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Prospect of Developed Graphite-Resin Electrodes for the Electro-Adsorption Treatment of Water and Wastewater

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ABSTRACT

The relationship between the structure of graphite electrodes and the electro-adsorption treatment process of water purification is not well documented. This paper examines the structure and other properties along with the estimated cost of graphite electrodes. Both non-heat-treated graphite-resin electrodes and commercially available heat-treated graphite electrodes were considered. The study characterized the structure of these electrodes and their prospect as materials for electro-adsorption treatment of water and wastewater. The study revealed that there was no significant difference between the selected properties of the developed graphite-resin non heat-treated electrodes and commercial heat-treated graphite electrodes at a 95 % confidence level ($F_{1,8}$ = 0.00067 and p = 0.97999). Pores observed on the surfaces of the two electrodes are similar in shape but vary in number and sizes. It was concluded that the two electrodes were similar

in structure however the prospect of the developed non heat-treated graphite-resin electrode for electro-adsorption treatment of wastewater is deemed to be higher based on its lower electrical resistance, low cost of production and availability of pores for adsorption.

Keywords: Graphite electrode, electro-adsorption treatment, wastewater, pollutants, freshwater

INTRODUCTION

Ballast and polluted wastewater can be harmful and toxic to the environment and aquatic animals in particular due to the presence of high concentration of dissolved solids and other chemical substances [1] – [6]. Ballast and polluted wastewater treatments using adsorption, electrochemical and electrodialysis are the most promising treatment alternatives. These treatments techniques provide an output that diminishes the environment polluting materials in the water and facilitates the production of environmentally friendly freshwater with minimization of solid or liquid wastes volume [7], [8], [6]. While electrochemical, ion-exchange, reverse osmosis membrane and distillation techniques have been acknowledged to be effective for the reduction of pollutants in wastewater, some of them such as reverse osmosis membrane, distillation and ion-exchange are not cost-effective and produce secondary wastes [9] – [13]. Some of these conventional treatment processes for the reduction of pollutants in ballast and polluted wastewaters have other critical disadvantages [3], [14]. For instance, application of the adsorption process only transfers the target pollutant from the liquid phase to the solid phase such as nano clays [13]. In the past few decades, electrochemical treatment technology has attracted great attention among many researchers as an advanced and emerging treatment technology for water and wastewater treatment [4], [5]. Electrochemical treatment techniques are electrical and voltage-driven technologies that have been utilised successfully in saline water and brine desalination [4], [5]. The treatment technique is based on the selective transportation of ions in aqueous solutions or electrolyte and utilises an applied electrical voltage gradient to drive anions and cations in opposite directions to the electrode [15], [16]. Electrochemical treatment techniques are adaptable and can be tailored to various types of water and wastewater, addressing specific treatment needs to meet regulatory requirements [4], [5]. Electrochemical treatment techniques often complement traditional treatment methods, enhancing overall system performance [17]. Electrochemical treatment techniques is relatively inexpensive due to its lower equipment and maintenance costs and because no additional chemicals are required [18].

In electro-adsorption, the process involves combination of electrochemical and adsorption processes. In the process, the electrodes are passive in nature and particles from the electrodes or electrode's surface act as an adsorbent to adsorb the adsorbates which are the pollutants [4], [5].

The main objective of the current study are to evaluate the structure of developed graphite resin electrodes such as reported in [19]. The study also undertakes an assessment of other properties to determine the prospects of these electrode types for the electro-adsorption treatment of water and wastewater.

MATERIALS AND METHODS

Carbon (graphite) - resin electrodes were prepared from graphite reclaimed from used and discarded dry cells. The graphite was crushed, powdered and separated into different particle sizes. A fixed amount by weight of the powdered carbon was mixed with resin and moulded into 25 mm diameter by 100 mm long electrodes. Microstructural examination was carried out on the developed electrodes and on commercially available graphite electrode (Beijing Great Wall Co., Ltd., Beijing China) using Carl Zeiss Smart Evo 10 Scanning electron microscope. The examination was carried out using the Secondary Electron (SE) detector and the High-Definition Backscattered Electron Detector (HDBSD). Further details on the preparation of the electrodes are documented in [20].

RESULTS AND DISCUSSION

Results from this study are presented and discussed as follows.

Properties and Stability of the Electrodes

The density and stability of composite carbon-resin electrode are functions of particle size, compressive forming pressure and percentage composition of the binder. Density of the electrode increased from 1.26 to 1.65 gcm^{-3} when carbon particle size ranged from 245 to 45 μm at 60 MNm^{-2} compressive pressure. It declines from 1.86 to 1.65 gcm^{-3} with a range of applied compressive pressure from 100 to 60 MNm^{-2}. The stability of the composite electrode is of increasing order with cumulative applied compressive pressure and declines with increase in current density and carbon particle size [21]. Table 1 presents ANOVA for the selected properties such as porosity, required for electro-adsorption treatment. Also, according to [22], the estimated cost of producing composite carbon-resin electrode is cheaper at \$13.25 m^{-1} than that of heat-treated electrodes at \$33.33 m^{-1},

Table 1: ANOVA for the selected properties required for electro-adsorption treatment

Source of Variation	Sum of Square	Degree of freedom	Mean Sum of Square	F-value	P-value	F critical at 95 % confidence level
Between electrodes	338.37	1	338.37	0.00067	0.97999	5.318
Within electrodes	4042820	8	505352.5			
Total	4043158	9				

SEM Microscopy of the Electrodes

Figures 1 displays the SE micrographs from the SEM examination of a sectioned and polished surface of the graphite-resin electrode surface. From the figure it is evident that the particles of the graphite-resin electrode were closely packed, and porosity is relatively low. This low porosity can be attributed to a low concentration of binder, high compressive pressure and small particle sizes utilized in the development of the electrode. The figures established that there are two categories of pores with reference to the nature of the pores. These are continuous pores (arrow A) and separated or standalone (blind) pores (arrow B). The pores have the tendency to adsorbed differing concentrations of water polluting particles at different times.

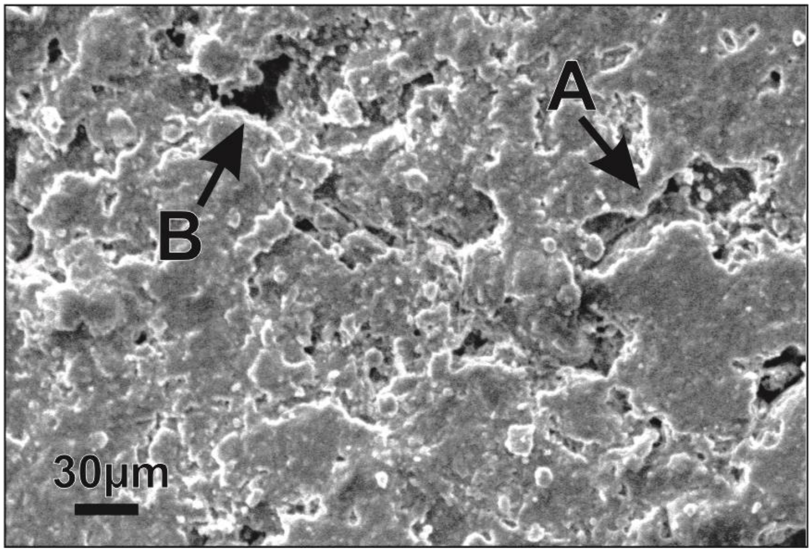

Figure 1: SEM (SE) micrograph of the non-heat-treated graphite-resin electrode showing the surface topology of the pore network

Figure 2 shows the SEM micrograph of the same region using a HDBSD detector. This detector provides a view of the compositional contrast of the surface, highlighting the distribution of the constituent phases.

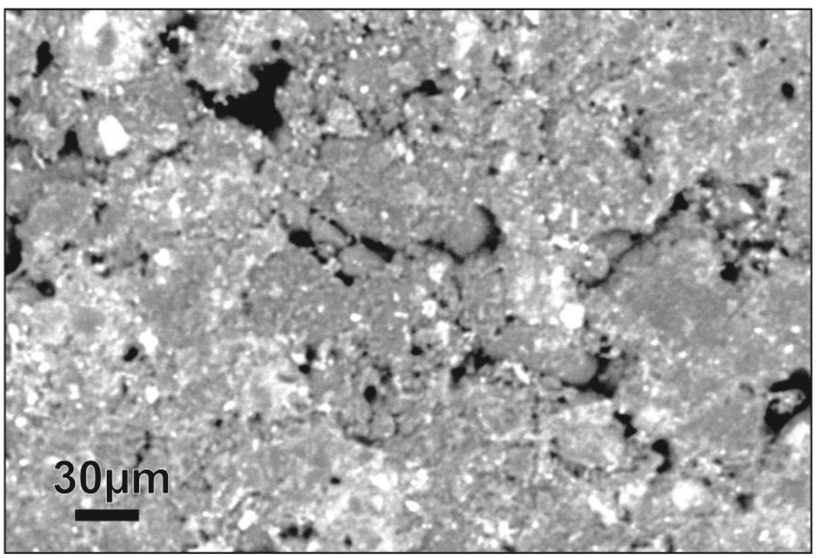

Figure 2: SEM (HDBSD) micrograph of the structures of the graphite-resin electrodes showing compositional contrast of constituent phases

From this image, the complex compositional makeup of the graphite-resin electrode is evident. The lighter regions in the image indicate the presence of high Z (atomic number) constituents while the darker areas are due to low Z elements. This is however traceable to the use of the resin binder. The darker areas are thus determined to be the graphite phase. The lighter areas are from the binder resin. However, the resin-infused areas are expected to be thinly spread on the surface, and their apparent coverage of the surface should thus not noticeably affect the conductivity of the electrode.

Figure 3 shows the SEM (SE) image of the commercially available electrode. This also revealed the presence of surface pores. These however do not appear to be interconnected. Rather, they appear to be standalone or blind pores that reach individually into the electrode structure.

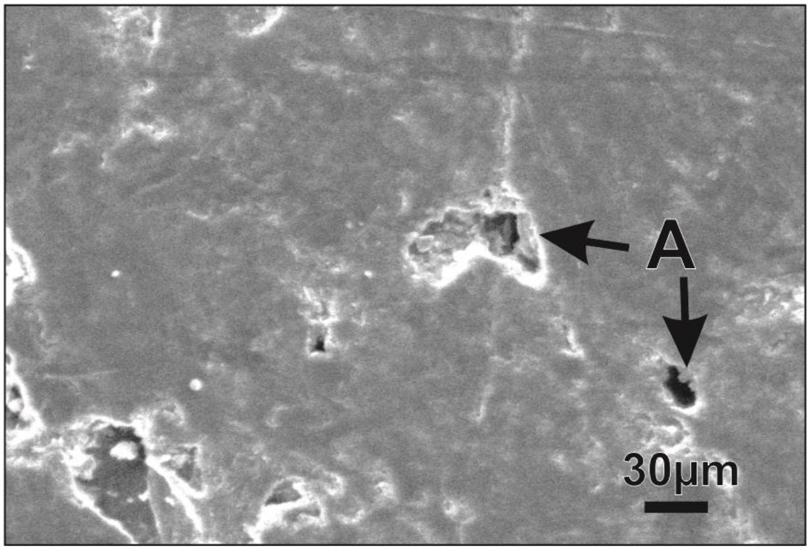

Figure 3: SEM (SE) micrograph of structures of commercially available graphite electrode the electrodes showing pores network

The SEM (HDBSD) image of the same region is presented in figure 4. This reveals a more uniform compositional make-up than was the case for the graphite-resin electrode. This is ostensibly due to the non-reliance on the use of binders in this electrode type. Also, individual particles are not discernable, indicating a very high compressive forming pressure. Furthermore, the grey region (graphite) is not occluded by any secondary phase. However, bright specks of material are embedded in the graphite matrix. The presence of pores in the two electrode types provide room for adsorption, thus making these two different electrode structures good adsorbents for the water pollutants.

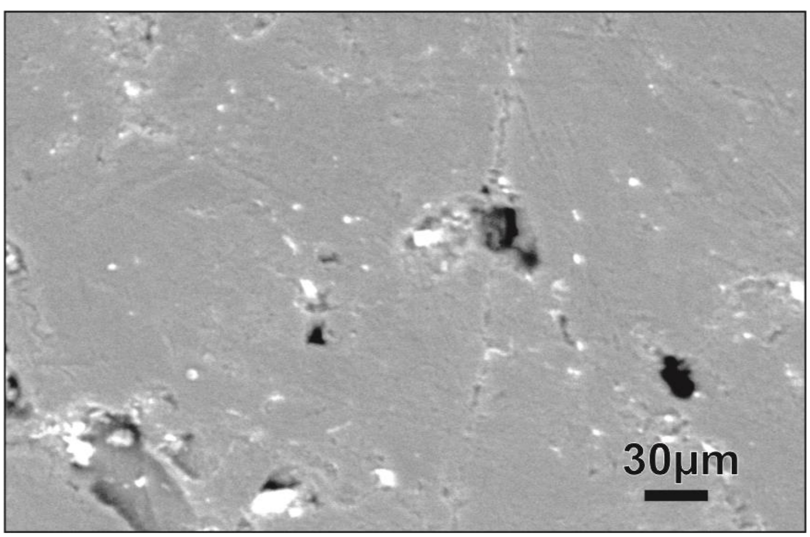

Figure 4: SEM HDBSD micrograph of structures of commercially available graphite electrode the electrodes showing pores network

CONCLUSIONS

It can be concluded that the non-heat-treated graphite-resin electrode and the commercially available heat-treated electrodes used were similar in structure. Both displayed surface pores, however the graphite-resin electrode appear to have interconnected pores; this is absent in the commercially available heat-treated electrode. The prospect of the non-heat-treated graphite-resin for electro-adsorption treatment of wastewater is deemed to be high based on its lower electrical resistance and lower cost of production.

The two types of electrodes would be suitable for electro-adsorption of water pollutants. There are however differences in compositional make-up. The commercially available heat-treated electrode exhibited a more homogenous microstructure dominated by graphite. The graphite-resin electrode on the other hand has a secondary resin-binder phase that is discernible across the surface.

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