettes, manufactured with dry sewage sludge and used vegetable oil, have a calorific power lower than the charcoal. However, since the sewage sludge briquettes have much higher apparent density that the charcoal, the calorific potential per volume unit is bigger for the sewage sludge briquettes.

As a large amount of sewage sludge is produced daily, the use of briquettes of sewage sludge with used vegetable oil looks to be a viable alternative to replace charcoal as a heat source in the industrial sphere, especially where low or medium temperatures are required. The use of sludge briquettes as renewable energy is an option among the types of biomass fuel production. Adopting this end of for sewage sludge, it is provided an increase in the useful life of landfills and reduce soil contamination because this material has a high potential for contamination and occupies a large volume that would be removed from the landfills. In addition, the replacement of charcoal by sewage sludge briquettes with used vegetable oil will reduce the deforestation of wood for charcoal production and will bring a renewable energy alternative with a high potential.

It is suggested for future studies the quantification of pollutants generated during the combustion process, the application of new materials as a binder, in addition to economic availability.

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Ethical Approval

Not applicable

Consent to Participate

Not applicable

Consent to Publish

Not applicable

Authors Contributions

Stéphanie Rocha – Data curation, Funding acquisition, Methodology, Resources, Writing – original draft, Visualization

Pedro Soares – Formal analysis, Investigation, Writing – original draft

Lino Maia – Conceptualization, Funding acquisition, Supervision, Validation, Writing – review & editing

Competing Interests

The authors declare that they have no competing interests

Availability of data and materials

Not applicable

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