Journal of Industrial and Engineering Chemistry 21 (2015) 230–238

Contents lists available at ScienceDirect

Journal of Industrial and Engineering Chemistry

journal homepage: www.elsevier.com/locate/jiec

Fast activation of natural biomasses by microwave heating

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ARTICLE INFO

Article history:
Received 24 October 2013
Accepted 17 February 2014
Available online 25 February 2014

Keywords:
Microwave heating
Biomass
Toxic dyes
Adsorption
Surface activation

ABSTRACT

Microwave was effectively applied as a fast heating tool for activating two natural biomasses, pine wood and Arabica coffee residues. The heated biomasses were tested for removing four food dyes: Allura Red E129, Sunset Yellow E110, Tartrazine E102, and Brilliant Black E151 from solution. The biomasses were heated by 2.45 GHz microwaves at different input powers 200–1000 W for 8 min. The results indicated that heating at high input powers is necessary to activate biomasses and to enhance dyes adsorption. Dielectrical properties (dielectric constant ε', dielectric loss ε'', tangent loss tan δ, and penetration depth *dp*) indicated that Arabica coffee is a better microwave absorber leading to significant structural damage when heating at high input powers. Microwave-heated pine wood showed a better performance for dyes removal compare to coffee residue. Heating at 1000 W is not recommended for both biomasses where oxidation reactions destroyed the structure of the materials. Moreover, microwave heating for long times had a bad influence on dyes removal. %Removal–adsorption capacity plot indicated that 0.8 and 1.0 g/100 mL is the optimum adsorbent dosage for E110 and E129, respectively. Analysis by Langmuir equation revealed that saturation values were 9.3 and 7.2 mg/g for E110 and E129 at pH 2.0 and 25 °C, receptively. Dyes removal by microwave-heated wood was a fast process and more than 90% of adsorbent's capacity was utilised within 30 min.

1. Introduction

Increasing adsorption properties of solid surfaces including natural biomasses is often performed by chemical or physical procedures at high temperatures [1]. Chemical activation involves treatment by strong acids/strong bases or strong oxidants; where, physical activation is carried out by heating the surface under inert atmosphere and in the presence of an activator [1,2]. For both procedures, heating at high temperatures (500–1000 °C) is necessary to end up with active surface [2]. As a result of the earlier modification procedures, active surface containing high density of functional groups and high porosity are often obtained [3]. In the conventional heating methods, the heat is generated from the source and then transferred from the external to internal part of the adsorbent by convection, conduction and radiation mechanisms [4]. Conduction of heat within the material is a slow process and consumes high amount of energy [5,6]. When using dielectric heating (or microwave heating), the heat is effectively given to the entire material in a short time [5]. In fact, microwave heating has some important advantages over classical conventional heating such as [6,7], (a) short heating time, (b) simple equipment when compared with common furnaces, and (c) less consumption for electrical energy.

To assess microwaves absorption, four characteristic parameters are necessary to be evaluated for a given material: dielectric constant ε', dielectric loss ε'', tangent loss δ, and penetration depth *dp*. The most important parameter is ε', it measures the ability of a material to store electromagnetic radiation, while, ε'' measures the ability of a material to dissipate electrical energy into heat [8]. Tangent loss is the tangent of the phase angles between the dipoles direction the irradiated material and the applied field. It measures the efficiency of conversion of radiations into heat [9]. Finally, *dp* the penetration depth shows how far a wave will penetrate inside the material before it reduces to 36% (1/e) of its intensity [8]. Dielectric properties depend on many experimental factors including the frequency of the applied field, moisture content, temperature and composition of the material [10]. Among the mentioned factors, moisture content is the most dominant factor and ε' and ε'' are often increase with moisture content [11,12]. Influence of temperature on dielectric

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http://dx.doi.org/10.1016/j.jiec.2014.02.029
1226-086X/

properties is inconsistent, increasing or decreasing with temperature depending upon the material composition, in particular moisture content and applied frequency [9,13].

In this work, adsorption of four food dyes (Allura Red E129, Sunset Yellow E110, Tartrazine E102, and Brilliant Black E151) by two common biomasses (pine wood and Arabica coffee) is studied after microwave treatment. Different varieties of wood and coffee residues have been effectively applied for removing toxic dyes from solution [14,15]. The selected biomasses are known of their availability across country and the tested dyes are often employed to colour soft drinks, chewing gum and many other foodstuffs. A domestic microwave generator (2.45 GHz) is applied as a fast heating tool to activate carbonaceous biomasses for enhancing food dyes removal from solution. As a significant experimental factor, pH of solution is studied over a wide pH range 2–12 to locate the best pH for dyes removal. Influence of mass and initial dye concentration are also studied. Effect of treatment time (4–20 min) and microwave input power (200–1000 W) on adsorption performance of biomasses are addressed. Different physicochemical tests are conducted to study the influence of microwaves on the textural properties of biomasses. The practical application of heated biomass is finally evaluated by conducting adsorption isotherms and running kinetic tests.

2. Experimental procedures

2.1. Conditioning biomasses in preparation for dyes adsorption

Pine wood was collected from a local wood workshop and stored in a closed container. The collected sample is made up of small flasks (1.0 cm × 1.5 cm). The sample was washed with distilled water and dried at 105 °C for 24 h. The collected coffee residue (Arabica coffee brand) was obtained from a local coffee shop. The grains of coffee residues (1–2 mm) were boiled with distilled water until a clear solution was obtained. The sample was then dried at 105 °C for 24 h. For most adsorption test, three to four identical measurements were repeated to get better precision. The estimated RSD values were within the range 3–10%, indicating the fair precision of the measurements.

2.2. Adsorbates

Four popular anionic food dyes of wide industrial application were selected: Allura Red E129, Sunset Yellow E110, Tartrazine E102, and Brilliant Black E151. The dyes were purchased from Sigma® with acceptable purity (60–90%). The studied dyes have high solubility in water at 25 °C and are used as colourants in many foodstuffs with maximum limit of 100–200 mg/kg [16]. The chemical structures of dyes are depicted in Fig. 1.

The pK_a values of dyes are 6.4, 9.4, 10.4, and 11.4 for E151, E102, E110, and E129, respectively [17]. A standard solution (1000 mg/L) of each dye was prepared by dissolving 1.0 g in 1000 cm^3 volumetric flask using distilled water. Buffered solutions were used in adsorption tests. A set of phosphate buffer solutions of different pH 2.0–12.0 were prepared using H_3PO_4 (0.05 mol L^{-1}), NaH_2PO_4 (0.05 mol L^{-1}), and Na_2HPO_4 (0.05 mol L^{-1}). Distilled water was used in this work. All chemicals and solvents were purchased from Sigma® with high purities.

2.3. Microwave heating

Microwave heating was carried out using a domestic microwave oven (SAMSUNG, triple distribution system, Japan) operating at 2.45 GHz with different radiation powers. Approximately, 5.0 g biomass was placed on a quartz dish. The dish was carefully exposed to the microwave radiations. The sample was subjected to microwaves for 4.0, 8.0, 12.0 and 20 min, where the material is subjected to high temperatures inside the oven. For better absorption to microwaves, biomasses were soaked in 0.01 M H_2SO_4 for 1.0 h, filtered, and then subjected to heat treatment.

The studied input powers of microwave are 200, 400, 600, 800, and 1000 W. After microwave heating, the hot samples were removed and allowed to cool down, and then stored in dry glass containers before running adsorption tests.

2.4. Physical, chemical, and dielectrical properties of biomasses

Textural characteristics including specific surface area (SSA), total pore volume (V_t), and average pore diameter of biomasses (ADP) before and after microwaving were determined using

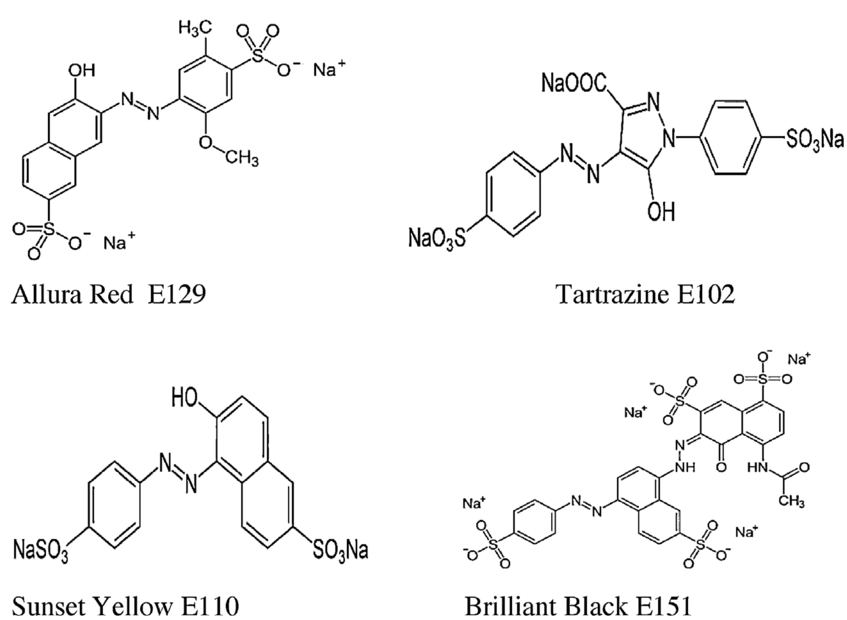

Fig. 1. Structural formula of food dyes in their sodium form.