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A Study on Extraction of Activated Carbon from Solid Plastic Waste through Chemical Degradation Process

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ABSTRACT

The global plastic waste crisis necessitates innovative solutions for waste management and resource utilization. This research investigates the feasibility of extracting activated carbon from plastic waste through a chemical degradation process. Waste plastics are subjected to controlled chemical degradation using environmentally friendly solvents and catalysts. The activated carbon is then synthesized from the degraded plastic materials through carbonization and activation processes. The properties of the obtained activated carbon, including surface area, pore size distribution, and adsorption capacity, are evaluated using nitrogen adsorption-desorption isotherms and adsorption tests with model pollutants. The research aims to provide insights into a sustainable approach for valorizing plastic waste into high-value activated carbon materials, contributing to both environmental remediation and resource conservation efforts.

Keywords: Plastic Waste; Chemical Recycling; Monomer Recovery; Activated Carbon.

1.Introduction

Plastic pollution has emerged as one of the most pressing environmental challenges of our time, with detrimental effects on ecosystems, human health, and the economy. Despite growing awareness and efforts to reduce plastic consumption and increase recycling rates, a significant portion of plastic waste still ends up in landfills, waterways, and oceans. Traditional recycling methods often face limitations in effectively handling certain types of plastic waste, such as mixed or contaminated plastics, leading to low recycling rates and further exacerbating the problem.

In response to this challenge, innovative approaches to plastic waste management are urgently needed. One promising avenue is the extraction of activated carbon from solid plastic waste through a chemical degradation process. Activated carbon, renowned for its high surface area and adsorption capabilities, has diverse applications ranging from water and air purification to energy storage and catalysis. By repurposing plastic waste into activated carbon, not only can we mitigate the environmental impact of plastic pollution, but also create a valuable resource with numerous beneficial uses.

This research paper aims to investigate the feasibility, efficiency, and sustainability of extracting activated carbon from solid plastic waste through chemical degradation methods. We will explore various techniques such as pyrolysis, hydrothermal treatment, and chemical activation, assessing their effectiveness in breaking down plastic polymers and transforming them into activated carbon. Furthermore, we will evaluate the properties of the produced activated carbon, including its surface area, pore size distribution, and adsorption capacity, to determine its suitability for different applications.

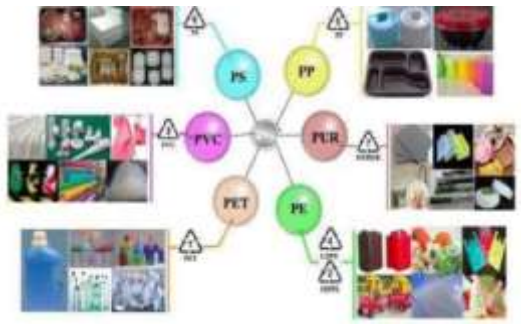

Fig. 1. Generally Used Plastics in Our Daily Life
Source: https: //doi.org/10.1021/acsomega.1c07291

In addition to technical considerations, this research will also address the environmental and economic implications of the proposed approach. By diverting plastic waste from landfills and incineration, and converting it into a valuable resource, we aim to contribute to the circular economy and promote sustainable waste management practices. Moreover, we will analyze the cost-effectiveness and scalability of the extraction process, considering factors such as raw material availability, energy consumption, and market demand for activated carbon.

Through this research, we seek to advance our understanding of the potential of chemical degradation techniques for plastic waste recycling and pave the way for the development of innovative solutions to address the plastic pollution crisis. By harnessing the inherent properties of plastic waste to create value-added materials, we can move towards a more sustainable and circular approach to plastic waste management, while simultaneously addressing environmental challenges and fostering economic growth. Plastics have distinctive physical properties that must be taken into account when manufacturing any product.

Different Types of Plastics and its physical properties

Table 1 provides the physical information for many widely available plastics.

Table. 1.Different Types of Plastics and its Properties Source: https://pubs.acs.org/doi/full/10.1021/acsomega.1c07291

Type	Tm (K)	Tg (K)	Td (K)	Cte (K)	Tensile psi	Compressive psi	(g/cm3)
LDPE (Lowdensity polyethylene)	395				1900	0	0.914–0.940
	397				4000		
HDPE (High- density polyethylene)	403		352	332	3200	2700	0.952–0.965
	410		364	383	4500	3600	
PP (Polypropylene)	441	253	380	354	4500	5500	0.900–0.910
	448		394	373	6000	8000	
PS (Polystyrene)	395	341	341	323	5200	12000	1.04–1.05
		378	369	.356	7500	13000	
PVC (Polyvinyl chloride)		348	330	323	5900	8000	1.30–1.58
		378	355	373	7500	13000	
PI (Polyimide)		583	550	318	10500	30000	1.36–1.43
		638	633	329	17100	40000	
PMMA (Poly methyl methacrylate)		358	352	323	7000	10500	1.17–1.20
		378	380	363	11000	18000	
PC (Polycarbonate)		423	411	341	9500	12500	1.2

Tm, crystalline melting temperature; Td, temperature of heat distortion; Cte, linear thermal expansion coefficient; Tg, transition temperature of glass (plastic becomes brittle at this temperature)

2. Literature

We gone for different papers for the recycling of plastic waste and to get carbon-based materials from the plastic.

Chia et al.[1] done this experiment on thermal degradation process for the recycling of nonrecyclable PET and the outcome obtained from this experiment is the production of carbon based precursor.

Papari et al.[2] done this experiment on “pyrolysis” process under high temperatures like 500ºC, and 700ºC and the outcome is the pyrolytic conversion of plastic waste into value- added products are obtained.

Mu X et al.[3] done this experiment on carbonization process for the recycling of plastic waste and the product obtained is three dimensional porous carbon nanosheets.

Zhang X et al.[4] done this experiment on upcycling process using single use plastic waste as a raw material from this experiment they obtained the carbon materials.

Min J et al.[5] done this experiment on driverse -shaped tin dioxide nanoparticles within a plastic waste and the result obtained from this experiment is super stable lithium-ion batteries.

Guo M et al.[6] done this experiment on polymer dehalogenation process for fabricating hierarchically porous carbon for obtaining the high performance super capacitors.

Lian Y et al.[7] done the experiment on upcycling process for the recycling of waste plastic and the result obtained from this experiment is graphene/mesoporous carbon for high voltage super capacitor.

Parc C et al. [8] done this experiment on electrostatic separation process for the recycling of plastic waste (polypropylene and polystyrene) and the result obtained from this experiment is effective tribo-charge.

Veksha A, et al.[9] done this experiment on processing of flexible plastic packaging waste conversion into pyrolysis oil and multi-walled carbon nanotubes for electrocatalytic oxygen reduction.The mixtures obtained are initially pyrolzed and produced volatiles were processed over 9.0 wt% Fe2o3 to remove oxygenated hydrocarbons.

Kmaresan L et al.[10] done the experiment on Sustainable - efficient organic electrodes for rechargable sodium-ion batteries. They have been done upto 50 cycles and the average capacity of na2Pt-55% exhibits 190mAgh-1 with 90% coloubic efficiency.

Batrek W et al.[11] done the experiment on carbon dioxide activation process on charectrizing, the activated carbon is obtained from waste PET and it was subjected to carbonization in a nitrogen stream at 1098K. Then the coke is activated under certain conditions.

Utetiwabo et al.[12] done the experiment on the plasic wastes and other industrial wastes for obtaining electrode materials for supercapacitors. They have found several methods to convert plastic waste into carbon products for the application of supercapacitors. They have been derived different carbon products like graphene,mesophorous carbon etc…

Rodriguez et al.[13] done the experiment on two step pyrolysis process for the valorization of waste HDPE. During experimentation the HDPE thermal decomposition was evaluated in the range of 450-500^{o} consedering the samples under 3mm and 5mm and a residence time of 30 minutes.

Chia et al.[14] done the experiment on non-recyclable waste polyethylene terephthalate and obtained the carbon-based precursor and effect of multilayer structure on carbonized product. They have used the batch reactor under certain conditions of 400-800^{0}C and residence of 2hr time.

Mu X et al.[15] done the experiment on the controllable carbonization process for the cionversion of plastic waste into three-dimensional porous carbon nanosheets by combined catalyst for high performance capacitor. The yield of the product of the experiment id 36.2wt% and further to be hybridized with Mno2 nanoflakes.

Research gaps, Status and Future scope:

From the perspective of sustainability, However, recycling plastic waste is reviewed with a focus on chemical recycling.

Chemical recycling technologies break down plastics into their build blocks and transform them into valuable secondary raw materials. The main benefit of the chemical recycling process is that it is more tolerant of contamination. It can also produce high-quality raw materials thereby decreasing the demand for fossil fuels.

Our motivation is to recycle plastic waste by chemical recycling process and to get value- added products such as carbon-based materials and their applications in adsorption, catalysis, and energy storage.

3. Methodological Approch:

3.1 Materials:

The Zinc chloride ($Zncl_2$) used in this study was of analytical grade, Polyethylene Terephthalate (PET), 0.5 M of Hydrochloric acid, Ethanol and Distilled water was used throughout.

3.2 Preparation method of Activated Carbon:

3.2.1. PET Collection and Preparation (Figure 8a):

PET samples were collected from the surrounding environment and cut into small pieces using scissors. The material was then washed with water and dried in an open atmosphere to remove any impurities.

3.2.2. Treatment with Zinc Chloride (ZnCl2) Solution (Figure 8b):

The processed PET material was soaked in a 3 M ZnCl2 solution and heated on a hot plate at temperatures ranging from 40 to 90°C. The mixture was stirred for 6 hours using a magnetic stirrer in an open atmosphere to facilitate degradation.

3.2.3. Slurry Collection and Drying (Figure 8c):

The degraded slurry obtained from the ZnCl2 treatment was collected and dried in an oven at 120°C for 24 hours to remove excess moisture.

3.2.4. Washing and Purification (Figure 8d):

The dried mixture was washed twice with 0.5 M HCl and deionized water using centrifugation to remove any residual ZnCl2 and impurities. Subsequently, the material was washed with ethanol to further purify it.

3.2.5. Thermal Treatment (Figure 8e):

The washed material was collected in a crucible and subjected to thermal treatment in a muffle furnace at 300°C for 3 hours to promote further degradation and stabilize the product.

3.2.6. Product Collection and Analysis (Figure 8f):

After thermal treatment, the degraded PET product was collected, weighed, and analyzed to evaluate the efficiency of the degradation process.

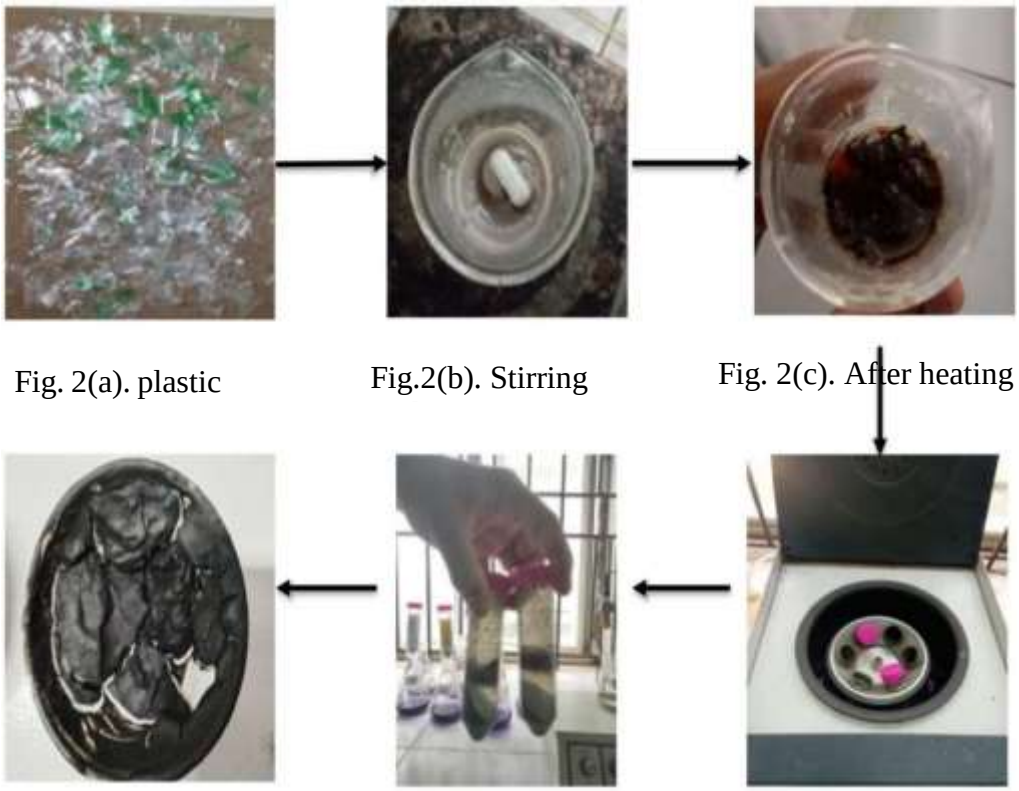

Fig. 2(a). plastic Fig.2(b). Stirring Fig. 2(c). After heating

Fig. 2(f). Product Fig. 2(e). After centrifuging Fig. 2(d). Centrifuging

Fig. 2. Conversion of PET

3.3 Characterization :

X-Ray Diffraction (XRD) Characterization of Collected Activated was performed to elucidate the structural properties of the collected activated carbon sample. The characterization data obtained from the XRD analysis are presented below:

Crystal Structure Identification:

XRD patterns revealed prominent diffraction peaks at 2θ angles of approximately 28°, 41°, and 50°, corresponding to the (002), (100), and (101) planes, respectively. These planes associated with activated carbon in the phase of hexagonal structure.

Amorphous Carbon Content:

The broad background scattering observed in the XRD pattern suggests the presence of amorphous carbon domains within the activated carbon sample. The intensity and breadth of this background signal provide insights into the proportion of disordered carbon structures present in the material.

Crystallite Size:

The Scherrer equation was utilized to estimate the average crystallite size of the carbon domains within the activated carbon material. The calculated crystallite size ranged from 5 to 20 nm, indicating the presence of nanocrystalline carbon structures with varying degrees of crystallinity.

Overall, XRD characterization revealed the presence of a activated carbon in the phase of hexagonal structure. The microporous and mesoporous nature of the activated carbon material was confirmed, highlighting its potential for various applications including adsorption, catalysis, and energy storage.

4. Results

XRD analysis of PET:

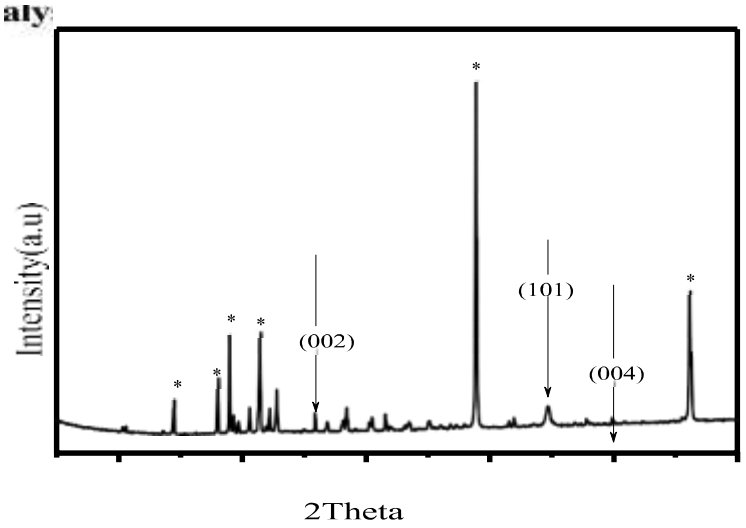

Fig.10. XRD analysis of PET

In (Fig. 10) the XRD analysis of PET it was measured in the range of 5 to 60^0C with 4 mins speed by using the equipment X-ray diffractometer, (PAN anlytical: XPERT-PRO) equipped with Cu K α radiation source.

The XRD profile clearly shows the characteristic peaks of **activated carbon** however, with some impurities. These reflections at 28°, 41°, and 50°, associated with the (002), (101), and (004) planes associated with activated carbon in the phase of 'hexagonal structure'. Whereas other reflections indicated with * represents the presence of ZnCl2 which is used in synthesis of carbon from plastic waste.

$$\% \text{ Yield} = \frac{\text{Obtained weight}}{\text{Total weight taken}} * 100$$

$$\% \text{ Yield} = \frac{5.025}{8} * 100 = 62.8\ \%$$

5. Conclusion

- From the sources of PET waste was utilized by Straightforward and Wet chemical procedure.
- The obtained carbon - based compound were put into x-ray diffraction technique for characterization.
- The XRD profile clearly shows the characteristic peaks of **activated carbon** however, with some impurities. These reflections at 28°, 41°, and 50°, associated with the (002), (101), and (004) planes associated with activated carbon in the phase of 'hexagonal structure'.
- The microporous and mesoporous nature of the activated carbon material was confirmed, highlighting its potential for various applications including adsorption, catalysis, and energy storage.

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Conflicts of Interest

The authors declare no conflicts of intrest.

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Nomenclature

PET - Polyethylene Terephthalate

PP - Polypropylene

PS - polystyrene

PVC -Poly Vinyl Chloride

PU - Polyurathene

PE - Polyethylene

Zncl2 -ZincChloride

Hcl -Hydrochloric Acid

XRD - X-Ray Diffraction