Use of sugarcane bagasse ash into silicon products

Aproveitamento da cinza do bagaço de cana de açúcar para a obtenção de produtos de silício

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ABSTRACT

Electricity and steam are produced from gasification process of sugarcane bagasse, a residue from alcohol, sugar and molasses production. The fly ash produces from gasification process are collected frequently by water spray gas filter in chimneys which is added to ash from boiler and bottom and afterwards it is very often discarded on soil which causes its degradation. The ash composition indicates a high concentration of quartz and charcoal powder. It is proposed a method which employing an alumina high temperature reactor to transform into silicon products. The heat source applied was microwaves in a resonant cavity, using a commercial microwave oven. It was characterized the regions of standing waves in the oven, in order to that the reactor could be placed in the most favorable position for heating. So far, it was possible to synthesize cristobalite, silicon carbide and metallic silicon. A new study in order to obtain other products may be conducted from different conditions and gases.

Keywords: Bagasse; Microwaves; Silicon.

RESUMO

Quando a cana é utilizada para produzir álcool, açúcar e melado, o bagaço é gasificada para produzir vapor e eletricidade. Na chaminé, um filtro com jatos de água recolhe as cinzas volantes misturado-as com as cinzas da caldeira; estas cinzas são descartadas nas plantações de cana ou em locais específicos, com danos ao meio ambiente. A composição da cinza indica uma alta concentração de quartzo e de carvão vegetal em pó. Neste trabalho foi proposto um método para transformar esta cinza em produtos de silício, usando um reator de alumina de alta temperatura. Como fonte de calor foi utilizado um forno de micro-ondas como uma cavidade ressonante, onde existem regiões bem definidas de ondas estacionárias, apropriadas para colocar ali, algum absorvedor destas ondas. A primeira parte deste trabalho foi localizar as posições das regiões de onda estacionária, espalhadas em toda a cavidade. Apó só, coloca-se o reator nessas regiões, esperando o aquecimento máximo capaz de iniciar as reações químicas esperadas. Até agora, pôde-se sintetizar a cristobalita, carboneto de silício e silício metálico; outros produtos podem ser obtidos de acordo com os gases utilizados.

Palavras chave: Bagaço; Micro-ondas; Silício.

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INTRODUCTION

Sugarcane is crushed mechanically in order to obtain a broth used for ethanol production, sugar and molasses. The remaining sugarcane by-product, called sugarcane bagasse, is used as fuel to produce steam and drive an electric generator. The steam and electricity generated is used in the plant itself, and extra electricity is sold to the energy market. This sugarcane processing waste, if not properly handled, can become a danger to the environment. This concerns ash and soot, called fly ash, eliminated by the chimneys of the plant and now, under pressure from environmental agencies, collected in a water spray gas filter. This fly ash together with the boiler ash, called bottom ash, consists mainly of quartz (60%), oxides (mostly Fe, 10%) and coal (30%). At this time, tons of water with sugarcane bagasse ash are thrown on the ground, saturating it and causing changes in the natural watercourse1.

Using a hydrocyclone, it is possible separate the carbon from the majority of sugarcane bagasse ash and produce charcoal briquettes2, but a quantity of quartz and other inorganic compounds remains and may be recycled. The recovery of silicon requires a reactor that reaches high temperatures, above 1000 °C3-5.

Among the heating methods developed in recent years, microwave heating stands out. It was decided to use it because of the presence in sugarcane bagasse ash of carbon microparticles, which are known to be good absorbers of microwaves6, and their heating can catalyze a chemical reaction between quartz (SiO2) and the coal itself7.

In order to harness the energy of microwaves, it was used a rectangular-shaped resonant cavity, i.e., a commercial microwave oven. From the Maxwell’s equations as function of the cavity geometry and microwave frequency is theoretically possible to find the hot zone also known as regions of standing waves. The first study of stationary wave region distribution8 showed that for each cavity, the distribution of standing wave regions must be known, and this should be the first study before starting any assembly that uses microwave energy as a heat source.

In initial tests using a quartz reactor, it was found that microwave absorption by carbon in the sugarcane bagasse ash, raised the temperature to values close to 700 °C, below the temperature required to initiate the chemical reactions expected of 1000°C that is required to initiate the chemical reactions expected. The high temperature alumina used yields the expected temperatures because of the thermal runaway process in alumina9. The initial purpose of this work was to use carbon microparticles present in sugarcane bagasse ash (and not burned in the boiler) as microwave absorbers in a resonant cavity. The resultant heat would cause a chemical reaction between SiO2 and C, promoting the formation of silicon carbide or, metallic grade Si as function of temperature process.

MATERIALS AND METHODS

The starting material in this study was the ash from sugarcane bagasse, which was a mixture of the ash collected in the water spray gas filter of the chimney and ash from the boiler. This mixture was dried at 150°C and afterwards sieved with different mesh sizes to mesh 120. With the help of a magnetic separator, consisting of a rubber band, carrying the ashes next to a Nd magnet bar (12 kGaus), was possible to remove (~ 60%) of iron present in the ash.

A commercial microwave oven (1kW maximum output, 2.45 GHz) was used as a resonant cavity, including the microwave generator. Commonly, the magnetron valve of the microwave generator requires two transformers: one for the filament (low voltage, high current) for the increasing electron flux and another (high voltage and low current) to apply a high voltage between the valve body and the filament to produce microwaves. The power supply has a dual transformer: high voltage and low voltage. To be able to control microwave energy, the low-voltage transformer was disconnected and substituted with another, with the same characteristics, controlled by an auto-transformer (Variac) (Fig. 1). Thus, the injection timing and intensity of microwaves could then be controlled.

For the purpose of to map the standing wave regions, a glass of the same size as the resonant cavity was placed horizontally. The moistened thermal paper was placed on the upper surface, and the microwave oven turned on for 2 min. The black spots obtained (Fig. 2) indicated the convenient position to put the reactor10.

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Figure 2: The black spots in a moistened thermal paper shows positions of standing wave regions in the resonant cavity, when microwaves is turned on for 2 min

Figure 1: Microwave control system, incorporating one auto-transformer for change the electrons flux of the filament and therefore, of the emitted microwaves

This procedure was repeated shifting the glass 4 mm each so as to be able to obtain the size of the regions of standing wave. Each of thermal papers obtained in this work stage, was scanned and analyzed utilizing the ARCGIS program, which shows a 3D distribution of the standing wave regions.

In order to obtain the desire compounds which occur at temperatures above 1000 °C, a tube appropriate to high temperature from alumina of 10 mm diameter, closed end with a parabolic shape (Fig. 3), was used. In this configuration, the carbon micro-powder initially absorbs microwaves, heats the alumina tube to a temperature where the thermal runaway effect begins to take effect, transforming it into a heat source.

SiO2 (s) + 3C (s) → SiC (s) + 2CO (g)
To obtain silicon, the following reaction was expected:
SiO2 (s) + 2C (s) → Si (s) + 2CO (g)

RESULTS AND DISCUSSION
The use of ARCGIS software showed that the standing wave regions in a resonant cavity, such as a microwave oven (Fig. 4), are not symmetrical or regular. It is necessary to determine the positions of standing waves to better leverage these regions for heating.

Knowledge of the distribution of standing wave regions led to place the alumina reactor with the sugarcane bagasse ash in regions of high concentration energy. After the pre-vacuum and purging with argon, the system was heated using microwaves. The crystallographic analysis, using a Shimadzu XRD 6000 diffractometer and the software Crystallographica, for three different temperatures are shown in Figures 5, 6 and 7.

At higher temperatures, 1500 °C, silicon carbide appeared\(^{(13)}\) (Fig. 6). Silicon carbide is a silicon and carbon compound with high erosion resistance, high corrosion and thermal cycling. A variety of silicon carbide is moissanite.

Its hardness is very high, with a value of 9.25; in nature, it is a very rare material, so it is normally obtained in the laboratory. Other phases of quartz coexist and are also shown in these figures.

For silicon carbide, SiC:

SiO2 (s) + C (s) → SiO (g) + CO (g)
SiO (g) + 2C (s) → SiC (s) + CO (g)
or

Figure 3: Diagram reactor showing on the top, the flange (with O’ring) for vacuum and alumina tube (in yellow) support

Figure 4: Standing wave regions of a microwave cavity obtained by ARCGIS program using the thermal paper moistened. It can be verified that these regions are small in thickness, with low homogeneity

Figure 5: At low temperatures, 1200 °C, the formation of cristobalite was favored as shown in this diffractogram. A large crystal obtained appears in detail.
Figure 6: Moissanite, a silicon carbide form, present with silicon carbide at 1500°C.

Figure 7: In high temperature >1700°C, began the silicon formation (black peaks). In this stage, SiC (gray peaks) and cristobalite (full black peaks) coexisting.

Silicon was formed at very high temperatures, above 1700°C (Figure 7). It is a very important element in the electronics industry.

CONCLUSIONS
These experiments serve to show that it is possible, using simple materials, to achieve high temperatures. We must continue to work to obtain specific materials and not just mixtures between them. It considers that at very high temperatures, the dissociation or change in state of some materials may eventually complicate efforts to obtain pure materials.

Other silicon compounds can be obtained, depending on the gas used for purging and as part of the reaction; for example, it is possible to obtain silicon nitride if nitrogen were used as the purge gas in place of argon.

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REFERÊNCIAS