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Articles

Alternative methodology for determining water content in wood biomass

Metodologia alternativa para a determinar o teor de água em biomassa de madeira

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ABSTRACT

The need for ever faster and more efficient instruments, techniques and methods to assist in industrial decision-making has been a major challenge for industry, given growing production requirements and economic demands. In the biomass sector, the purchase, receipt and storage of batches requires increasingly efficient, fast and accurate instruments. The aim was to develop a rapid methodology for determining the water content of woodchip (eucalyptus or native wood) and sawdust samples using microwave ovens. When the water content values for woodchip and sawdust samples exposed to microwaves and forced-air ovens were compared, the results were similar, which indicates the reliability of the microwave method in relation to the results of the standard oven method. Samples with higher initial water content require a greater number of exposures in microwave ovens to reach mass stabilization for all the materials evaluated. Therefore, from this research, we can conclude that the microwave oven method guarantees results that are as reliable as those obtained using the standard forced-air oven method.

Keywords: Exposure interval; Mass stabilization; Microwaves; Reliability

RESUMO

A necessidade de instrumentos, técnicas e métodos cada vez mais rápidos e eficientes para serem usados como evidências nas tomadas de decisões industriais tem sido um grande desafio para as indústrias diante da crescente necessidade produtiva e exigências do comércio. No setor de biomassa, a compra, a recepção e o armazenamento de lotes necessitam de instrumentos cada vez mais eficientes, rápidos e precisos. O objetivo foi desenvolver uma metodologia rápida para a determinação da umidade de cavacos de eucalipto de madeira nativa e de pó de serra através do uso de fornos de microondas. Quando comparados os valores obtidos para umidades em amostras de cavaco de eucalipto, do cavaco de madeira nativa e de pó de serra expostas ao microondas e a estufa de circulação de ar forçada, os resultados foram semelhantes, o que indica a confiabilidade do método de microondas para com os resultados do método padrão de estufa. Amostras com maiores umidades iniciais necessitam de um número maior de exposições intervaladas em fornos de microondas para alcançarem a estabilização das massas para todos os materiais avaliados. Por isso a partir dessa pesquisa é possível concluir que o método do forno de microondas garante resultados confiáveis quanto aqueles obtidos através do método padrão em estufa de circulação de ar forçada.

Palavras-chave: Intervalo de exposições; Estabilização de massa; Microondas; Confiabilidade

1 INTRODUCTION

Biomass is one of the energy sources most consumed by the Brazilian agro-industrial sector but also important for other sectors, representing 19,7% of total energy consumed in Brazil in 2023 (EPE, 2025; Beber et al., 2024; Stefanelo; Silva et al., 2024; Delarmelina et al., 2023; Silva et al., 2005) and its classification can be considered important for the commercial sector (Costa Júnior et al., 2023). Wood derivatives play a significant role in industry as well as for the thermoelectric generation sector (Santos Júnior et al., 2022; Brito, 2007), which is a major consumer of this resource as fuel for furnaces (Melo et al., 2010). When coupled with boilers, it is used to heat raw materials for the thermal conversion of products (Brand et al., 2021) and also to produce water vapor, which is mainly used for thermal and mechanical work, which can be converted into electrical energy (Santos Júnior et al., 2022; Parmar et al., 2008).

Wood in the form of woodchips or sawdust from processing industries, reforestation areas or forest suppression is the major part of this biofuel and the knowledge of the fuel's properties is essential for any consumer of biomass, especially large-scale consumers, given that many properties can influence energy efficiency. One of the most important properties is the water content, which directly affects the

useful energy available from combustion (Przywara et al., 2023; Parmar et al., 2008). The purchase, receipt, storage and transportation of biomass are also influenced by water content, and this is an important parameter that may influence its quality (Ferreira et al., 2024), so it is necessary to determine this property as quickly and accurately as possible.

The Brazilian Association of Technical Standards (ABNT), the agency responsible for establishing standard methods for analyses, has established that the water content of wood chips is defined as the ratio between the mass of water contained and the total mass of the wood, after desiccation in a circulating oven to a constant final mass, after a minimum exposure time of 18 hours (ABNT NBR 14929/2017).

In industry, the adoption of this method can result in problems during the buying or sale of biomass, since the time for analysis, including can be extensive, at least 24 hours. This would be a sufficient timeframe to expose biomass to a fan-forced oven at a temperature of 103±2°C for complete water evaporation. Industrial processes require increasingly rapid decision-making, including for receipt and storage of biomass batches. The industrial sector therefore needs a faster procedure or method that guarantees precision.

There are numerous methods and devices available on the market for rapid water content determination, including capacitive and resistive methods. However, the precision of these devices and methods has come under scrutiny and revaluation, since these methodologies are based on indirect methods of determination. Indirect methods do not directly measure the amount of water present in the sample but use a physical-chemical property that is influenced by water content to estimate this value (Silva et al., 2008).

Microwave drying occurs due to the incidence of radiation on water molecules (dipoles), which promotes their heating and evaporation by increasing the level of molecular agitation in response to exposure to high frequencies. By heating the samples selectively and quickly, water removal conditions are achieved with less influence on volatiles, as occurs with the use of ovens (Luz et al., 1998).

The objective was to develop a rapid methodology for determining the water content in processed wood samples, in the form of chips or sawdust, using microwave ovens, ensuring that the results are consistent with those obtained through the official method using a forced-air circulation oven.

2 MATERIALS AND METHODS

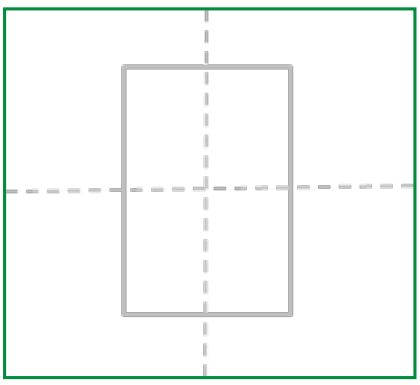
Woodchip (native or eucalyptus) and sawdust samples were obtained from the industrial sector in companies located in the Municipality of Sinop, MT; Sorriso, MT; Nova Mutum, MT; Vera, MT and Dourados, MS between January to August 2022.

Once received, a portion of each sample was immediately tested for water content in a forced-air oven and the remainder was used to develop and validate the alternative microwave-oven methodology.

Domestic 700W microwave ovens were used to evaporate the water contained in samples of processed wood in the form of chips or sawdust, whether originating from species traditionally used in reforestation (eucalyptus) or species native to the Cerrado and Amazon biomes.

Before testing in the microwave ovens, the container/support used to hold the samples inside the chamber was selected. Ceramic, glass or even paper containers were considered. For reasons of economy, 75 g/m² sulphite paper was chosen as the support for samples. A sheet of this paper was cut into four equal parts (Figure 1), each part being used as a support to contain samples for the microwave oven test. As a safety measure, metal containers should not be employed in microwave ovens.

Figure 1 – Sheet of 75 g/m² sulphite paper cut into equal parts to be use as a support for the samples placed in the microwave oven



Source: Authors (2025)

During preliminary testing, it was observed that the piece of paper (¼ of an A4 sheet of 75 g/m² sulphite) used as a support for the samples lost weight when it was exposed to microwaves and then weighed on an analytical scale with a precision of 0.001g. For this reason, the ¼ A4 sheet was kept for 10 seconds in the 700 W microwave oven so that the traces of water contained in it could be removed and then weighed. This test was maintained for a further 15 seconds and we checked whether the weight had remained constant. After this procedure (10-second exposure) the weight of the support was recorded.

A first investigation was carried out to determine the exposure time of the samples to microwave energy, however, as it is a fuel and depends on the water content of the material, the numerous samples burnt in the furnace chamber during the preliminary tests made it impossible to define a single time for any water content condition and origin of the processed samples. For this reason, short exposure times were set for these samples at staggered intervals until weight loss and stability were established when measured on an analytical scale with a precision of 0.001g. The exposure period was 30 seconds, repeated until a constant weight was reached, adopting a period that presented no risk of initiating combustion.

After all preliminary investigations have been determined, 20g (initial mass) of woodchip (eucalyptus or native) or sawdust sample were weighed. This amount was used in each repetition. The samples from three different origins were analysed for eucalyptus, and the same for native wood and sawdust. Ten replicates were established for each condition (three eucalyptus, three native and three sawdust) and these were subjected to the microwave oven test.

In the microwave oven, the samples were heated at 30-second intervals. After this exposure, the sample was removed and weighed to determine its mass. This procedure was repeated until the sample reached constant mass. A constant mass is

one where the difference between two consecutive weighings, after exposure to the microwave, is less than 0.05g.

To determine the water content, the measured values were submitted to Equation (1):

$$U = \frac{mi - ms}{m_i} . 100 \quad (1)$$

where: U: Water content on a wet basis (%); *mi*: initial mass of the sample (g); *ms*: mass of the dry sample (g).

For the purpose of counter-testing, samples from the same batches evaluated in the microwave oven test were subjected to the standard test in a forced-air oven, where they were kept at 103±2°C for 24 hours according to the standard NBR 14929/2017, which states that the water content, of wet wood, corresponds to the ratio between the mass of the water contained in it and the mass of the wet wood, according to the Equation (1).

The water content data for woodchips (eucalyptus or native) and sawdust were compared with those obtained by the forced-air oven method using the F-test with $p< 0.05$ to see if there were any differences between the values obtained for the water content present in the masses.

In order to study the mass stability of the eucalyptus and native woodchip and sawdust samples, according to the number of microwave exposures, confidence intervals were established to show the tolerable stability limits with $p< 0.05$ and their consequent number of exposures according to the initial water content.

All statistical analyses were carried out using Action Stat Pro software version 3.7 (Estaticamp, 2020).

3 RESULTS

The results obtained for the water content of woodchips (eucalyptus or native) and sawdust obtained in microwave ovens and in the forced circulation oven were similar (Table 1).

Table 1 – Water content determined by the microwave method based on mass stability (difference in mass between subsequent weighings of less than 0.05g) and by the official oven method

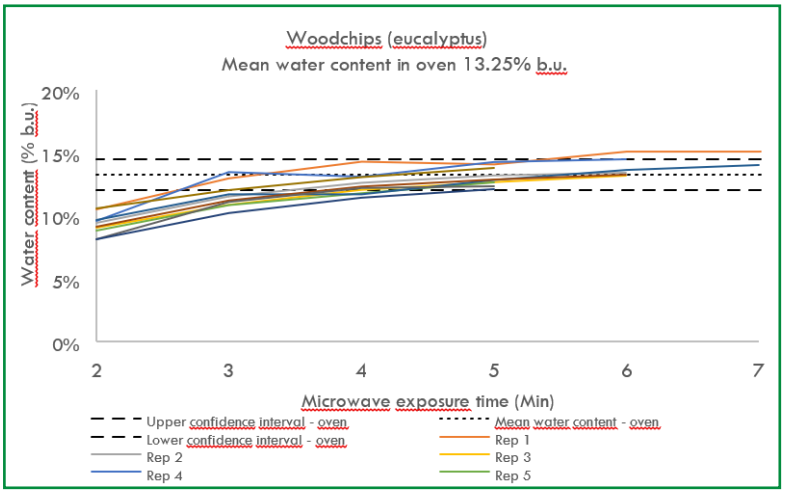
Sample types	Water content in the microwave (Mean ± SD) %	Water content in the oven (Mean ± SD) %	ANOVA
Woodchip (eucalyptus)	13.41 ± 0.95a	13.35 ± 0.96a	F=0.10; *p=0.*75
Woodchip (eucalyptus)	26.88 ± 2.04b	29.36 ± 1.75b	F=2.31; *p=0.*15
Woodchip (eucalyptus)	43.86 ± 2.05c	45.83 ± 2.25c	F=2.77; *p=0.*12
Woodchip (native)	14.14 ± 0.72d	13.91 ± 0.88d	F=0.25; *p=0.*60
Woodchip (native)	29.72 ± 2.68e	29.82 ± 1.97e	F=0.01; *p=0.*94
Woodchip (native)	40.79 ± 2.92f	38.94 ± 3.94f	F=1.07; *p=0.*32
Sawdust	54.79 ± 1.66g	52.14 ± 5.42g	F=2.15; *p=0.*16
Sawdust	60.53 ± 0.61h	62.21 ± 2.09h	F=4.73; *p=0.*05

Source: Authors (2025)

In where: * Means followed by the same letter in the line do not differ by the F test with $p < 0.05$.

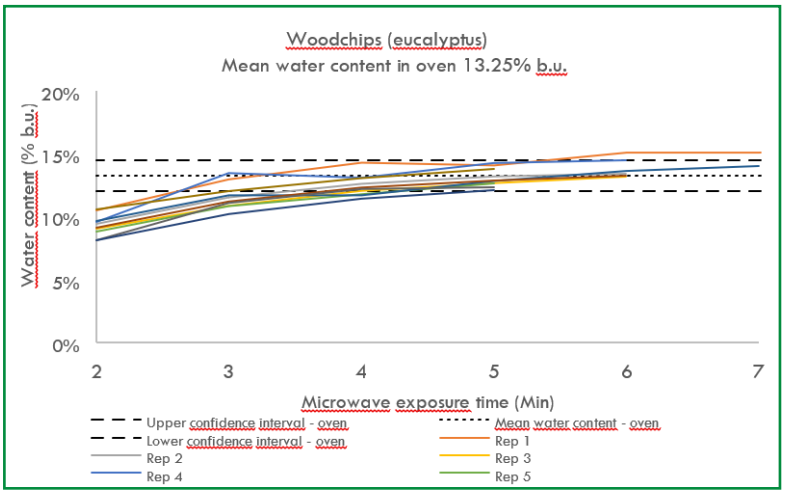
The stabilization behavior of the mass for woodchips (eucalyptus) at water content of 13.25, 29.36 and 45.83 % b.u. was observed through confidence interval analysis, which showed that samples with higher initial water content require more microwave exposures until they reach mass stability (Figures 2, 3 and 4).

Figure 2 – Stabilization of the sample mass in microwaves for woodchips (eucalyptus) with a mean water content of 13.25%



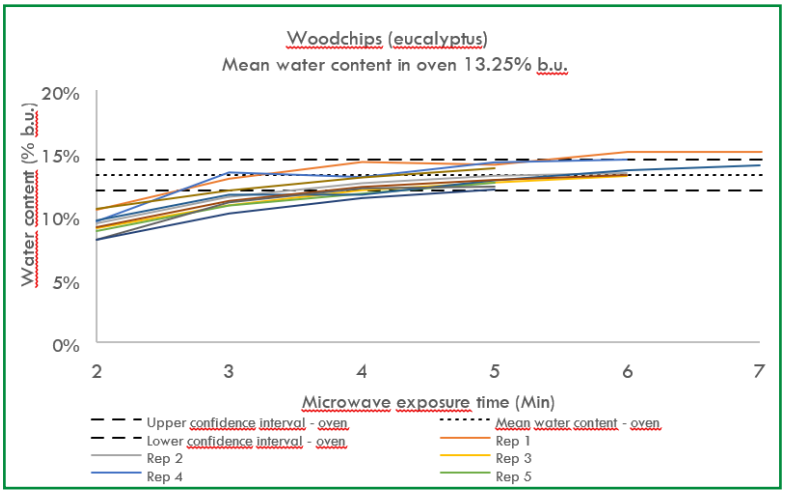
Source: Authors (2025)

Figure 3 – Stabilization of the sample mass in microwaves for woodchips (eucalyptus) with a mean water content of 29.36%



Source: Authors (2025)

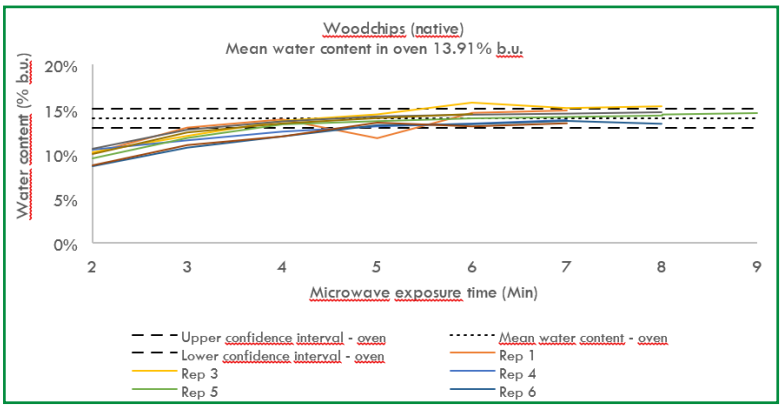
Figure 4 – Stabilization of the mass in microwaves for woodchip (eucalyptus) samples with a mean water content of 45.83%



Source: Authors (2025)

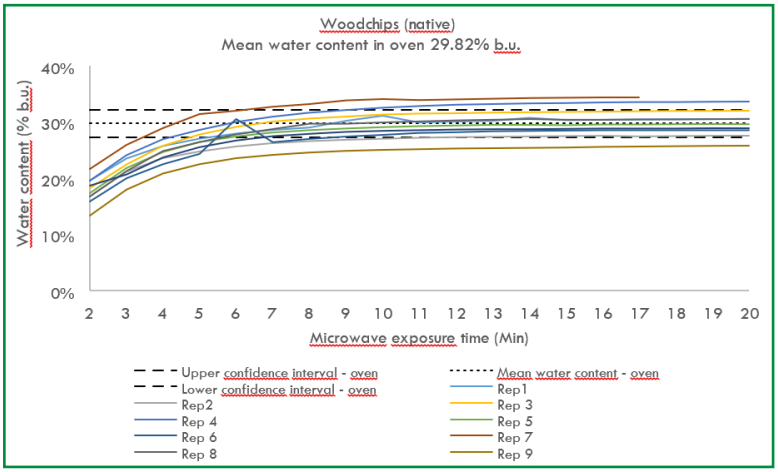
The same mass stabilization behaviors were observed for woodchips (native) and sawdust, which shows that samples with higher initial water contents require more exposures in the microwave oven until they reach mass stability (Figures 5, 6, 7, 8 and 9).

Figure 5 – Stabilization of the mass in microwaves for woodchip (native) samples from a sawmill, with a mean water content of 13.91%



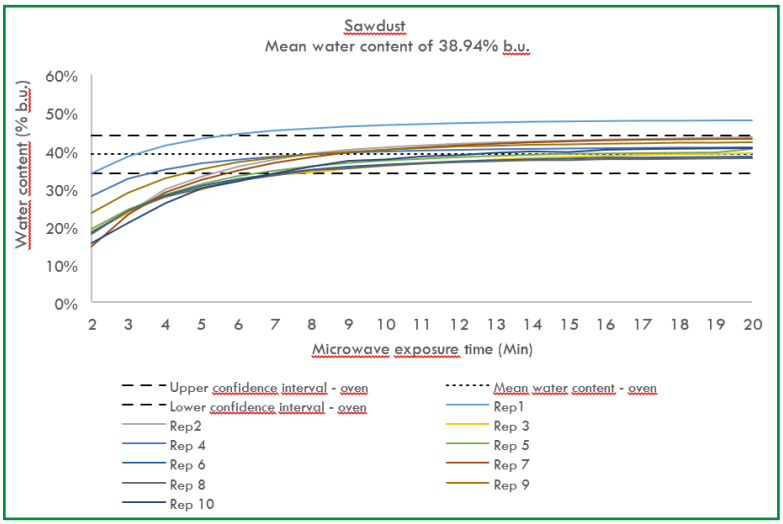
Source: Authors (2025)

Figure 6 – Stabilization of the mass in microwaves for woodchip (native) samples from a sawmill, with a mean water content of 29.82%



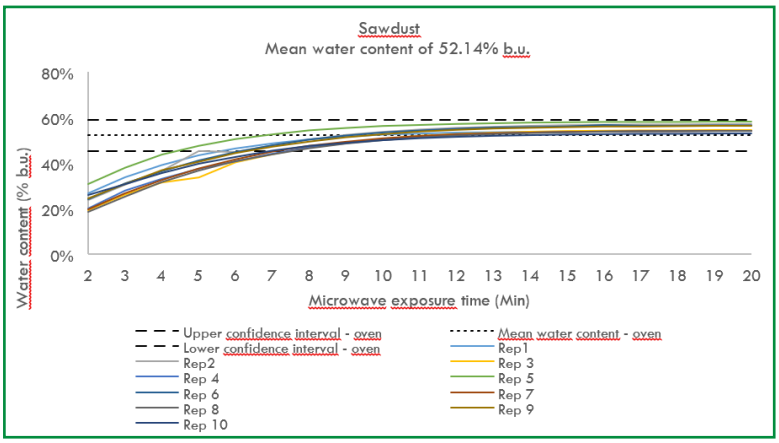
Source: Authors (2025)

Figure 7 – Stabilization of the mass in microwaves for woodchip (native) samples from a sawmill, with a mean water content of 38.94%



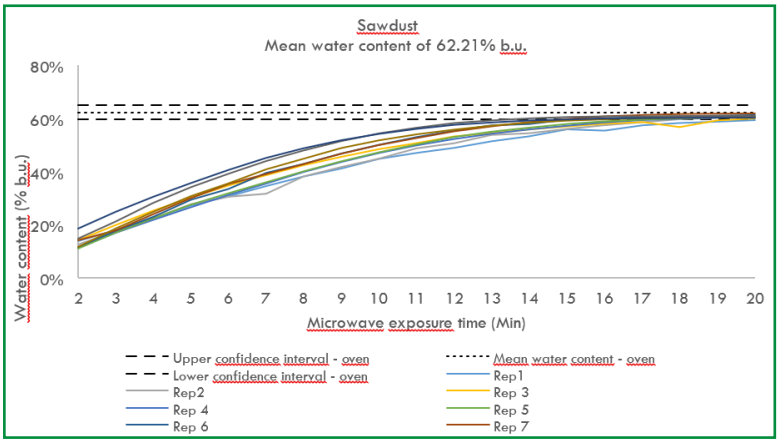
Source: Authors (2025)

Figure 8 – Stabilization of the mass in microwaves for sawdust samples, with a mean water content of 52.14%



Source: Authors (2025)

Figure 9 – Stabilization of the sample mass in microwaves for sawdust samples, with a mean water content of 62.21%



Source: Authors (2025)

4 DISCUSSIONS

The combustion that occurred in the microwave oven chamber during preliminary testing occurs because wood samples or derivatives (fuel) exposed to high energy levels, as happens inside a microwave oven, can initiate a combustion process. This can

be favored by the presence of some elements in the sample and in the environment (Pereira et al., 2016; Costa et al., 2008), since the temperature increase depends on variables such as the dielectric constant, molecule size, and product viscosity (Barbosa et al., 2001) etc., rather than on the sample mass (Pereira et al., 2016). The procedure for determining water content in microwave ovens can lead to a loss of dry matter, associated with a loss of water, with only the latter being what is desired. As such, it is essential that the samples are exposed to the microwave oven at intervals and are also supervised by an operator during the entire period that the oven is on. If the operator notices that the sample begins combusting, the oven should be immediately switched off and the sample carefully removed and duly discarded.

The similarity observed indicates that the use of microwave ovens, when operated correctly, guarantees consistent and reliable results when compared to the standard method in a forced air circulation oven at 103±2 °C for 24 hours in accordance with standard NBR 14929/2017 of the Brazilian Association of Technical Standards. However, to operate microwave ovens, certain procedures should be considered, such as the dynamics of exposure to radiation, since a variable number of exposures to microwave radiation for 30 seconds may be necessary in order to stabilize the sample mass. Microwaves act internally by breaking the vessels and creating microcracks in the cell walls, accelerating the removal of free water and constitutive water. As the heating occurs from the inside out, through the action of the electromagnetic energy beams in the core of the exposed material, the water is forced to move from the center to the periphery, through the action of the osmotic effect that acts as a type of plunger pushing the water, since the vibration of the molecules is greater inside the material exposed to the operation of the microwave (Talgatti et al., 2020). Samples with higher initial water content values, both for woodchips (eucalyptus or native) and sawdust, required a greater number of exposures until the mass stabilized. This phenomenon must be taken into account due to the loss of water through exposure to microwave energy in the oven chamber, another phenomenon must be considered, which is the

rapid excitation of the molecules in the sample as a whole, which is why it needs to be carried out at intervals to minimize the impact of this rapid excitation on molecules other than water and thus avoid combustion of the sample, so that the energy emitted only dries the water contained in the sample.

5 CONCLUSIONS

Based on the data obtained in this study, it is possible to conclude that the microwave oven can replace the forced-air circulation oven in determining the water content of wood samples in the form of chips or sawdust.

The microwave method, when applied following the guidelines established in this research, produces results statistically equivalent to the standard oven method, at a significance level of $p < 0.05$.

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