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Constant power and constant temperature microwave regeneration of toluene and acetone loaded on microporous activated carbon from agricultural residue

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ABSTRACT

The effect of flow rate, microwave power, and humidity of purge gas on microwave regeneration of agricultural based activated carbon saturated with toluene and acetone was investigated. To compare with microwave heating, conductive heating was also employed to follow the effect on adsorption capacity, regeneration ratio, desorption rate, time and energy consumption. Desorption rate of constant power microwave heating was 32.9% per minute, which was 20 and 40 times higher than constant temperature microwave and conductive heating, respectively. Energy consumption of microwave heating (constant power) was only 4.5 kJ/g. Adsorption isotherms data can be well fitted with Dubinin–Radushkevich model.

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1. Introduction

Activated carbon has been proven to be an effective adsorbent for the removal of volatile organic compounds (VOCs) from commercial and residential indoor air as well as industrial gas streams [1]. When activated carbon reaches its saturation adsorption capacity, it is typically taken to a landfill where it can potentially pollute the surrounding leachate [2]. Therefore, the regeneration and recycling of activated carbon is of great interest to the carbon industry and users. Among the large group of VOCs, toluene and acetone, are the most frequently detected compounds within indoor and industrial air and gas streams [3]. In our previous work, the preparation of activated carbon from pine and wheat straw, by chemical activation using KOH and microwave heating was studied. The regeneration of activated carbon will lead to effective recycling, increasing the feasibility and efficiency of the material since the advantage of using agricultural wastes and microwave heating.

Microwave heating is recognized as a promising technique for the regeneration of activated carbon due to its ability to rapidly increase temperature by dielectric heating [4,5]. The dielectric heating properties can be explained by the Maxwell–Wagner effect, which depends on a material's dielectric constant and dielectric loss factor [6,7].

Many previous studies have investigated the influence of microwave radiation on adsorbents, adsorbates and adsorption–desorption processes. The different adsorbents studied includes zeolites [8–10], silica gel [11], activated carbon [12–14], and polymeric adsorbents [15]. Hashishio [16] et al. developed a microwave swing adsorption system for the capture and recovery of organic vapors from air streams using an activated carbon fiber cloth. Roh et al. investigated the feasibility of microwave application in the adsorption–desorption cycle of zeolites H-ZSM-5 for the removal of NO_x [10]. However, in their work, it showed the pure zeolite does not absorb microwave heat and only constant power experiment was conducted. Therefore, it is important to find other materials such as activated carbon which can absorb microwave heat and also need to vary the different experimental condition i.e., constant temperature and power. Previously microwave heating were also used to investigate the

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regeneration of methylene blue-loaded activated carbon produced from durian shell and jackfruit peel [17], mangosteen peels [18], and fibers, empty fruit bunches and shell of oil palm [19]. Microwave regeneration may increase the surface area of the adsorbent resulting in a higher adsorption capacity for VOCs. Ania [2] et al. compared a microwave device to a conventional electric furnace, where the regeneration of phenol-saturated activated carbon was studied. Chen [13] et al. optimized the operation conditions for microwave irradiation of activated carbon loaded with toluene. However, to our knowledge, polar of VOCs such as acetone have not been studied on agricultural-based activated carbon. This is of crucial interest due to the weak affinity of most activated carbon surfaces for polar VOCs [20]. Another challenge is that in these studies, the regeneration ratio of the activated carbon could not reach 99%, which shortens the activated carbon life span, below what is acceptable for industrial application. Additionally, processes based on microwave energy are becoming important in industrial application [21]. However, to the best of our knowledge there are no studies which compare the constant power and constant temperature microwave heating with other regeneration techniques in terms of temperature rising rate and energy consumption, by using activated carbon prepared from agricultural residues as an adsorbent.

The present work is devoted to examining the regeneration of spent activated carbons from pine and wheat straw via constant power and constant temperature microwave heating. Toluene and acetone were chosen as exampled non-polar and polar to determine which VOCs are more suitable for microwave regeneration. A focus is placed on the effect of operating conditions on regeneration of toluene/acetone saturated activated carbon, with the goal of achieving 99% regeneration ratios. Desorption rates, heating times, heating rate and energy consumptions for both microwave and conductive heating regeneration are compared. Additionally, swing capacity, measurement of adsorption isotherms and fitting with Dubinin–Radushkevich (DR) isotherm models of microwave heating were investigated over 5 adsorption-regeneration cycles.

2. Experimental

2.1. Adsorbent and adsorbate

The activated carbon prepared from pine and wheat straw was chemically activated by microwave heating using a KOH/char ratio of 3.0. A particle size fraction of 0.5–2 mm was used. The physical properties of activated carbons are provided in Table 1. Toluene (99.99%, Fisher Scientific) and acetone (99.5%, Fisher Scientific) were used as sample adsorbates.

2.2. Adsorption–desorption setups and methods

To conduct the adsorption-conductive heating regeneration and microwave heating regeneration experiment, two distinct apparatus were used, which are shown schematically in Fig. 1 and Fig. 2, respectively.

Table 1
Specific surface area and pore volume of activated carbon use in the experiment (PAC – pine activated carbon; WAC – wheat activated carbon).

Sample	Surface area S_p (m^2/g)	Micropore surface area S_{micro} (m^2/g)	Micropore volume V_{micro} (cc/g)	Total pore volume V_{pore} (cc/g)
PAC	2044	1712	0.701	0.9329
WAC	1250	993	0.411	0.601

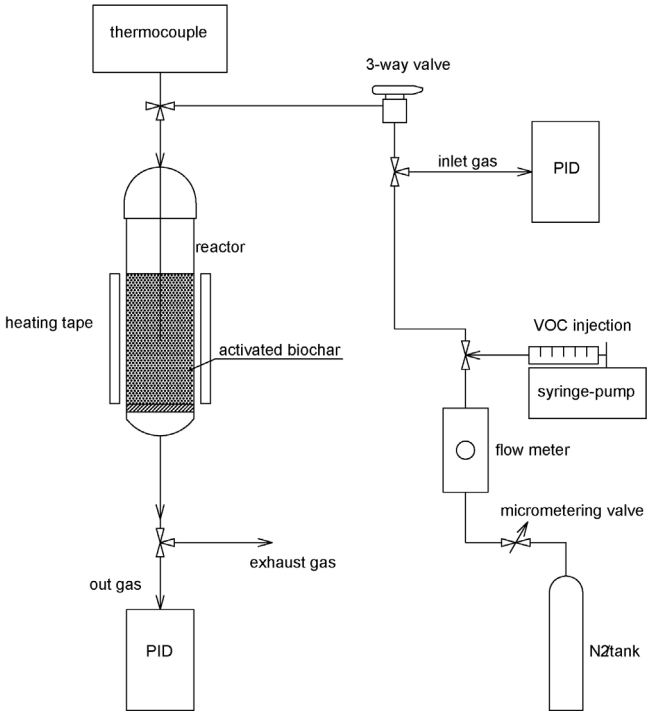

Fig. 1. Schematic diagram of adsorption and conductive heating regeneration process of activated carbon for removal of toluene/acetone.

During the adsorption cycle, the toluene/acetone vapor was generated and controlled by the use of a syringe pump (KD Scientific, model 200), where 100 mL syringe (Hamilton) was used. A 3-way valve with a photoionization detector (PID) (Rae Systems, Minirae 2000) was set to continuously determine the inlet concentration before N_2 was mixed with toluene/acetone and fed into a quartz reactor (300 mm × 30 mm) filled with 8 g activated carbon. All experiments were conducted at an initial concentration of 200 ppmv of toluene/acetone. The outlet concentration was recorded in every 10 min until the outlet gas concentration was stabilized to 99% of the inlet concentration.

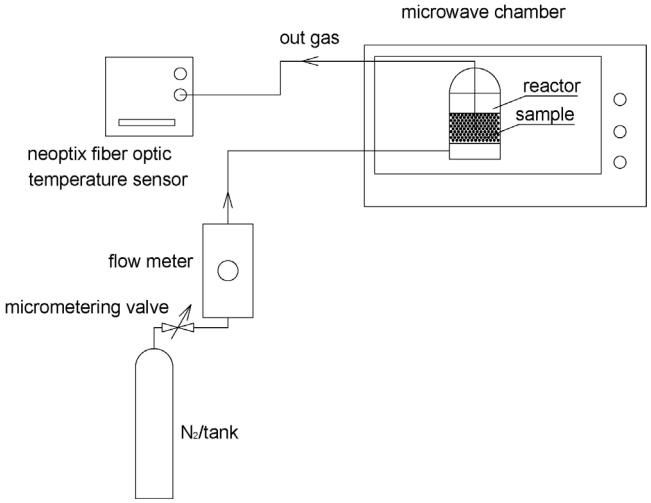

Fig. 2. Schematic of microwave swing regeneration for toluene/acetone saturated activated carbon.

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