

ENCIT-2018-0504

EFFECT OF MOISTURE AND PARTICLE SIZE ON THE COMBUSTION CHARACTERISTICS OF SEWAGE SLUDGE IN A FIXED BED

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Abstract. *The present study aims to study the influence of moisture and particle size on the combustion of sewage sludge to verify if burning can be used as a form of treatment for biomass. For this, experiments were carried out in a fixed bed reactor with controlled parameters. The biomass characterization was performed by immediate analysis. For the particle size control sieves with four different meshes were used. With the results of the immediate analysis, values of moisture, volatile material, ash and fixed carbon were obtained, 46.04%, 39.45%, 49.04% and 11.51% dry basis, respectively. With the characteristic temperature profile it was possible to analyze the behavior of the biomass before the combustion. For the lower particle size the higher firing temperatures and the higher flame propagation velocities were observed. The samples with larger particle size presented a lower percentage of residual mass. For the influence of humidity, it was verified that for lower values of humidity the firing temperatures are higher, the higher the percentage of water in the sample before the test the lower the percentage of residual mass due to the release of this plot during the experiment and the sample with the highest percentage of moisture presented a higher flame propagation velocity.*

Keywords: *combustion, sewage sludge, biomass*

1. INTRODUCTION

Water is an essential natural resource for the maintenance of life, but finite, which is being degraded due to population increase, causing an increasing consumption, and the absence of public policies aimed at its preservation, since any human activity leads to the production of waste that often goes to the waterways.

Domestic and industrial sewage is the main polluter of water in urban areas. Brazil has approximately 207 million inhabitants (IBGE, 2017) producing, according to NBR 7229 (ABNT, 1993), an estimate of 100 liters per person per day of low standard residence effluents, 130 liters for medium and 160 liters for high standard homes, often dumped directly into rivers, lakes and seas without proper treatment. Therefore, the treatment of sewage in sewage treatment plants is essential for reducing water pollution and improving public health of the population.

The by-products generated in sewage treatment are treated effluents, biogas and sludge (COPASA, 2018). The term mud is used to designate the solids removed during treatment and consists of a mixture of organic and inorganic matter. The amount and nature of the sludge are extremely variable and depend on the characteristics of the wastewater and the treatment system used (Andreoli, Von Sperling and Fernandes, 2007).

This by-product is gaining importance due to the growing demand of environmental agencies. The final disposal of sewage sludge is a worldwide concern, due to the increasing volume produced (Lopes *et al.*, 2005), which is still a problem that has not been adequately remedied. It is estimated the production of about 7.2 million m³ / day of sewage sludge in Brazil (PROSAB, 2009). In addition to the considerable volume produced, there is a risk of contamination of the environment due to the presence of heavy metals and pathogens in the sludge (Lopes *et al.*, 2005).

The search for economically and environmentally viable solutions for the treatment and final disposal of sewage sludge remains a challenge in several countries, especially in Brazil, where the subject is more recent (Tsutiya and Hirata, 2001).

Andreoli (2001) stipulates that 90% of the waste produced in the world goes through three main processes in its final destination: incineration, disposal in landfills and agricultural use.

But global urbanization leads to the growth of large metropolitan areas, imposing restrictions, among others, on alternatives to final disposal of sludge. The large volume produced, lack of space in landfills, freight costs and the adverse impact of heavy traffic in metropolitan areas favor the adoption of alternative treatment and disposal of sludge within the wastewater treatment area (Andreoli, Von Sperling and Fernandes, 2007) and (Bettiol and Camargo, 2006).

Many countries are increasingly using the incineration process in response to growing difficulties in keeping landfills as a final route of sludge disposal due to increased competition for space, disposal costs, legislative restrictions and incentives for the recycling of sludge (Andreoli, Von Sperling and Fernandes, 2007). In addition, landfills do not take advantage of the energy potential of sludge (COPASA, 2018).

An alternative to the methods used for the final disposal of sewage sludge is combustion. This process has advantages over other forms of treatment. The reduction of its volume after combustion is very significant, besides the thermal destruction of toxic organic products (Otero *et al.*, 2002). The final products of these processes are inert, sterile and can serve as aggregates of concrete, landfills and the like (Andreoli, Von Sperling and Fernandes, 2007).

Sludge combustion is only autogenous when the solids concentration is greater than 35%. Dehydration is done and has a major impact on the transport of sludge and final disposal costs. The main reasons for dehydration are: reduction of transport costs to the final disposal site, improvement of handling conditions and increase in the calorific value of sludge, among others (Andreoli, Von Sperling and Fernandes, 2007).

The calorific value of dry sludge corresponds to that of brown coal (Werther and Ogada, 1999). The fuel components found in the sludge are carbon, sulfur and hydrogen, present as fat, carbohydrates and proteins (Andreoli, Von Sperling and Fernandes, 2007). Then this energy content can be harnessed through combustion.

For the study of combustion variables are considered, such as fuel properties and process conditions. The type of fuel, air flow and preheating, particle size and fuel moisture influence the combustion characteristics (Zhao *et al.*, 2008).

Therefore, the research project has the objective of studying the influence of parameters, such as grain size and humidity, on the sewage sludge combustion behavior to determine a better way to dispose of sewage sludge.

2. METHODOLOGY

The samples of sewage sludge were collected at a sewage treatment plant in the municipality of Linhares-ES, as shown in Fig. 1. For its characterization, the immediate analysis was carried out and, before the tests were carried out, the preparation of the samples was carried out.



Figure 1. Sewage sludge in sewage treatment plant

The preparation occurred with the reduction of the size of the sewage sludge blocks to the grains with controlled particle size, as shown in Fig. 2, using sieves of four different meshes for the accomplishment of the combustion tests. These sieves have 12.50, 5.60, 4.00 and 1.70 mm which are placed in decreasing order with the thinnest one embedded in a bottom. As the biomass was sieved, the material retained between two sieves was collected and stored. For the immediate analysis, the 500 μm and 250 μm sieves were used to control the particle size of the 1 g samples.

The procedure of the immediate analysis followed the standard ASTM D1762 - 84 (2013), which presents methods for determination of moisture, volatile material, ash and fixed carbon in wood charcoal, characterizing the biomass studied in these four levels. The procedure was performed twice, each with four samples. For this step 30 mL porcelain

crucibles were used with lid, a desiccator with silica gel in blue gel, a Shimadzu AUY220 analytical balance, a VulcanBox 3-550PD muffle furnace, a tenacious and particle size sieves for grain control.



Figure 2. Three samples with different particle size used in the tests, retained in the meshes of 1.7, 4.00 and 5.6 mm

The combustion tests were carried out in a fixed bed combustion reactor, with the temperature measurement made by ten type K thermocouples spaced 50 mm along the reactor, reading the data with the help of two Arduino Mega 2560 microcontrollers and ten modules MAX31855 for the interface between the thermocouples and the Arduino boards. A computer was needed to store the data during the tests. The air injection, fixed at 20 normal cubic feet per hour or SCFH, was done with a Schulz PraticAir 2HP compressor, the flow control by means of a needle valve present at the compressor outlet and the measurement with a rotameter of 10 a 100 normal cubic feet per hour or SCFH. In addition, the ignition of the test was performed with an oxyacetylene torch.

Deoclecio and Santos (2016) constructed the reactor to be used in the combustion test, as exemplified in the diagram of Figure 3. It is a stainless steel tube with 610 mm length, 63 mm internal diameter and 73 mm external diameter. This tube is connected to an exhaust pipe at the bottom and closed at the top by a threaded cap. The air inlet has been installed at the top.

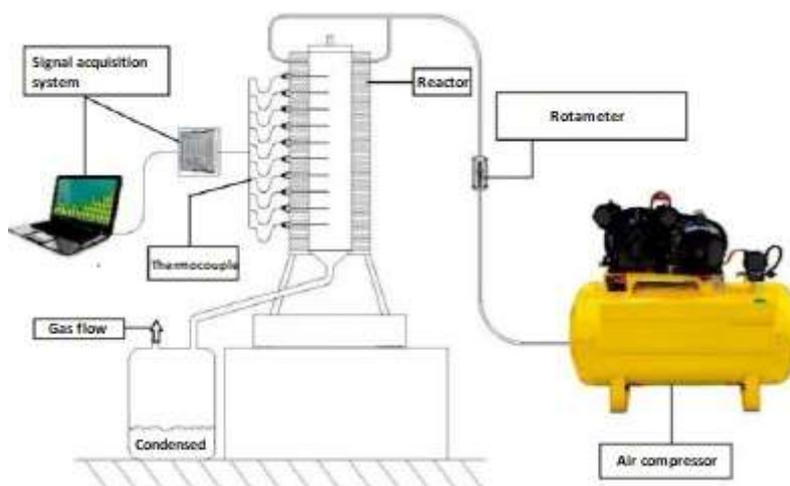


Figure 3. Schematic drawing of the experimental apparatus

To begin the test, a slurry sample with controlled particle size was deposited inside the cell with a thin layer of charcoal about 1 cm at the top to ignite the torch through the hole in the reactor cap. The test was terminated when all thermocouples read a temperature below 423 K.

Exhaust gases pass through a copper tube at the bottom of the reactor, where a high temperature resistant automobile radiator hose has been connected and has led the gases into a vessel with water for washing, ie the condensate and / or condensate. gaseous pollutants were trapped in the water in the vessel. The condensed material was retained and the rest was exited to the laboratory chapel, being released to atmosphere.

For the analysis of the results, 15 tests were necessary, nine of them to analyze the influence of the particle size, three tests for each of the particle size controlled. In order to analyze the influence of moisture plus six tests were made, three tests for two different drying times of the sample in the muffle, 1h and 2h, with the same particle size, were compared later with the same particle size tests of samples without drying.

For the drying, a quantity of biomass was placed in a stainless steel vessel taken to the muffle with a temperature of 378 K, after which the sample was analyzed for moisture according to ASTM D1762-84.

With the temperature profiles of each of the 15 experiments, it was possible to determine the maximum temperature, residual mass and flame propagation velocity. The maximum temperature was obtained by analyzing the highest peak of each thermocouple by means of the generated graphs. The residual mass calculated from weighing the ashes at the end of each experiment, the percentage being obtained in relation to the sludge mass in the reactor before the test was started. The propagation velocity of the flame front was calculated between each thermocouple and then the averaged calculated velocities were averaged. This calculation is the ratio of the space between the thermocouples to the time required, the time difference between the peak temperature of a thermocouple and the peak of the preceding thermocouple, for the flame front to travel through these thermocouples.

With the results, the mean and standard deviation of the tests were calculated for each grain size and moisture value. Then, graphs of the mean values of the experiments of each group of samples were created according to the particle size and the humidity so that a comparative analysis was made between them.

3. RESULTS

3.1 Immediate analysis

The final result of the immediate analysis for the sewage sludge collected is presented in Table 1. The amount and nature of the sludge are extremely variable and depend on the characteristics of the wastewater and the treatment system employed (Andreoli, Von Sperling and Fernandes, 2007), so the result is consistent.

Table 1. Immediate analysis of sewage sludge obtained experimentally

Properties	Média (% dry basis)	Standard deviation
Moisture	46,04	1,27
Volatile matter	39,45	1,34
Ashes	49,04	2,75
Fixed carbon	11,51	1,41

The volatile material and the fixed carbon of the biomass contribute in the calorific power of the biomass and in the case of the sludge studied these properties correspond to 50.96% on a dry basis of the sample, making the combustion favorable. The remaining 49.04% are ashes which after combustion will remain as waste which should be discarded.

3.2 Temperature profile

The combustion temperature profile of the studied sewage sludge is shown in Fig. 4. With its analysis it is possible to observe that after the start of the fire the flame front propagates downwards reaching the thermocouples along the cell. The vaporization of moisture is the first step to be performed, ie at that time the heat generated is used to transform the water present in the fuel into steam. This occurs at temperatures close to 373 K and for a few seconds.

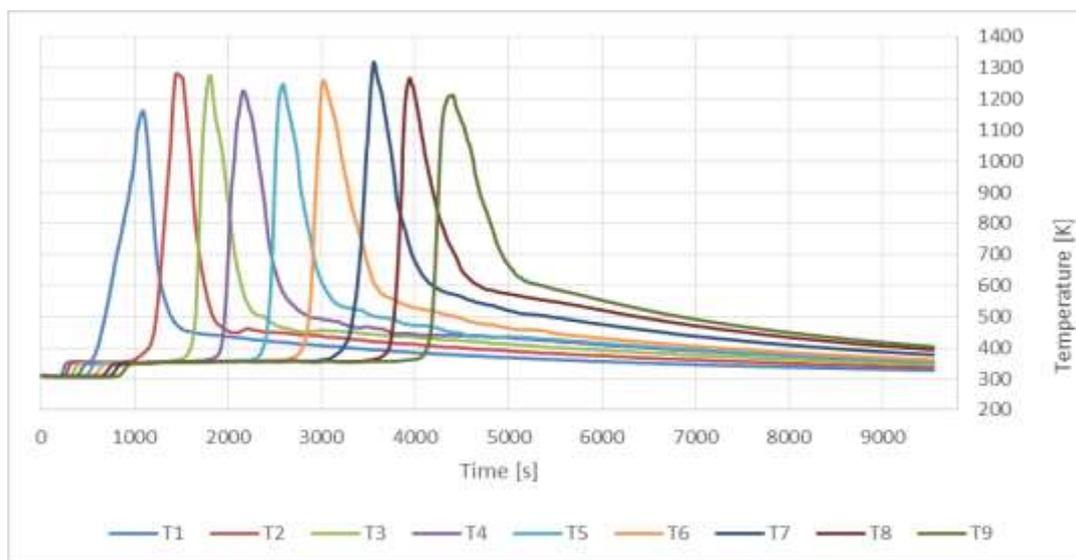


Figure 4. Bed temperature profile of combustion sewage sludge

With the release of moisture, there is a rapid increase in temperature up to the peaks of the nine thermocouples, approaching 1423 K in some tests. At this point the volatile material is burned until it reaches the temperature peak. Subsequently, during the temperature drop, the fixed carbon of the biomass occurs. Remaining only the ashes inside the reactor, temperatures begin to fall rapidly, ending the test.

3.3 Effect of particle size

In Fig. 5, 6 and 7 it contains the results concerning the means and standard deviations for the maximum temperature, residual mass and flame propagation velocity comparing the particle size of the sewage sludge samples. With the experiments it was possible to note that for the lower grain size the temperatures reached the highest values, this also occurred for the flame propagation velocity. And for the residual mass, which is the material to be discarded as residue, presented the highest value. As the particles of the samples smaller the speed of burning is higher, because according to Virmond (2007) the particle size determines the rate of heat transfer.

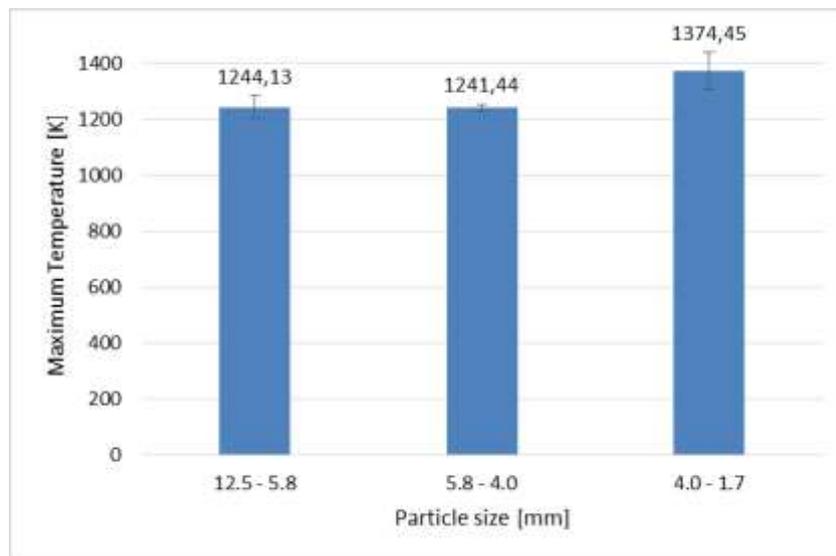


Figure 5. Graph of the influence of particle size on the maximum temperature

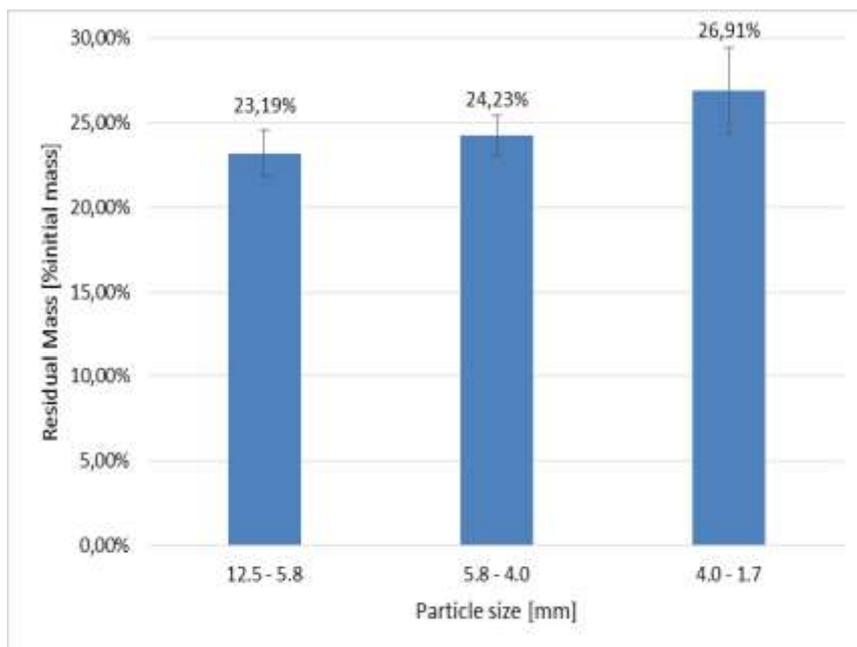


Figure 6. Graph of the influence of particle size on residual mass

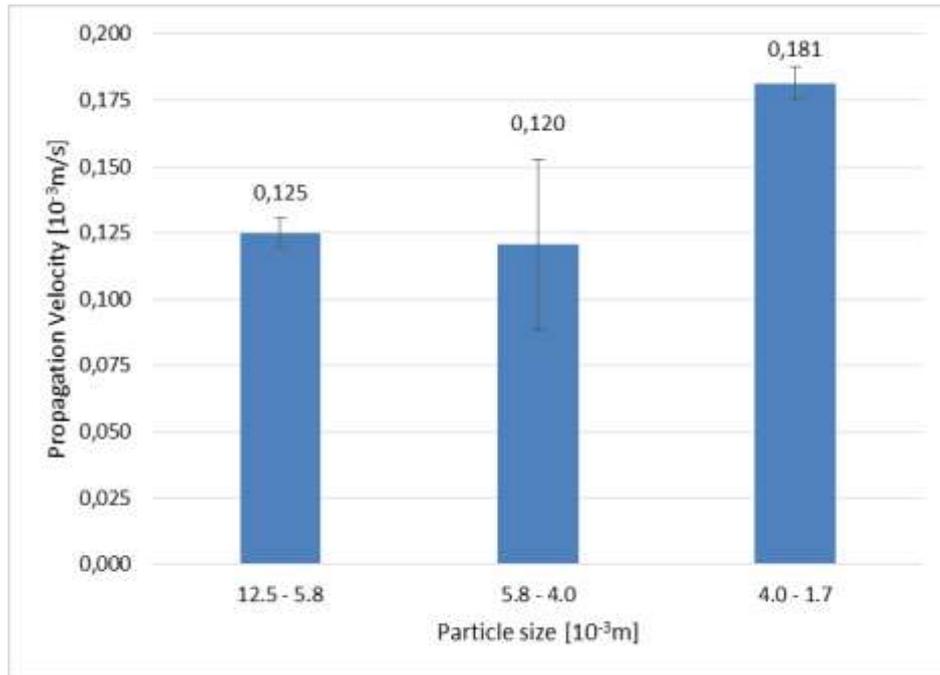


Figure 7. Graph of the influence of particle size on flame front propagation velocity

3.3 Effect of moisture

The humidity of the samples without drying time is that shown in Table 1, which corresponds to 46.04%. The average percentage of moisture for the samples with 1h of drying in the oven is 41.17% and for the samples with 2h of drying 45.46%. For the samples with the highest percentage of humidity, without drying time, they obtained the lowest percentage of residual mass. This can be explained by the fact that a significant portion of the sample mass before the test is water that was withdrawn during the experiment, and Fig. 9 shows an increase in residual mass with a decrease in moisture. Fig. 8 shows the influence of humidity at the maximum temperature and the results are confirmed, since it is known that a high content of moisture in the fuel can result in poor ignition (Virmond, 2007), and the samples with lower values for humidity presented the highest firing temperatures. For the values of flame propagation velocity shown in Fig. 10, the samples without drying had the highest values.

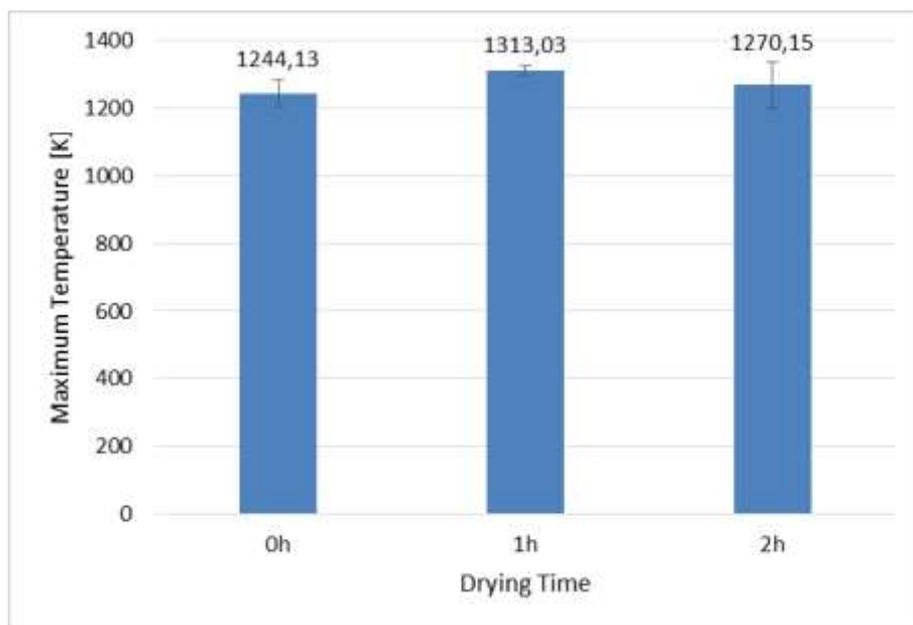


Figure 8. Graph of the influence of moisture on the maximum temperature

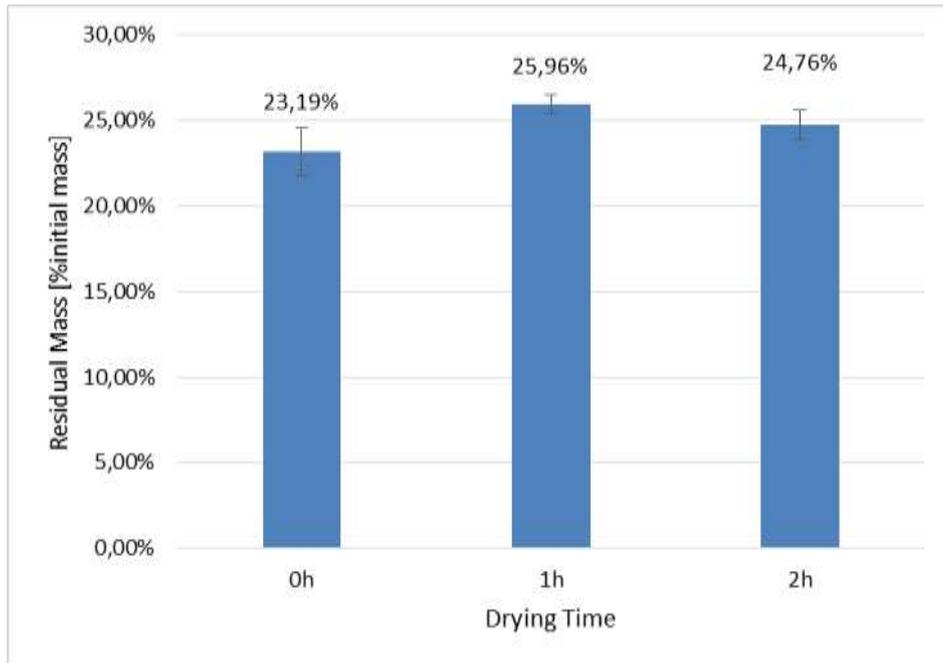


Figure 9. Graph of the influence of moisture on residual mass

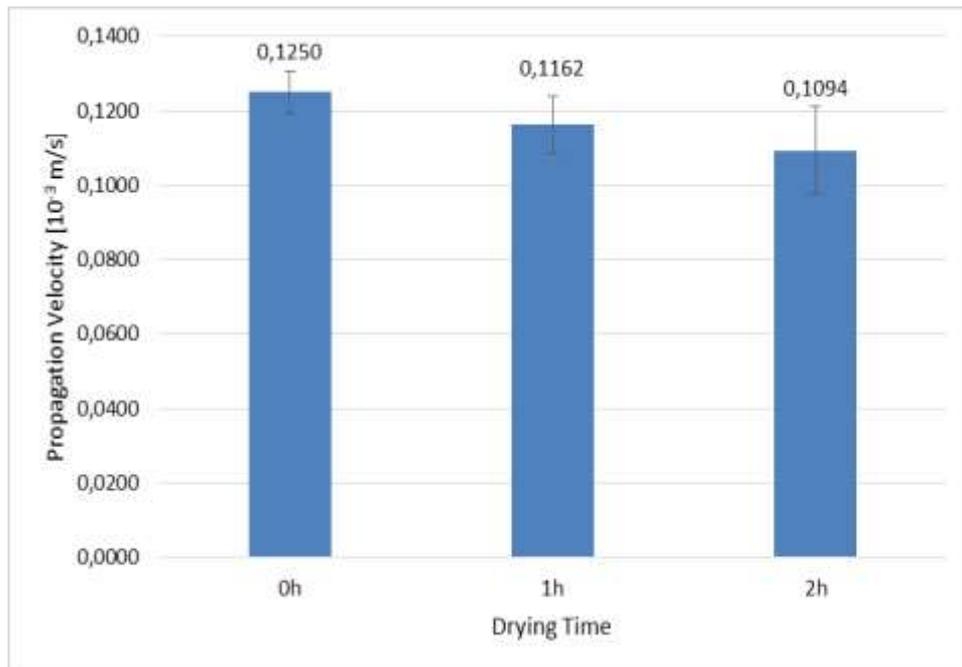


Figure 10. Graph of the influence of moisture on flame front propagation velocity

4. CONCLUSION

Taking into account that urbanization leads to the growth of large metropolitan areas by imposing restrictions on sludge disposal alternatives, and that freight costs and the adverse impact of heavy traffic in metropolitan areas favor the adoption of alternative sludge treatment and disposal, the study of the combustion of sewage sludge aims at proposing an adequate treatment for biomass.

By varying the particle size and humidity of the samples in the tests it will be possible to determine some favorable conditions for the best use of the combustion to take place, transforming the dry sewage sludge into an inert material and reducing its volume significantly, being able to serve, after the treatment, as aggregates of concrete, landfills and the like.

5. REFERENCES

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6. RESPONSIBILITY NOTICE

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