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# Effects of Cu and CuO on the preparation of activated carbon from waste circuit boards by $H_3PO_4$ activation

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ABSTRACT

In order to study the effects of Cu and CuO on the activated carbon synthesized from waste circuit boards, we choose non-metal part without metal as the precursor, $H_3PO_4$ as the activating agent, Cu and CuO were added in the preparation process respectively. One was only activated by $H_3PO_4$, one was activated by $H_3PO_4$ and Cu powder, and another was activated by $H_3PO_4$ and CuO powder, which were named AC, AC/Cu and AC/CuO, respectively. Thermo-gravimetric analysis detected that the introduction of Cu and CuO powder into the activation process accelerated the decomposition of organic matter in the precursor. The BET surface area followed an order of AC/CuO > AC/Cu > AC. Compared with AC, the graphitization degree of AC/Cu and AC/CuO decreased, the amorphous carbon content increased, implying the introduction of Cu and CuO powder changed the activation reaction process. For these three adsorbents, the Langmuir model was better to describe the equilibrium data with a higher $R^2$ value. The maximal adsorption capacity followed an order of AC/CuO > AC/Cu > AC. Besides, the adsorptions of cephalexin (CEX) on these three adsorbents were dependent on pH values. The adsorption-regeneration cycle experiment showed they were stable for CEX removal. The characterization and adsorption experiment proved the introduction of Cu and CuO could improve the properties of activated carbon. The results of cost analysis suggested these three adsorbents were practical for producing activated carbons.

## 1. Introduction

With the advancement and growth in electronic industries, the number of electronic products has experienced a rapid growth in recent years. At the same time, the rate of replacement of electronic products has been greatly improved, resulting in large amount of waste electrical and electronic equipment (WEEE) [1]. Approximately 45 million tons WEEE are produced globally per annum and the number is growing at an exponential rate [2]. WEEE has been one of the greatest amount of solid wastes in the world [3].

Printed circuit boards (PCBs) is the fundamental component of WEEE. PCBs consists of substrate, copper foil and adhesives. The substrate is made up of glass fiberboard and plastic board. The surface of the substrate is copper foil. Copper foil is firmly glued to the substrate to form a copper plate. In other words, PCBs can be divided into metal part (30%) and non-metallic part (70%) [4]. Due to the large amounts of hazardous materials in PCBs, properly handling PCBs is a problem need to be resolved urgently.

Generally, metal part and non-metallic part are separated through various separation techniques, metals are recycled and non-metals are reused [5]. Mechanical separation is a common approach in the practical industrial process. Mechanical separation methods take advantages of the differences in density, magnetism and electro-conductivity between metal and non-metallic parts, but the nonuniformity of the particle size will make the metal and metallic oxide left in the non-metal part [6]. Copper foil is one of the major component of PCBs, thus Cu has the highest content of the metal part. The metal residues in non-metals are mostly Cu and CuO [7].

Considering the high content of carbon in non-metals due to the addition of substrate, non-metal is also a carbon source for preparing activated carbon. The residue of Cu and CuO in the non-metal may affect activated carbon prepared from the non-metal part of PCBs, in order to study the effect, we choose non-metal part without metal as the precursor, $H_3PO_4$ as the activating agent, Cu and CuO were added in the preparation process respectively. This study covered comparison of three activated carbons, one was just prepared by $H_3PO_4$ activation (AC), one was added Cu during $H_3PO_4$ activation process (AC/Cu), another was added CuO during $H_3PO_4$ activation process (AC/CuO). The studies we had performed showed the introduction of Cu or CuO had improved the performance of activated carbon. In order to

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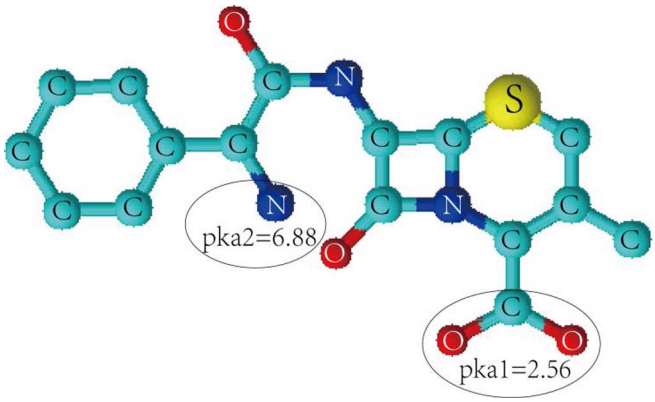


**Fig. 1.** The molecular structure of CEX.

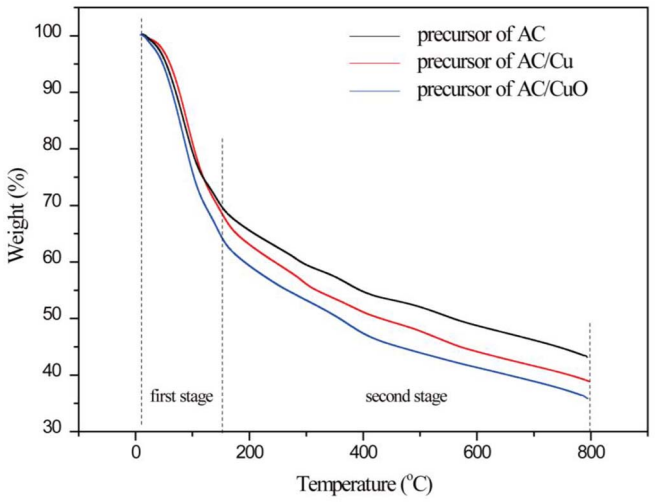


**Fig. 2.** TGA curves for the pyrolysis of the precursors of AC, AC/Cu and AC/CuO.

determine adsorption properties of three activated carbons, cephalexin (CEX) was chosen as the adsorbate.

Cephalexin is an antibiotic widely used in treating various infections in human or animals [8]. Since CEX cannot be completely metabolized by humans and animals, the residues are eventually released into the environment. Hospital, pharmaceutical factory, household, livestock and aquaculture industry are the major sources of CEX wastewater [9]. Because of the extensive usage of CEX, its presence in aquatic environment has been widely reported: for example, 10 ng/L, 182 ng/L and 283 ng/L of CEX had been detected in Qiantang River in Zhejiang [10], Hong Kong coastal water [11] and Begej River in Serbia [12], respectively. In China, the flow benchmark of CEX is 1900 $m^3$/t. CEX is highly resistant to degradation process, thus it can remain in the environment for a long time. Besides, the gradual accumulated CEX residues will lead to increase the antibiotic-resistant bacteria numbers and hinder the physiological functions of human and animal through mutagenic effects. Thus, the long-term presence of CEX in the environment will cause health problem not long in the future, which verifies the importance of removing CEX from environment [13,14]. The treatments for removing CEX from aqueous solution are biological filtration [15], reverse osmosis [16], activated sludge [17] and adsorption [18]. Among all the methods of CEX removal, adsorption has been widely used due to its advantages of low investment and simple technique [19]. Therefore, AC, AC/Cu and AC/CuO were employed in treating CEX wastewater.

As far as we know, most studies focus on employing copper salt [20–22] to modify the ready-made activated carbon, which may block the pore and decrease the BET surface area of activated carbon. However, studies about the introduction of copper and copper oxide powder into the impregnation process of preparing activated carbons are few. Therefore, the novelty of the study is to research the effect of Cu and CuO on the preparation of waste circuit boards-based activated carbon by $H_3PO_4$ activation. Compared with AC, AC/Cu and AC/CuO displayed better characteristics and adsorption properties. The surface functional groups of the three activated carbons also showed differences. The mechanisms of activation and CEX adsorption were investigated using different characterizations and experiments. The regeneration experiment was studied in this paper. In order to estimate the practicality of

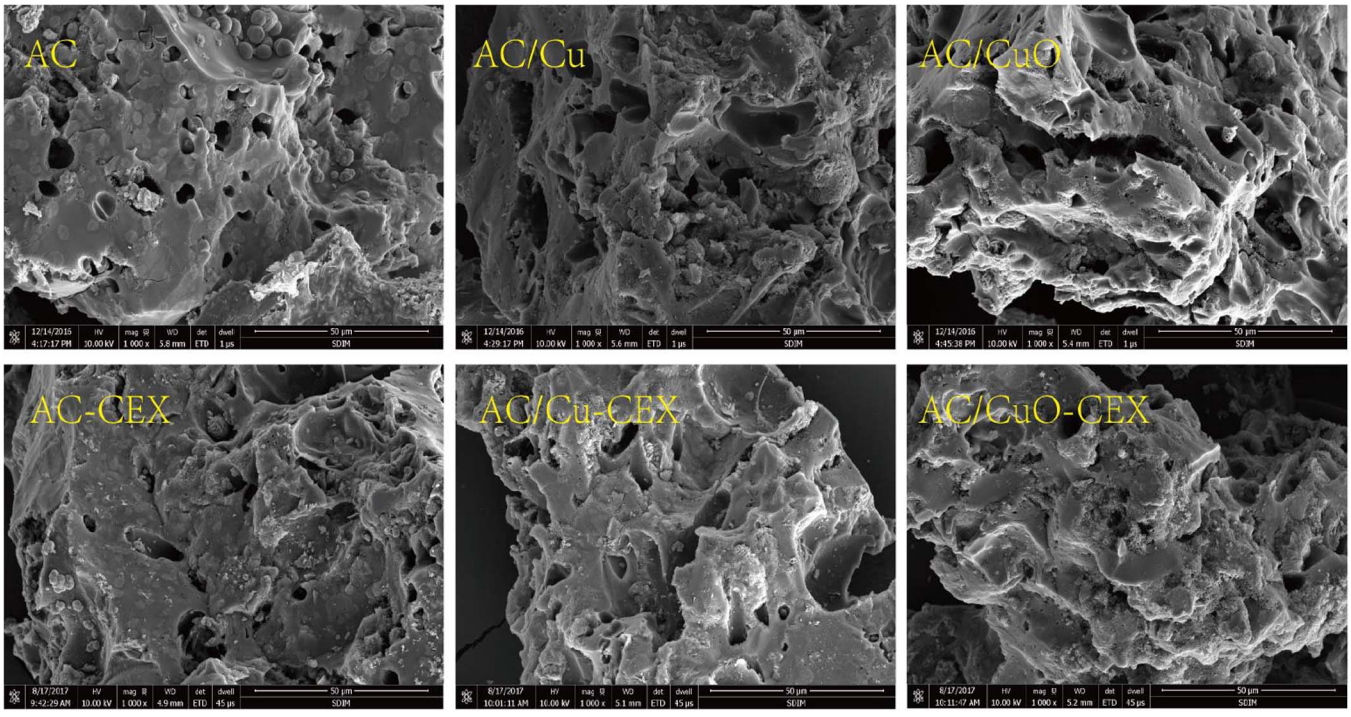


**Fig. 3.** The SEM images of AC, AC/Cu and AC/CuO before and after CEX adsorption.