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PRODUCTION OF GLASS FROM ORGANIC WASTE OF FOOD

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Abstract: Glass can be classified as a solid and amorphous material, without a fixed melting point, with a defined shape and certain mechanical rigidity at room temperature. Its origin dates back to very ancient times, around 3000 BC, when it was obtained from the accidental burning of sand by the Phoenicians. Since then, many changes in the technological and chemical areas have been carried out, directly affecting the manufacturing process of this material. Nowadays, the importance of obtaining better production results with the least possible environmental impact is evident. Recently, a new method of obtaining glass has emerged as a more sustainable option to the traditional way: its synthesis from organic food waste with a high content of inorganic oxides. The objective of the present research is to evidence if, in fact, such an innovative form of production is possible and applicable. For this, organic tailings were collected in food stores in the city of Limeira (interior of São Paulo, Brazil), which went through a cleaning, drying and calcination process, followed by characterization of the ashes, formulation of a vitreous mass according to the type of glass of interest and, finally, the sintering of the material. At the end of all the steps, it was found that it is possible to produce glass from organic food waste, but that the yield of calcination of the waste, in certain cases, differs from the scientific literature and, as it is very small, it may represent a bottleneck in the process as a whole. In the future, it is possible to conduct further research and studies in order to further improve the form of production in question, improving it to ensure positive progress from an economic and environmental point of view.

Keywords: Glass, production, chemistry, sustainability, innovation.

INTRODUCTION

Various classifications can be assigned to glass in relation to its constitution and structure. According to certain perspectives, glass is considered a liquid of infinite viscosity, and this definition is sometimes still used (AKERMAN, 2000). From other perspectives, it can be referred to, as mentioned by ARAUJO (1997), as a super-cooled liquid. However, according to the same author, the most used definition says that glass is an amorphous solid, whose molecules do not have long-range symmetry.

Currently, some scholars indicate that the first production must have taken place around 3000 BC, when, by the accidental burning of sand, glass was generated by the Phoenician peoples and then widely spread throughout the ancient world (BERGAMO and MOTTER, 2014). Other records, however, even cite times from 4500 BC, and attribute the discovery of the manufacture of this material to the region of Mesopotamia or Egypt (ARAUJO, 1997; PEREIRA, 2012).

After many years of history, glass production has changed and evolved. The glass industries currently base their production method on a sequence of steps, which begin with obtaining the necessary oxides. Since the oxides found in nature in the form of minerals, it can be said that the extraction of such components is done from the mining activity (DAMASCENO, 2017). Although there are several methods in the production of glass, most producers do it by melting the components at high temperatures, in a process called sintering (CALLISTER and RETHWISCH, 2016). However, mining activity usually causes several impacts to the environment (DAMASCENO, 2017); therefore, certain alternatives may be more viable from an economic and, above all, an environmental point of view.

According to SANTOS (2009), one of the actions that can help in the promotion of sustainability is the recycling of glass, being possible to carry out it by incorporating used fragments of the material in the manufacture of a new product, as was done by TRENTIN et al. (2016). Another more recent option in the search for sustainable production is to improve the way of obtaining the raw material that constitutes glass. Instead of obtaining the essential oxides through mining, it is possible to obtain them from organic food waste. The calcination of these residues results in different oxides that can be used to form glasses, ceramics and glass-ceramics with compositions practically identical to commercial ones, according to the desired application (CORNEJO et al., 2014).

Therefore, it can be admitted that this new production method represents an advance towards a more sustainable industrial glass manufacture, since it collaborates with the recycling of waste and is based on technical/ technological development with respect to the environment, without consumption. of virgin raw materials. In the future, the topic can be further studied, researched and improved, to bring more and more benefits to society and less environmental impacts.

MATERIALS AND METHODS

The production of glass takes place through a sequence of six steps, each one of paramount importance to obtain a satisfactory final result, which are, in this order: collection and separation of the raw material, cleaning and drying of the materials, calcination, ash/oxide characterization, glass mass formulation and sintering.

Initially, it was decided to produce float glass, used in containers and windows, as it is one of the most accessible and common commercial glass on the market. The materials chosen to carry out the work were eggshells, corn cobs and sugarcane bagasse, which contain, respectively, calcium oxide (CaO), sodium oxide (Na2O) and silicon oxide (SiO2), basic components of the aforementioned glass. The collection of such raw materials took place in commercial establishments in the food sector in the city of Limeira (interior of São Paulo, Brazil), which agreed to contribute to the research by providing organic waste.

Subsequently, the materials were processed for better storage and ease of future steps; the eggshells were broken manually and washed with running water, aiming to remove all types of undesirable material in their environment (egg remains, earth and other contaminants), placed to dry naturally and beaten in a blender until they acquired a powdery characteristic, this being then sieved through a 100 mesh granulometric analysis sieve. The corn cobs, in turn, passed through a processor, blender and were dried in an oven at 100 ºC for 24 h (due to their high humidity). Finally, the sugarcane bagasse was kept in an oven at 80 ºC for 6 h and then underwent the same mechanical procedure as the corn cobs.

The step of calcination of the organic residues was carried out using three muffle furnaces (model FORNITEC F2 - DM Single-phase). All weighings were performed in triplicate using a semi-analytical balance (Marte AD500 model). This step was carried out in the chemistry laboratories of Fundação Hermínio Ometto – FHO (City of Araras, countryside of São Paulo, Brazil). In total, to hold the samples, three pairs of porcelain capsules were used (one pair for each muffle) previously washed with aqua regia (3:1 hydrochloric acid and nitric acid solution) and calcined for 60 minutes at 600 °C. in order to eliminate any organic matter that could interfere with the results. About 10 g of sample was inserted into each of the capsules. The calcination parameters were 900 ºC for 6 h for eggshells and 700 ºC for 6 h for corn cobs and sugarcane bagasse, with a heating rate of 20 ºC/min. It is worth mentioning that the muffles were operated in such a way that each one contained only one type of organic residue, in order to avoid contamination during the firing stage.

After this process, the ash was weighed to enable calcination yield to be calculated and then stored in 80 mL universal collection flasks. Due to the capacity of the muffles used, the calcination was repeated several times until the amount of ash of each organic residue exceeded 1.5 g, because, this way, it would be possible to carry out several sintering tests until the identification of the ideal percentages of each oxide in the final composition of the desired material.

From that point on, all the other stages of glass production take place on the premises of the Faculty of Animal Science and Food Engineering at the University of São Paulo (FZEA-USP) in the city of Pirassununga (São Paulo, Brazil). Thermogravimetric analysis (TG/DTG) was performed to evaluate the metallic oxides obtained from the calcination of organic residues. The equipment used is from NETZSCH (model STA 449 F3 Jupiter ®), in a temperature range of 25 ºC to 1200 ºC, with a flow rate of 2 mL of nitrogen per minute, and a heating rate of 1 oC/min. From the thermograms, it was possible to determine the percentage of oxides present in the calcined samples, essential information for the follow-up of the project.

Sequentially, the formulation of the vitreous mass was made by means of simple mathematical calculations from the percentages obtained by the thermogravimetric analyses. Four different compositions, named A, B, C and D, were tested for the production of formulated glass. Table 1 presents the compositions used.

After weighing, all inputs were mixed using a porcelain pestle and mortar. After that, the powders were shaped into 12 mm diameter pellets by uniaxial pressing at 50 MPa in a manual hydraulic press (Marcon, model MPH-10).

After forming, the samples were sintered. This process, responsible for generating the final product, was conducted several times using different temperatures, in order to test and evaluate the best conditions for glass production. The first test was carried out at 1500 °C for 1 h (with compositions A and B), the second at 1300 °C for 1 h (using compositions B and C) and the third at 1359 °C for 2 h (using composition D) , with all procedures performed in a conventional sintering furnace (MAITEC, model FE50RD) with a heating rate of 10 °C/min.

RESULTS AND DISCUSSION

The phase of collecting, separating, washing and processing the raw materials took place

Metal oxides	**Compositions (% by mass)**			
	A	**B**	**C**	**D**
SiO_2	65,8	76,5	70,3	75
CaO	10,4	8,6	12,7	10
Na_2O	17,2	14,8	17	15
Al_2O_3	6,6	-	-	-

* Al_2O_3 was not obtained by calcination. The oxide used is commercial, produced by Alcoa, and provided by the MatMod laboratory (FZEA/USP).

Table 1 - Percentage (%) by mass of metal oxides used in the production of glass.

Source: author.

at the beginning and lasted throughout the entire project, showing good consistency with regard to the shapes and color of the waste, as they were always collected in the same locations.

Eggshells were the easiest material to process, due to their low mechanical strength, facilitating their breakage and reduction to dust. On the other hand, corn cobs and sugarcane bagasse proved to be difficult to process mechanically due to their stiffness (cob) and the large amount of fiber (sugarcane bagasse); both factors made it difficult to use the processor and blender. However, it was possible to make a considerable decrease in the physical size of these inputs, allowing the calcination process to occur satisfactorily.

Figures 1, 2, and 3 present the organic matter as they were collected, and Figures 4, 5 and 6 show the appearance of the samples after having gone through the procedures mentioned above.

The calcination of the processed materials was able to reduce them to ash without major problems. The mass losses of each residue (in view of the release of organic matter and water) were quantified and are presented in table 2, in comparison with theoretical data from other calcinations of the same types of raw materials.

The yields obtained experimentally for eggshells and corn cobs were very close to the theoretical data, exceeding only 5% in the first case and being only 1% below in

Figure 1 – Sugarcane bagasse.

Source: Author.

Figure 2 – Corn cobs.

Source: Author.

Figure 3 – Eggshells.

Source: Author.

Figure 4 – Processed sugarcane bagasse.

Source: Author.

Figure 5 – Processed corn cobs.

Source: Author.

Figure 6 – Processed egg shells.

Source: Author.

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Material	Performance in Literature	Observed Yield
Eggshells	40 % a 50 %	55%
Corn cobs	2%	1%
Sugarcane bagasse	10%	0,5%

Table 2 – Theoretical and experimentally obtained yields in percentage.

Source: * PAULA et al. (2009), NERIS *et al.* (2018) e CORNEJO, RAMALINGAM and REIMANIS (2015).

** Author.

Figure 7 – Sugarcane bagasse ash.

Source: Author.

Figure 8 – Corn cob ash.

Source: Author.

Figure 9 – Ash from egg shells.

Source: Author.

the second. However, there is a substantial difference in the percentages of sugarcane bagasse, with the literature record being about 20 times higher than the experimental one. This fact can be caused by several reasons, such as the type of sugarcane used, its cultivation method, climatic conditions, soil in which it was developed, amount of water inside, processing method, among others. Due to this low yield, the sugarcane calcination needs to be carried out a large number of times, until a satisfactory amount is obtained.

Figures 7, 8 and 9 present the visual appearance of the ash removed from the muffle and already packed in the proper containers. It is possible to observe a whitish color in all of them, due to the presence of CaO (in the eggshells), SiO2 (in the sugarcane bagasse) and Na2O (in the corn cobs). Small gray dots are also noted, as there may also be other types of oxides in the ash.

While the calcination step took place sequentially, the ashes were left in a desiccator to ensure that they did not absorb any type of moisture from the atmosphere, resulting in a material suitable for the experiment.

The analyzes of the TG/DTG thermograms of the three ashes were performed to determine the percentages of the metallic oxides of interest present in them. The thermogram of sugarcane bagasse, with the application of the first derivative for better visualization (DTG), indicated a first loss of mass around 100 ºC, possibly because of the moisture (water) that still persisted being eliminated. of the samples. Then, you can see the beginning of a second event around 1000 °C, whose curve does not appear completely due to the temperature range used initially (25 to 1200 °C).

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As SiO_2 is the most present oxide in the ash under analysis, and knowing the fact that the decomposition temperature of this compound is very high, it can be said that this second curve is associated with silica. Observing the Y axis (mass %) at the beginning of the aforementioned curve, one has the information that there is 86.89% of silicon oxide in the composition of this sample.

The thermogram of corn cobs also showed a mass loss close to 100 °C, also caused by the removal of water. Around 1000 °C, a second loss was noticed, this being related to Na_2O, around 92.8%. As well as the first, the calculation of the derivative was also done, aiming to make the observation of the points of mass reduction clearer.

Finally, the eggshell thermogram showed no weight loss at 100 °C, indicating that this sample had much less moisture than the others. A loss of around 400 °C is noticeable, in the case of the elimination of the other oxides contained in the mixture and, with only CaO remaining in the system (since its decomposition does not occur in this temperature range), it can be observed that the amount of this compound present in the ash analyzed, in terms of percentage, is 96%.

Then, the metal oxides of the samples were mixed based on their previously described compositions (Table 1). The materials were formed without major difficulties.

Figure 13 exemplifies two tablets obtained by forming, and it is possible to perceive good homogeneity in their color and shape, indicating that the mixture of oxides was satisfactory.

Sintering, the final part of the project, showed different results according to each test performed. The divergences were caused by the specific compositions of each tablet and, concomitantly, by the different periods of exposure to heat and different temperatures, conditional factors capable of altering the final result. In total, three tests were carried out.

In the first test, with compositions A and B, under 1500 °C and 1 h, the tablets were transformed into glass, but the conditions used led to the decomposition of the glassy mass at the end of the process. Although, in the literature, this temperature has been used in the manufacture of glass, these conditions were not suitable for the present experiment.

The second test used compositions B and C. After sintering at 1300 °C for 1 h, it was noticed that B also decomposed as in the first test, while C did not show any visual changes, suggesting that this is a mixture that would need higher temperatures. higher or longer heating time for glass formation.

The third test used composition D and was done in a porcelain crucible. After sintering at 1359 °C for 2 h, glass formed inside the container, showing that these conditions are adequate to generate the final product in the desired shape.

Figure 14 shows the glass produced. It is possible to notice that the referred material has a dark amber color, precisely due to its composition, and it is possible to change this characteristic by adding pigments, if necessary.

CONCLUSION

It can be concluded, in view of the results obtained, that it is possible to produce glass from organic food waste, provided that these undergo a process of cleaning, drying, calcination, quantification and the sintering parameters are strictly controlled.

However, some aspects can and must be highlighted in order to improve and adapt the technique used. Calcination yields were very varied and, specifically in the case of sugarcane bagasse, the percentage of ash obtained was only 0.5%; With such a low rate of use, the energy used to calcify a larger mass of organics (in order to obtain

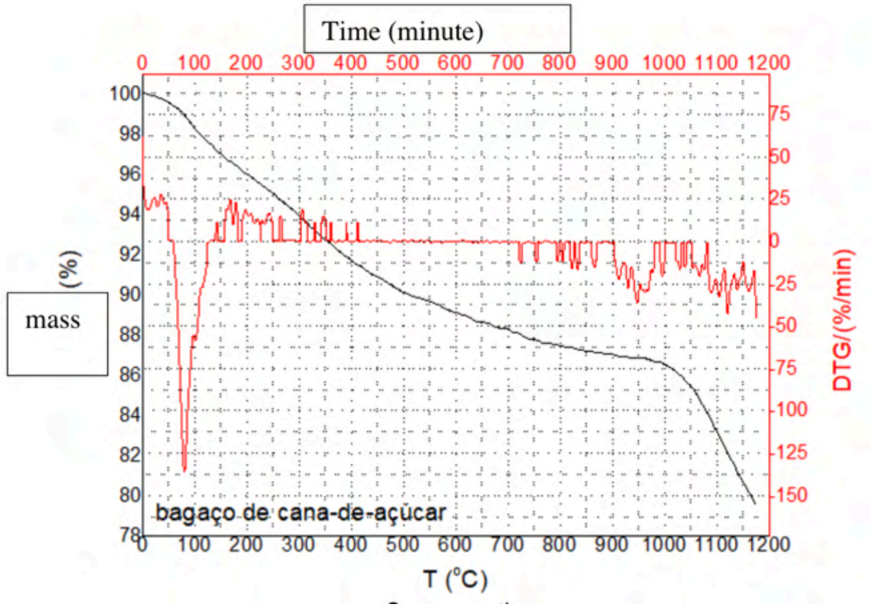

Figure 10 – TG/DTG thermograms of sugarcane bagasse.

Source: Author.

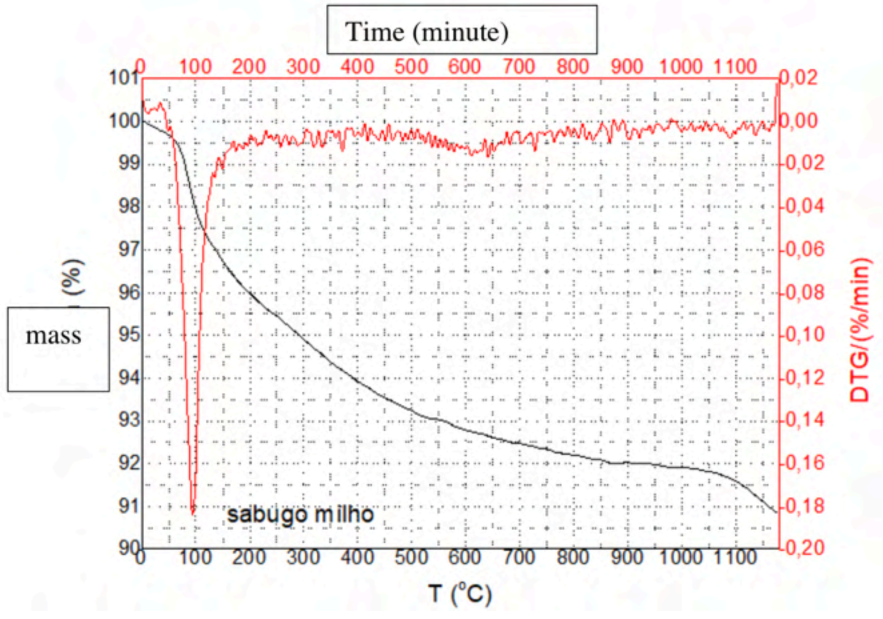

Figure 11 – TG/DTG thermograms of corn cobs.

Source: Author.

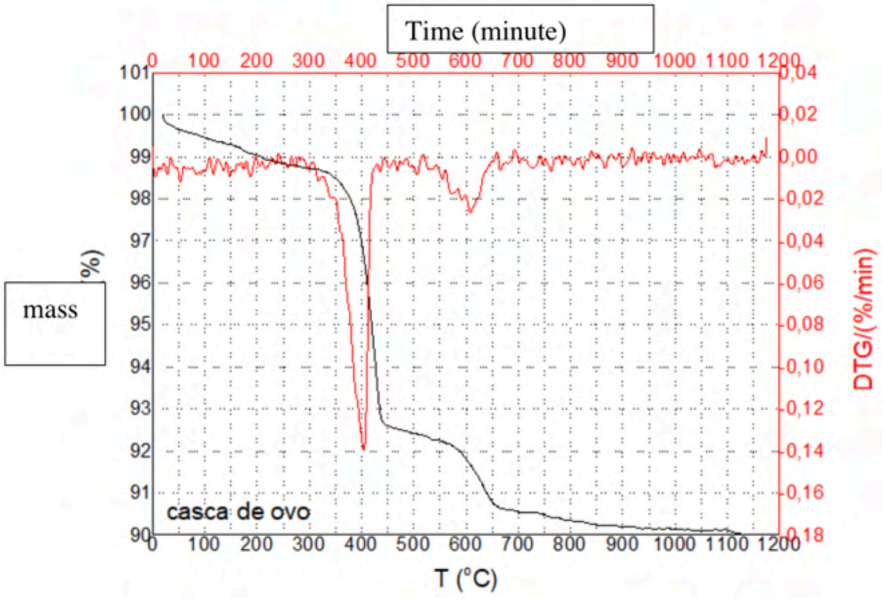

Figure 12 – Eggshell TG/DTG thermograms.

Source: Author.

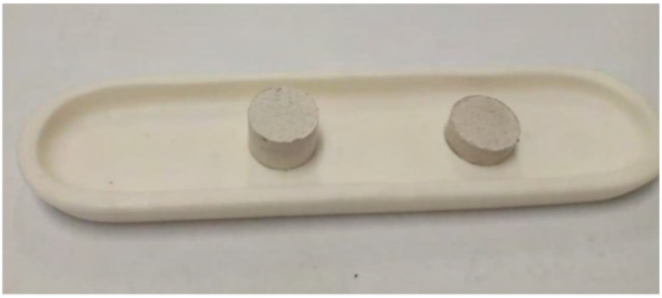

Figure 13 – Formed powder pellets before being taken to the electric oven to obtain the glass.

Source: Author.

Figure 14 – Glass produced with composition D.

Source: Author.

a satisfactory amount of oxides) ends up being higher, generating a higher cost for the procedure and preventing it from being even more sustainable.

Therefore, two alternatives can be studied in the future to overcome the aforementioned difficulty. The first one is to test various types of organic residues, submitting them to calcination and quantification, in order to find the best options for obtaining the metallic oxide of interest, with higher yield and better ash composition. The second alternative is, instead of producing glass entirely from food waste, to incorporate only certain oxides obtained by the calcination of waste (with favorable yield) in the common glass production chain.

Eggshells, for example, are easy to clean, process, have a good yield and percentage of CaO, making it feasible to use them to obtain the oxide of interest and add it to glass production, while other types of oxides, which are obtained by calcination would be unfeasible or too expensive, they can have their production maintained in the original way until an environmentally favorable alternative is found.

Finally, it can also be concluded that studies and research in the area of sustainable development are constantly growing and are fundamental to guarantee the supply of social needs with reduced (or no) environmental degeneration, an extremely important factor in the contemporary era.

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