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Investigating The Water Absorption Behavior Of Biocomposites Containing Activated Carbon And Plastic Waste For Fuel Cell Application

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ABSTRACT

Due to the rise in municipal and agro-based waste, there is growing concern about waste-to-energy conversion, especially regarding plastic waste. One highly effective approach to waste-to-energy conversion involves the potential reuse of plastic waste in fuel cells. This re-search focuses on the preparation of a polyethylene terephthalate (PET)-Activated carbon (AC) biocomposite by treating polyethylene terephthalate (PET), a commonly available plastic waste, with activated carbon (AC) derived from two different biomass sources (orange peels and sawdust). The objective of this study is to examine the impact of various biomass materials on the water absorption behavior of the synthesized biocomposite, which can serve as a cost-effective alternative electrode material in fuel cells. To accomplish this, different ratios of PET-AC mixtures were prepared using the solvent casting method. Thin films of PET-AC were formed through drying, and their water absorption behavior was assessed. The findings indicate that the sample activated with orange peels exhibits greater responsiveness in terms of moisture intake compared to the samples derived from sawdust, as confirmed by the analysis of variance demonstrating the significance of water absorption. Incorporating PET-AC biocomposites into fuel cell applications would not only decrease plastic disposal but also offer a sustainable and environmentally friendly solution for energy generation.

KEYWORDS: Biocomposite, Plastic wastes (PET), Activated carbon, Water Absorption, Waste-to-energy, Fuel cells.

INTRODUCTION

The extensive utilization of petroleum hydrocarbon-derived products has resulted in significant environmental pollution, posing serious threats to valuable natural resources. Among these concerns, the management of plastic waste has emerged as a major problem due to its detrimental impact on the environment. To address this issue and mitigate the associated environmental pollutants, the utilization of fuel cells has gained attention as a potential solution, offering the additional benefit of bioelectricity generation. The rise in the production of municipal and agro-derived wastes has spurred the development of waste-to-energy conversion methods (Adelaja, 2015). Consequently, the conversion of waste materials into valuable products without causing environmental pollution has become an essential and practical approach. In this regard, the use of activated carbon derived from carbon-based wastes has shown promise in various applications. Specifically, activated carbon obtained from biomass sources has gained attention as an electrode material in fuel cells due to its cost-effectiveness and abundance (Isil et al., 2016; Geethapriya and Barathan, 2016). Nonetheless, the utilization of plastic waste treated with biomass-derived activated carbon in fuel cells remains an unexplored area

The growing popularity of biocomposites in both commercial and research domains can be attributed to their numerous advantages, such as renewability, affordability, recyclability, and biodegradability (Michael, 2013; Brendon, 2010; Fazeli et al., 2018). Concurrently, the utilization of microbial fuel cells (MFCs) for wastewater treatment, coupled with bioelectricity generation, has emerged as an appealing and dependable technology for mitigating pollutants before their release into the environment (Adelaja, 2015).

This research focuses on the synthesis of Polyethylene terephthalate (PET)-Activated Carbon (AC) Composite biocomposites derived from orange peels and sawdust, intended for use as low-cost electrode materials in fuel cell applications. PET was selected as the precursor material due to its abundant availability as plastic waste, while orange peels and sawdust were chosen as source materials for activated carbon production owing to their widespread availability, cost-effectiveness, and carbon-rich composition (Joshua et al., 2004). The PET-AC biocomposites were synthesized using a combination of continuous and discontinuous fibers, resulting in composites derived from renewable resources that exhibit moderate mechanical properties and considerable biodegradability (Joshua et al., 2004). Additionally, the study examines the water absorption behavior of the synthesized biocomposite, with a particular emphasis on its potential as an alternative low-cost electrode material for fuel cell applications. The aim of this study is to investigate the suitability of PET-AC biocomposites as an economical substitute for electrode materials in fuel cell applications, while also considering the advantages of utilizing microbial fuel cells (MFCs) for wastewater treatment. By incorporating PET-AC biocomposites into fuel cell applications, not only can the issue of plastic waste disposal be mitigated, but also a sustainable and environmentally friendly solution for energy generation can be achieved.

METHODOLOGY

Local vendors were approached to acquire recycled plastic waste bottles (PET), which were subsequently washed and cleaned to eliminate impurities. These PET bottles were then processed into smaller pellets using a grinder. In parallel, activated carbon was synthesized from two distinct biomass wastes: orange peels and sawdust. The sawdust was obtained from local wood vendors operating at the Roadblock Sawmill in Akure, Ondo State, Nigeria. On the other hand, the orange peels (pericarp) were collected after the extraction of juice from households and juice shops. The research activities were carried out at the Federal University of Technology in Akure, Ondo State, Nigeria. The biomass precursors were separately washed in distilled water to remove dusts and impurities and then sun-dried for four days. Both biomass materials were then crushed by ball milling process to powder and sieved to acquire a particle size between 0.3-0.8 mm in order to increase its surface area; after which they were kept to be carbonized and activated by chemical method. The specifications and production units of regents and materials used in this experiment are potassium Hydroxide (KOH), Phenol and distilled water.

Preparation of activated carbon

The crushed sawdust and the orange peels were carbonized by heating at 500^0C for 1 hour and at 500^0C for 3hrs respectively, in a muffle furnace at a temperature elevation rate of 20^0C per minute from room temperature. The carbonized samples were soaked with four weights of KOH (potassium hydroxide) as the chemical activating agent in the ratio of 1:1 and left to stand for 24hrs. Then they were washed five times with distilled water to remove the excess alkali present. The resulting products (Cpeel and Cdust) were kept in hot air oven for about 3 h at 110^0C (Taer et al, 2016; Subramani et al, 2017).

Preparation of PET-AC composite samples

PET-AC composite samples were prepared by dissolution technique using solvent-casting method in phenol. Five samples of the PET-AC mix ratios of 10:90%, 30:70%, 50:50%, 70:30%, and 90:10% compositions for each of the two AC samples (Table 1) were used to form thin PET-AC films upon drying; and their water absorption behaviour was evaluated. The data collected were analyzed using simple percentage method to verify how activated carbon gotten from different sources will perform with each PET mixture. A control sample of only PET (without the addition of any AC) was also prepared to enable the study of the effect of method of activation on the composition of the waste PET for use in fuel cell application. Recycled PET acted as the polymer matrix in the composite. The optimized sample was then selected after analyzing the results of their individual water absorption behavior.

Table 1: Designation and detailed composition of the composite

Designation	Composition	Treatment
P10A0(control)	Polyethylene Terephthalate (PET) (100wt%)	Control
CP9AP1	PET (90wt%) + AC (10wt% Orange peels)	Chemically treated
CP7AP3	PET (70wt%) + AC (30wt% Orange peels)	Chemically treated
CP5AP5	PET (50wt%) + AC (50wt% Orange peels)	Chemically treated
CP3AP7	PET (30wt%) + AC (70wt% Orange peels)	Chemically treated
CP1AP9	PET (10wt%) + AC (90wt% Orange peels)	Chemically treated
CP9AD1	PET (90wt%) + AC (10wt% Sawdust)	Chemically treated
CP7AD3	PET (70wt%) + AC (30wt% Sawdust)	Chemically treated
CP5AD5	PET (50wt%) + AC (50wt% Sawdust)	Chemically treated

CP3AD7	PET (30wt%) + AC (70wt% Sawdust)	Chemically treated
CP1AD9	PET (10wt%) + AC (90wt% Sawdust)	Chemically treated

Material Characterization of the Composite

Moisture Content

The samples produced were exposed to moisture for 96 h. The weight of the samples was then recorded from a digital balance before and after oven drying at 100 °C for 12 h for the determination of moisture content.

$$Mc = \frac{Ma}{Mb} \quad (1)$$

In Eq. (1), Mc is the moisture content, whereas Ma and Mb are the masses of the composite before and after drying, respectively.

Water Absorption Test

The water absorption test of the PET-AC composites were done in accordance with ASTM D5229M-12 by immersion in distilled water at room temperature (ASTM, 2012). The samples were taken out periodically and after wiping out the water from the surface of the sample weighted immediately using a precise balance machine to find out the content of water absorbed. The specimens were weighed regularly for sixteen days. The water absorption is calculated by the weight difference of the samples. The percentage weight gain of the samples is measured at different time intervals by using the following equation

$$\text{Water absorption (\%)} = \frac{W_2 - W_1}{W_1} \times 100\% \quad (2)$$

Where, W_1 and W_2 are the weights of the dry and wet samples respectively.

RESULT AND DISCUSSION

The results of the moisture intake and the percentage of water absorption are depicted in Figure 1. It is well-known that PET samples typically exhibit hydrophobic properties when submerged in water. This characteristic accounts for the lower moisture intake observed in the pure PET sample (P10A0) when compared to the other reinforced composites, as illustrated in Figure 1. Comparatively, no notable difference in moisture intake was observed between the CP9AP1 and CP9AD1 composite blends and the control sample (P10A0). This similarity in moisture intake could be attributed to the relatively small amount of activated carbon incorporated into the blend. However, as the proportion of PET in the blend decreased, the moisture intake demonstrated a significant increase. Among the samples tested, CP1AP9 exhibits the highest moisture intake value, followed by the CP7AP3 sample. This outcome indicates a greater responsiveness of the orange-peel activated sample, in terms of moisture intake, compared to the sawdust-derived samples. Therefore, it can be inferred that as the amount of activated carbon increases within the individual samples, accompanied by a corresponding decrease in PET content in the reinforced composite, the moisture intake tends to rise. This phenomenon can be attributed to the hydrophilic nature of the activated carbon derived from biomass, which naturally possesses carbonaceous properties, rendering it susceptible to moisture and water absorption. The presence of hydroxyl groups in the activated carbon enables water molecules to form hydrogen bonds within the sample, resulting in increased water uptake within the composite (Law and Mohd-Ishak, 2011).

This trend is consistent with the average percentage water absorption behavior observed for each of the composites, as illustrated in Figure 1.

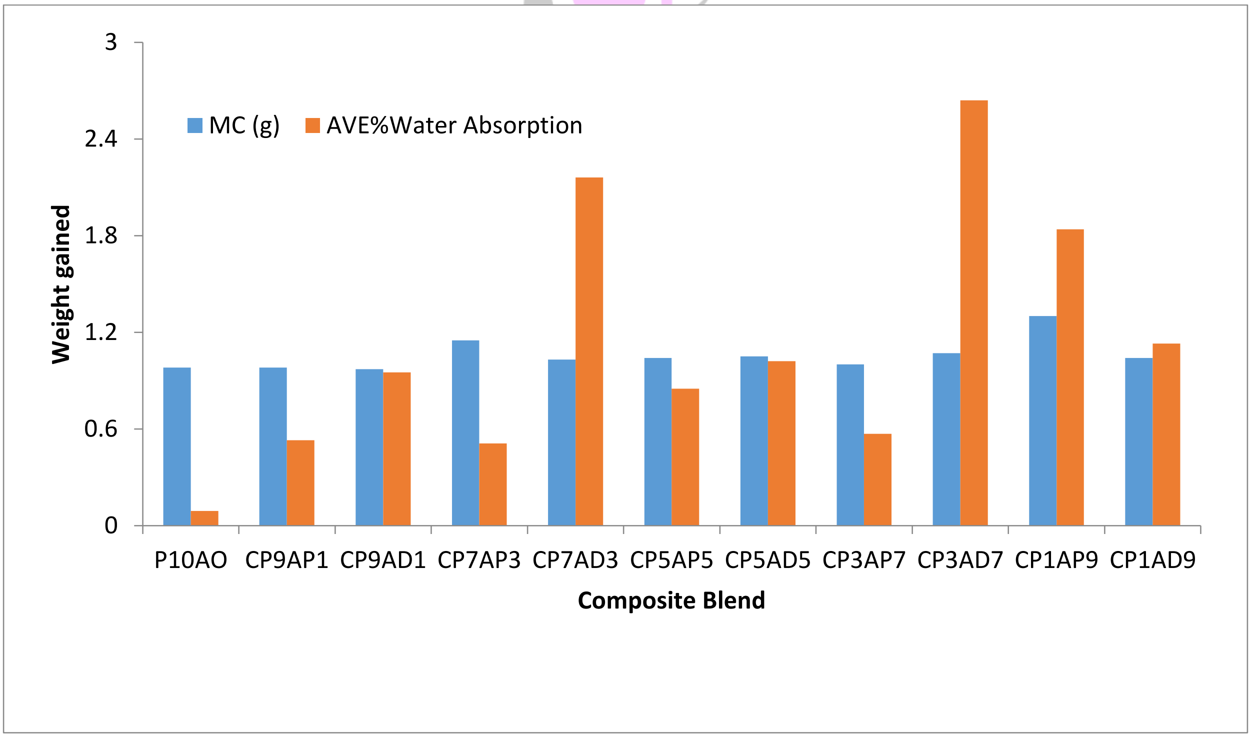

Figure 1: Moisture Content(g) and Average %Water Absorption of the PET-AC Composite

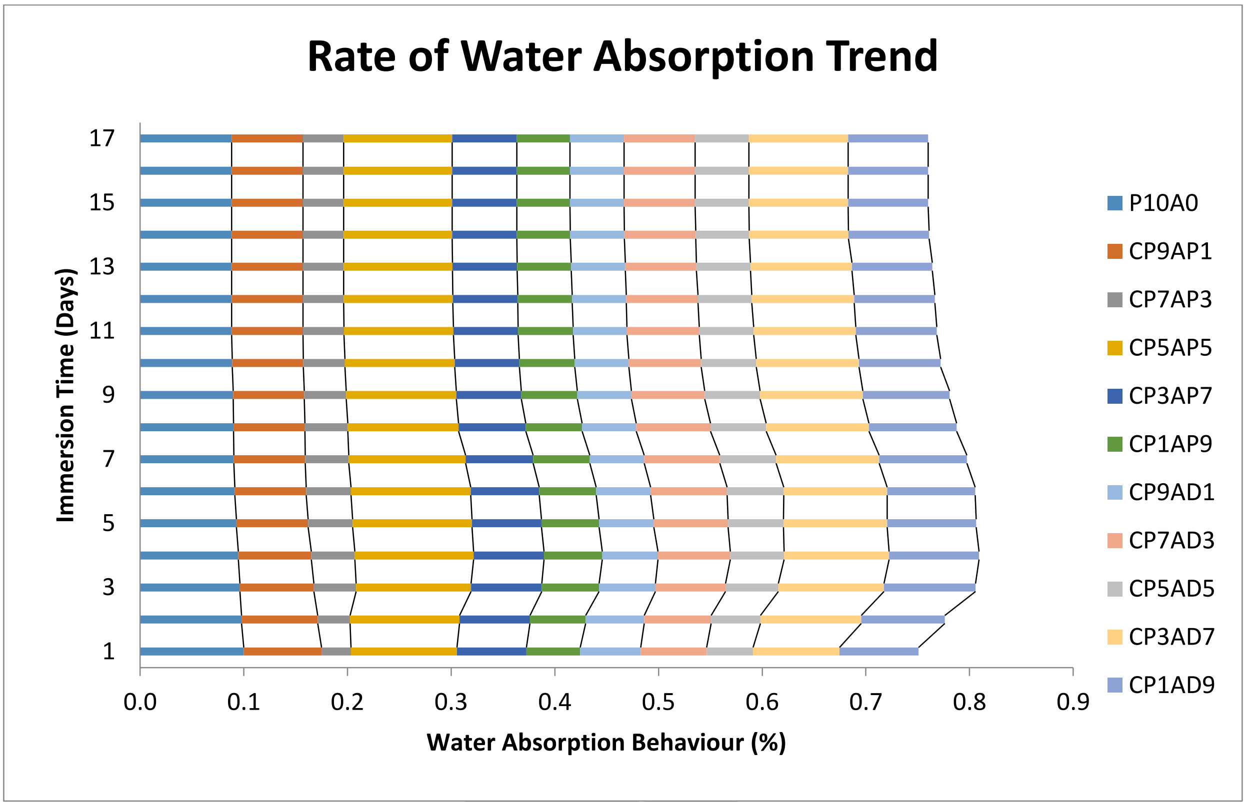

Figure 2: Rate of PET/AC water absorption trend with variation in their mix ratios

Similarly, the water absorption of the different composite blends, as illustrated in Figure 1 and 2, revealed that the percentage water absorption increases with immersion time, until a certain value is attained at saturation point (96hrs), where no more water is further absorbed. This behaviour can be attributed to the diffusion of water molecules into micro-voids between polymer chains, capillary transport into the gaps and flaws in the matrix/filler interface as well as transport by micro-cracks in the matrix formed during processing (Tezara et al, 2016), as further displayed by the rate of water absorption trend shown in Figure 2. This behaviour is found to be absent for the P10A0 (untreated) sample which has fewer flaws within its matrix, resulting in it having the lowest percentage water absorption. Fluctuations in water absorption values of the composites are possibly due to variation in prevailing absorption mechanisms such as presence of micro-cracks and interfacial adhesion (Wang *et al,* 2012). Therefore, the trend of moisture content and water absorption in the PET-AC composites is strongly influenced by PET-AC fraction present.

CONCLUSION

In summary, successful synthesis of PET-AC composites was achieved by modifying the surface of plastic waste (PET) with activated carbon derived from orange peels and sawdust biomass. The moisture content and water absorption behavior of the PET-AC composites were found to be predominantly influenced by the proportion of PET-AC in the synthesized biocomposite. Specifically, the water absorption of the composite increased as the amount of activated carbon incorporated into the matrix increased, until reaching the percolation threshold. Additionally, environmental factors such as ambient temperature, influenced by weather conditions, contributed to the overall fluctuations in composite weight and moisture absorption rates. Furthermore, the results demonstrated a higher degree of responsiveness in terms of moisture intake in the orange-peel activated sample, compared to the sawdust-derived samples. This finding was statistically significant according to the analysis of variance, highlighting the importance of water absorption. These outcomes hold promise for the development of electrode materials with enhanced conductivity and biodegradability, thereby offering an environmentally friendly approach to waste disposal

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