Activated carbon production from yeast residues to boost up circular bioeconomy

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1. Introduction

The exploitation of bio-resources in order to overcome the challenges to be faced will require a process of innovation to boost up the global bioeconomy. Therefore, it is sought the conversion of biomass, preferably from the management of residues or renewable sources, in inputs that supply chemical and pharmaceutical companies, as well as in products for the food industry, the production of energy, and that enable new technological applications, including environmental remediation and green processes (Enriquez-Cabot, 1998; ETP, 2011; Labuto and Carrilho, 2016, Prasad, 2016). In the meantime, several activities in the productive sector employ yeasts in fermentative processes generating large amounts of yeast biomasses (YB) as byproducts. For instance, 30 g of YB is generated for each liter of ethanol produced. According to the projection made by the Organization for Economic Cooperation and Development (OECD) 158 billion liters of ethanol will be produced in 2023, indicating a great availability of YB residues. In this case, the commercial value of YB may be improved by enabling new uses of this biomass in the world bioeconomic market. Nowadays, YB has a low price (around US$200/ton) and is mainly used as feed supplement for animals due to its protein content (MAPA, 2017), and after the extraction of β-glucan it becomes a residue (YR). In this way, YR is a renewable, low-cost, and carbon-rich material (ca 43%), requires no comminution, is dried at the end of β-glucan extraction, and is usually discharged in large amounts at accessible locations, which favors the logistic of its transportation (Labuto et al., 2015).

On the other hand, activated carbons (ACs) have a global market of USD 3.22 billion (2018) and it is expected to be higher than USD 6 billions in 2023 (Global and China Activated Carbon Industry Report, 2018-2023). The ACs have an exceptionally high surface area (above 500 m^2/g) and well developed internal microporous structure, in addition to the presence of a broad spectrum of functional surface groups (Marsh and Reinoso, 2006). The ACs have gained a prominent global position, being used in food, beverage, fertilizers, pharmaceuticals, automobile and chemical/metallurgy industries as catalyst and/or support for catalysts, and as adsorbent for different applications (Araujo, 2006). Worldwide, the production of activated carbon depends on mineral carbon or materials of renewable sources, which require a series of steps involving transportation, drying and grinding in the productive process (Ioannidou and Zabaniotou, 2007). This scenario denotes the need of alternatives for the production of high-quality activated carbon from abundant raw material, which associates low cost of production with high yield. Using the principles of circular economy, in the present study YR is used to produce activated carbon by physical activation with CO_2 and water vapor, which are also byproducts of generates in ethanol production). An experimental design was used to optimize the parameters employed in the activated carbons synthesis and the efficiency of production was monitored by three responses surface area, yield, and percentage of mesopores.

2. Material and Methods

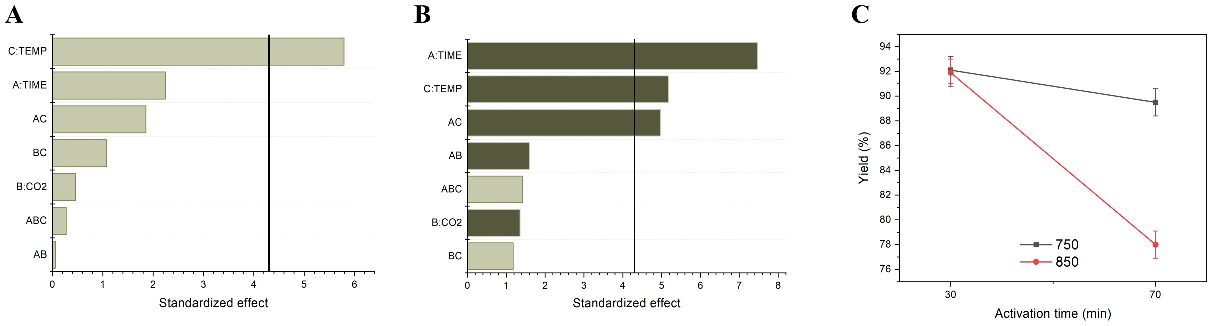
Synthesis and characterization of activated carbon from yeast residue (YR): Known amounts of YR (provided by Biorigin Company, São Paulo – Brazil) were carbonized using a heating program at a 10°C/min temperature rate up 800 °C and remained for 2 h, employing a nitrogen flow (0.1 L/min). An experimental design was conducted for the activated carbons synthesis for which the parameters varied in three levels, activation time (30, 50, and 70 min), CO_2 flow rate (0.09, 0.12, and 0.19, calculated based on the residence time of CO_2 inside the reactor), and activation temperature (750, 800, and 850 °C). The responses obtained were yield, surfaces areas, and % of mesopores. Carbonization and activation procedures were conducted in a quartz reactor (45 × 700 mm) in a 1-zone horizontal tubular furnace. Carbon and CAs produced were characterized by surface area and pore size by gas sorption analysis (BET), X-ray diffraction (DRX), elemental analysis, scanning electron microscopy (SEM), Fourier transform infrared spectroscopy (FTIR), thermogravimetric analysis (TGA), pH at point of zero charge (pH_{PCZ}), and Total Acid Groups (TAG). The best conditions predicted by the experimental design was employed to carry out a new experimental design to evaluate the influence of water vapor and the mixture of CO_2 and water vapor on the physical characteristics of the activated carbon.

3. Results and Discussion

The evaluation of the design was performed considering three responses such as yield, surface area, and % of mesopores. The standardized estimated effects (first order and interactions effects) are used in the production of the Pareto charts for the graphical evaluation of the statistical significance of the effects on each response. The obtained model as fitted explains 90.1% of the variability in BET surface area. A lack-of-fit test was performed and it is designed to determine whether the selected model is adequate to describe the observed data, or whether a more complicated model should be used. Since the p-value for lack-of-fit in the ANOVA table is greater or equal to 0.05, the model appears to be adequate for the observed data at 95.0% confidence level. The first order effect related to activation temperature (p-value < 0.05) indicated that it is significantly different from zero at the 95.0% confidence level. Temperature has a positive effect on surface area and higher surfaces areas can be obtained at 850 ^{o}C. The Pareto's chart for surface area (Figure 1A) illustrates the statistical significance of this parameter. In this chart, each bar is proportional to the standardized effect presented in decreasing order of importance. The vertical line is used to judge which effects are statistically significant at 95% confidence level. Any bar that extends beyond the line corresponds to the effects, which are statistically significant for the biosorption process. As all the effects have positive values, all bars have the same color. Three effects have p-value < 0.05, namely the first order effects related to activation time and activation temperature, and the second order interaction effect between these two factors. These effects have negative signals as one can be denoting in Pareto's chart for yield (Figure 1B). Light and dark gray bars correspond to positive and negative effects, respectively. The ANOVA was performed for the response yield and obtained model as fitted explains 97.0% of the variability in this parameter. The lack-of-fit test performed indicated that the p-value was greater than 0.05, indicating that the model adequately fits the observed data at 95.0% confidence level.

Considering solely the first order effects, higher yields can be obtained at 750 ^{o}C and 30 min of activation time. However, the significance of the interaction effect must be considered to understand the combined influence of both factors activation time and activation temperature, in the studied system. In Figure 1C, the behavior of the response yield regarding the AC interaction (activation time *vs.* activation temperature) points out that there are no significant differences of yields by performing the activation at 30 min despite the temperature employed, or at 750 ^{o}C despite the activation time spent. However, yield is significantly lower if the activation is performed at 850 ^{o}C for 70 min. The desirability function was used to obtain the most adequate activation condition, that is, the one that provides an activated carbon with the highest surface area, yield and percentage of mesopores. The higher desirability was obtained with activation at 850 ^{o}C, 30 min, and 0.09 L CO_2/min flow rate, corresponding to experiment number 7 of the factorial design, with BET surface area of 511 m^2/g, 91.5% of yield, and 11.3% of mesopores.

Figure 1. Pareto's charts for A) surface area, B) yield, and C) interaction of yield and activation time.



4. Conclusion

It is possible to produce carbon and activated carbon from yeast byproducts of fermentative processes, employing physical activation, aiming its production in an industrial context of circular economy, allowing the valorization of this type of residue with the possibility of its insertion in the bioeconomic chain.

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