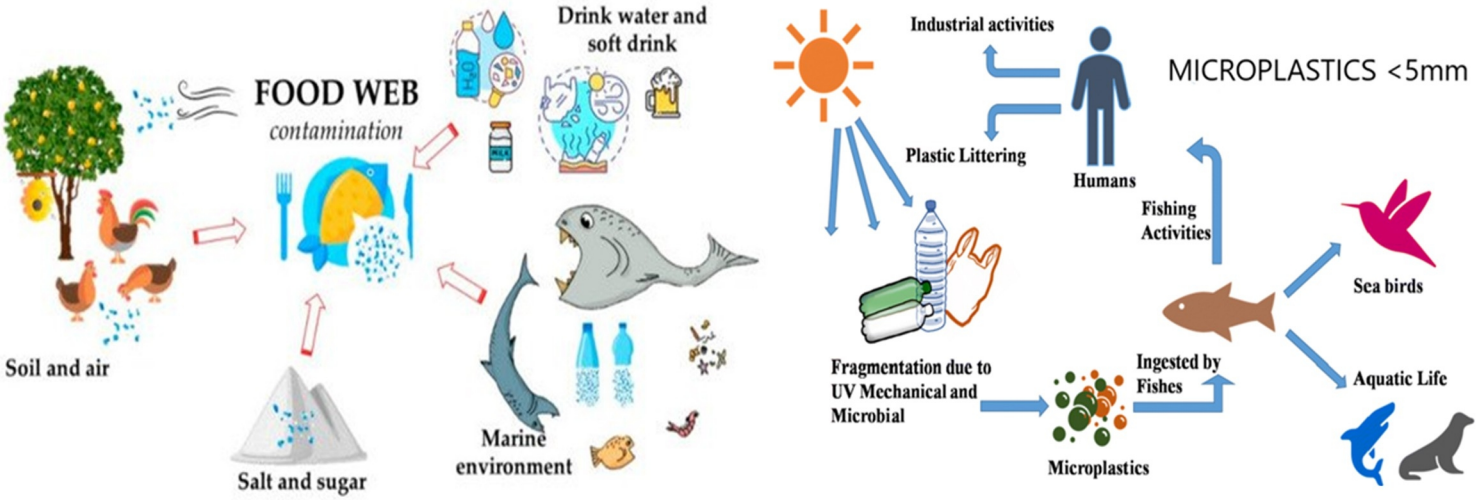
TCE EIACP PC-RP NEWSLETTER

AN EIACP RESOURCE PARTNER ON PLASTIC WASTE MANAGEMENT OF INDIA

(Funded by Ministry of Environment, Forest & Climate Change, Government of India)

PLASTIC SPEAKS

"Plastic Waste Management"



VOLUME : V - ISSUE: II
JUL - SEP 2022

This Newsletter Composes of Research Articles, Latest News on PWM, Know Your Polymer, Infographics / Statistical Data, Kids Corner & Awareness

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EIACP Resource Partner Plastic Waste Management of India

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Editorial Message

DEAR READERS,

We are very happy to bring an another issue of our Newsletter on Plastic Waste Management (PWM). The present issue majorly focuses on the current trends in PWM.

The issue also provides some infographic data on PWM. The research on finding solution to Plastic Waste has become an unavoidable scenario in the present field of research.

An elaborative research article on the same is being given in this issue for readers better understanding on the current scenario of PWM.

Thank you

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Research Article:

Source: Hindawi, Journal of Chemistry, Volume 2022, Article ID 3699076

Co-pyrolysis Characteristics and Synergistic Interaction of Waste Polyethylene Terephthalate and Woody Biomass towards Bio-Oil Production

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In this study, the impacts of co-pyrolyzing wood-based biomass from *Ficus benghalensis* with PET on liquid oil output, reactivity, and heating values were investigated. The effects of temperature on the product distribution of individual pyrolysis and the biomass-plastic ratio on co-pyrolysis were investigated. For individual pyrolysis, a maximum amount of 40.8 wt (%) liquid oil was obtained from biomass at 450°C. On the other hand, a maximum of 59.5 wt (%) liquid oil was obtained from PET at 500°C. The co-pyrolysis experiments were conducted by blending PET with biomass at different percentages, such as 20%, 40%, 60%, and 80%. At 60% addition of PET, a more positive synergistic effect was identified due to radical secondary reactions. In addition, the physical and chemical characterization studies conducted on pyrolysis oil showed that biomass and plastic materials could be used to make valuable chemicals.

1. Introduction

Due to increased population and industrialization, energy from biomass is rapidly being evaluated as a crucial option for conventional fuels [1]. According to the International Energy Agency (IEA), it is expected that biomass will account for 10% of the total global energy production by 2035 [2]. Renewability, CO_2 neutrality, and availability are the major driving forces for the utilization of biomass materials for energy extraction [3]. The world's total biomass availability is assessed to be around 100 billion tonnes per year [4]. Biomass has the ability to produce heat, power, fuel, and value-added chemicals [5].

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Through biochemical and thermochemical conversion techniques, biomass can be transformed into biofuels and chemicals. Higher biofuel production and compatibility are the main advantages of the thermochemical conversion process over biochemical conversion techniques [6]. Pyrolysis, gasification, combustion, hydrothermal liquefaction, and hydrothermal carbonization are the various thermochemical conversion techniques [7]. In the absence of air, pyrolysis is an efficient conversion process that converts biomass materials into valuable biofuels. It is a viable platform for producing fuels and chemicals from a variety of biomass. Char, oil, and gas are the three types of yields, and their energy content and yield are highly dependent on the reaction conditions.

Since 1990, the use of plastic has increased at a pace of 5% per year [8]. The increased use of various forms of plastics combined with inadequate recycling has resulted in global plastic waste management issues. In underdeveloped countries, most plastics constitute long-term economic, environmental, and health risks [9]. Urbanisation and population growth are the two important factors for the accumulation of a massive amount of plastic waste. The waste accumulation in nature severely affects economic activities and living standards [10]. Plastics are mostly produced from petroleum hydrocarbons. They are not an easily decomposable material which can endure in the environment for more than two decades. The continuous accumulation of waste plastics in landfills causes severe environmental problems for future generations [11]. Plastics come to the market in different forms and accomplish our daily needs in various domains. The production rate of plastic has improved by almost 20 times in the last six decades [12]. Polyethylene terephthalate (PET) is the most commonly used plastic for a variety of purposes, including garment fibres and liquid and food containers. Polyethylene (PE) and PET account for over half of the worldwide plastic market (40%). Due to significant advantages over other plastics, PET $(C_{10}H_8O_4)n$ is the most common plastic and comes in a variety of shapes and sizes [13]. After polypropylene (PP) and low-density polyethylene (LDPE), it is the third most popular plastic material broadly used for the packaging industry [14, 15]. Recycling of used plastics considerably benefits the environment. This process reduces the demand for raw materials as a new product can be replaced by a recycled product. Furthermore, it reduces the quantity of plastic disposed of through landfill. Like biomass pyrolysis, pyrolysis of waste plastics is a significant approach for recycling plastic wastes. Rather than mechanical and chemical processing, pyrolysis of plastic materials is a flexible approach that can produce value-added chemicals and energy-rich liquid fuel along with municipal wastes, biomass, and electronic wastes [16]. Among a variety of plastics, PET plastics are widely used in everyday life. The polymer has a wide range of industrial uses, including those in electronics, packaging, and textiles. Every year, millions of tonnes of PET materials are collected across the globe. The recyclable PET materials can be further processed and sent to the market. The nonrecyclable plastics end up in land fill, where they could take up to 500 years to degrade and might seep contaminants into the soil and water.

Due to the simplicity of the technique, energy production from biomass via thermochemical conversion could be accomplished [17–19]. Pyrolysis of giant mullein was carried out by Aysu and Durak [20]. The authors conducted the experiment in order to get more pyrolysis oil through catalytic and noncatalytic processes. In this study, at 500°C, a 10% zinc oxide catalyst produced a maximum liquid yield of 40.43 wt (%). The study suggested that giant mullein was a good candidate for the production of pyrolysis oil. In another study, Alayont et al. [21] utilized *Sinapis arvensis* biomass for the production of pyrolysis oil. The authors pretreated the biomass and processed it for pyrolysis using acidic, alkaline, and high-temperature water. The study determined that the alkaline and acidic pretreatment had influenced higher oil production. Through a characterization study, it can be understood that high temperature water and alkaline pretreatments produce mono-aromatic compounds. Biomass co-pyrolysis with waste plastics is an effective solution for plastic waste disposal [22]. The combination of biomass with plastic materials during pyrolysis produces synergistic effects that increase the value of the end products by altering hydrogen and oxygen concentrations [23]. Recently, many literatures focused on the production of high-quality bio-oil by co-pyrolysis [24, 25]. Nardella et al. [26] carried out co-pyrolysis experiments and analysed synergistic effects on product yields by utilizing fir and chestnut as softwood and hardwood biomass materials combined with the collection of PE and PS. In this study, secondary pyrolysis reactions of holocellulose biomass material were encouraged by the addition of polymeric material. Xu et al. [27] looked into the synergistic effects on co-pyrolysis of combined microalgae and plastics with the presence of zeolite. The study produced liquid with a reduced level of acids and oxygenated chemicals due to radical reactions that have also been studied in the literature [28–30]. Brebu et al. [31] investigated the synergistic effects on the production of pyrolysis oil and biochar during co-pyrolysis of pinecones and mixed plastic wastes and showed positive results with more bio-oil yield and energy-rich biochar. The synergistic effect on gas yield with tobacco straw and polypropylene was experimentally tested by Chen et al. [32]. The results also showed higher biogas production with reduced char components.

Ficus benghalensis is commonly known as the Indian banyan. It is the largest tree native to the Indian subcontinent, and it appears throughout the country in all the states and tertiary units. It is the fastest growing tree that can reach a height of 70 feet. The availability of this tree in India is plenty. The tree can grow in almost all parts of the country. Different parts of the tree, including leaves, are used for a variety of purposes [33, 34]. The wood obtained from this tree cannot be used for construction work or firewood, but it is used for making paper pulp. The hardest heartwood can be used for making small furniture. But the thin wood, stalks, and bark have no utility in terms of industry and medicine. The wood and wood bark of *Ficus benghalensis* have not been thoroughly researched in terms of biofuel production. One of the families of the tree *Ficus religiosa* was previously utilized by Rao et al. [35] for yielding bio-oil through a pyrolysis reaction. Ganeshan et al. [36] showed a degradation study of mango seed wastes with PET through a

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thermal and co-pyrolysis process. In this study, compared to mango seed kernel, the degradation of mango seed shell takes place at a higher temperature due to the higher cellulose in the shell. During co-pyrolysis, the rate of degradation of biomass was increased with the addition of PET.

In this study, experiments on the co-pyrolysis of *Ficus benghalensis* wood and waste PET were performed in a lab-scale fixed bed reactor. Thermal and co-pyrolysis characteristics of wood-based materials and PET polymers were conducted to analyse the influence of reaction temperature and biomass-to-plastic ratio on getting maximum bio-oil with improved quality. Initially, *Ficus benghalensis* and PET were pyrolyzed separately, and then, the blend was co-pyrolyzed with the addition of LDPE with the biomass at 20%, 40%, 60%, and 80% by weight to investigate the interaction during pyrolysis product yields. This study is novel in terms of feed selection. To the best of our knowledge, no study has focused on the co-pyrolysis of *Ficus benghalensis* and PET. The study ends with the physical characterization of the obtained bio-oil to determine its suitability for various applications.

2. Materials and Methods

2.1. Feedstock Preparation. The waste PET bottles were obtained from local vendors in Coimbatore, India. In order to avoid the blend of other plastic polymers, the PET bottles were carefully screened and crushed. The wood of *Ficus benghalensis* as the representative biomass was collected from the tree available at a local residence in Coimbatore, India. The collected PET bottles were smashed into a powder form. Before being utilized for experimentation and characterization studies, the biomass and plastic materials were crushed and sieved to get a uniform size of <0.5 mm and then dried in a furnace kept at 100°C for 2 hours.

2.2. Material and Product Characterization. The proximate analysis of both biomass and plastic materials was carried out by following the ASTM standards, and the results are displayed in Table 1. The facilities used by SiTarc, Coimbatore, were used for testing the samples. The ultimate analysis of the feedstocks was carried out by an element analyzer (Elementar Vario EL-III). The various chemical elements of the liquid oil were determined with the help of Thermo GC-Trace Version: 5.0, Thermo MS DSQ II spectroscopy.

2.3. Pyrolysis Experiment. The pyrolysis tests were performed in a fixed bed reactor that included a reactor, heater, condenser, and liquid collector. The reactor can be heated up to 900°C, and the experiments in this study are conducted to a maximum temperature of 600°C. For each run, 30 g of biomass and biomass-plastic mixture was placed inside the reactor, and they were pyrolyzed by keeping the reactor at the fixed temperature. The reactor was ensured to keep the reaction going in the absence of air and continued till no vapour was visually released. The reactor has a diameter of 100 mm and a length of 150 mm. The outlet of the reactor is connected to a water-cooled condenser, which is connected to a surplus amount of water kept at 0°C. Finally, the condensed bio-oil is gathered in a bottle and analysed for various physical characteristics. The amounts of liquid oil and char were calculated by weighing directly. By subtracting the liquid and solid product yields from the total, the gas yield was calculated.

Table 1: Characterization of the feedstocks.

Parameters	*Ficus benghalensis*	PET
Proximate analysis (wt (%))		
Volatile matter	70.3	83.9
Fixed carbon[a]	17.4	16.1
Moisture content	6.9	—
Ash	5.4	—
Ultimate analysis (wt (%))		
Carbon	50.1	64.2
Hydrogen	6.2	3.9
Nitrogen	1.8	0.32
Sulfur	0.3	0.09
Oxygen[a]	41.6	31.49
H/C molar ratio	1.474	0.723
O/C molar ratio	0.623	0.368
Heating value (MJ/kg)	18.1	23.4

[a]Estimated by difference.

The synergistic effect on product distributions due to the co-pyrolysis process was calculated using the following equation based on the yields achieved from individual thermal pyrolysis of *Ficus benghalensis* and PET.

$$\text{Predicted yield} = (X1 * Y1 + X2 * Y2), \quad (1)$$

where X_1 and X_2 are the mass ratios of biomass and plastic. Y_1 and Y_2 are the individual pyrolysis reactions from biomass and plastic.

3. Results and Discussion

3.1. Thermogravimetric Study. Typical TG and DTG analyses of *Ficus benghalensis* and waste PET pellets were carried out under a nitrogen environment to analyse their pyrolysis and combustion characteristics. The materials were heated from the atmospheric temperature to 700°C for biomass and 900°C for plastic material at a heating rate of 15°C/min. For biomass, the preliminary weight loss that appears at 30–100°C represents the release of moisture [37]. The sudden weight loss of the biomass was caused by the release of volatile matters after 240°C. This is also confirmed by the results obtained through the DTG curve. At around 500°C, *Ficus benghalensis* was completely pyrolyzed, and there was a progressive decline in weight loss after this temperature till 620°C. This was ascribed to the burning of biomass particles or char that remained [38]. Figure 1 represents the report of TG and DTG analyses of *Ficus benghalensis*. The unburned char is estimated as 18%, which means that the biomass is a source for the production of char up to 20 wt (%). The TG and DTG weight loss curve of PET in a nitrogen environment is shown in Figure 2. The figure shows that, unlike biomass materials, PET polymer exhibits single-step decomposition due to its homogenous structure. The degradation of polymers

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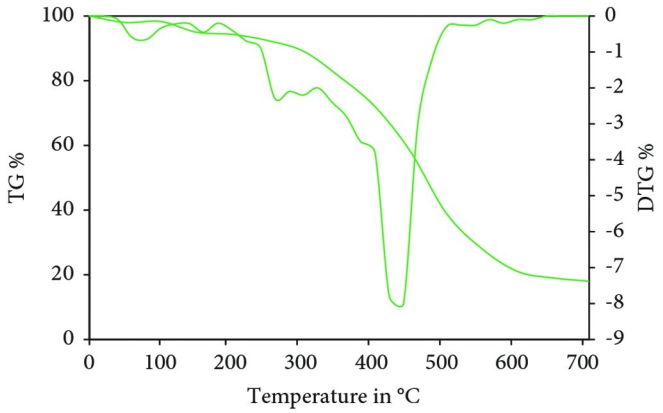

FIGURE 1: TG and DTG analyses of *Ficus benghalensis*.

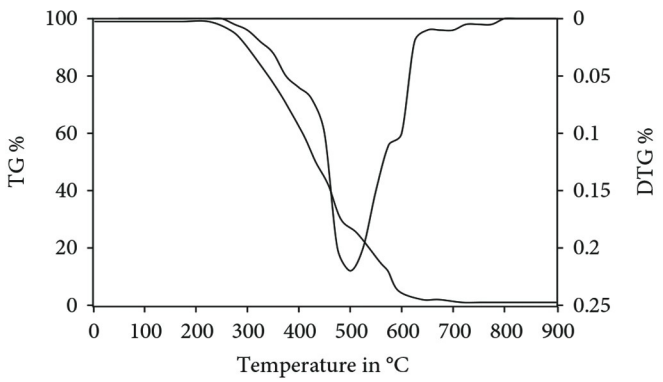

FIGURE 2: TG and DTG analyses of waste PET polymer.

is mainly due to the end group-initiated process and degradation of yields produced during the polymer chain degradation [39]. PET lost 80% of its total mass between 325 and 575°C, and after 625°C, there was no degradation. The aforementioned thermal decomposition data are used for the selection of the pyrolysis temperature for maximum decomposition.

3.2. Biomass Thermal Pyrolysis. Thermal pyrolysis of biomass can be conducted under various reaction temperatures to control the quality of the bio-oil and fulfil the needs of individuals. The relationship between the yield qualities and its compositions are not always easy to predict [40]. It generally depends on the various operating factors. Among the various operating parameters, the pyrolysis temperature is the one that determines the quality as well as the quantity of the yield [41, 42]. During biomass pyrolysis, the liquid oil is formed due to the immediate destruction and depolymerization of the lignocellulosic content of the biomass material. In this study, the yield of oil enhanced with increasing bed temperature. The yield of oil has reached a maximum value of 40.8 wt (%) at a temperature of 450°C. Further increments of the temperature reduce the yield of oil to 37.0 wt (%). The yield of this gas fraction increases continuously with increasing bed temperature. The gas yield varies from 29.3 wt (%) to 40.5 wt (%) when the temperature is increased from 350°C to 550°C. In Figure 3, the variation in different product yields based on process temperature is

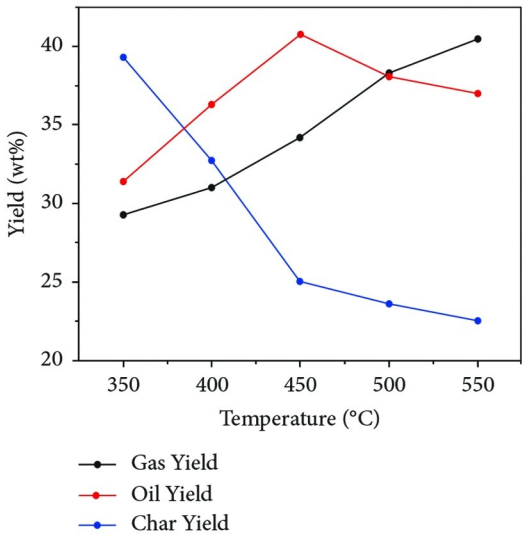

FIGURE 3: Effect of temperature on pyrolysis of *Ficus benghalensis*.

displayed. From the figure, it can be noticed that there is a steep decrement in the production of char. At 350°C, the yield of char was 39.3 wt (%), and the value was lowered to 22.5 wt (%) when the reactor temperature was increased to 550°C. The decreased char yield with higher temperatures is prominently due to the increased conversion of lignin in the biomass material [43]. The increased gas production with increased temperatures can be elucidated by increased biomass conversion. The secondary reactions of vapours to gases become more prominent at increasing temperatures.

3.3. PET Thermal Pyrolysis. PET material was employed in this study. It was pyrolyzed separately by changing the reaction temperature to get the suitable reaction conditions. In this case, the maximum conversion of bio-oil was found at 500°C. At 350°C, the production of oil is as low as 48.6 wt (%). At that point, the yield of char was a maximum of 26.3 wt (%). The yield of char reduced drastically from 26.3 wt (%) to 6.3 wt (%) with the increase in temperature from 350°C to 550°C. The production of gas increased steadily as the temperature rose. At 350°C, the gas yield was 25.1 wt (%), with a maximum of 35.2 wt (%) at 550°C. The difference in the thermal stability of the PET increases the yield of liquid oil and gas. According to Garba et al. [44], when the polymeric material was subjected to higher temperatures, there was a chance to break the stability by flouting C=C bonds, which increases the release of the gas fractions. Figure 4 shows the effect of temperature on pyrolysis of PET.

3.4. Co-pyrolysis Characteristics. Co-pyrolysis characteristics of *Ficus benghalensis* and PET mixture are illustrated in Figure 5. The experiments for this phase were performed at a constant temperature of 500°C with the addition of PET with biomass. The addition of PET with biomass increased from 20% to 80% with an interval of 20%. From the figure, it can be understood that the char decreased with an increased PET component, which was comparable to that of individual

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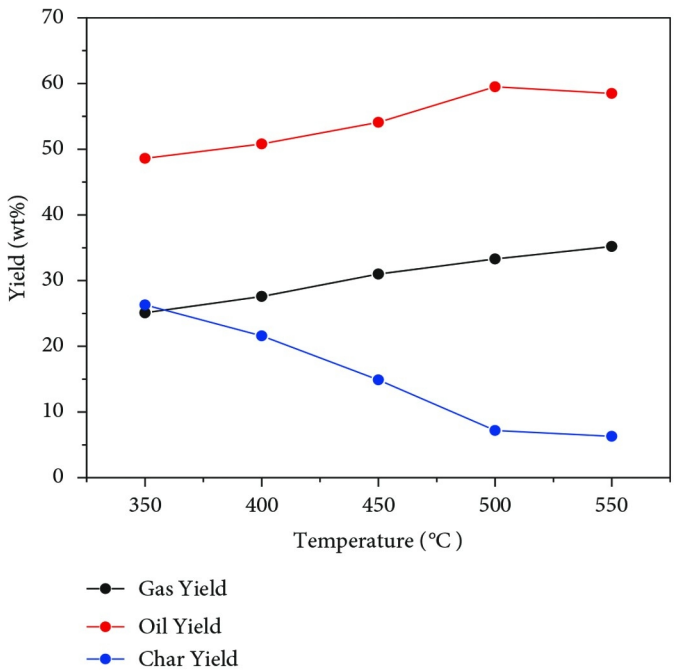

Figure 4: Effect of temperature on pyrolysis of PET.

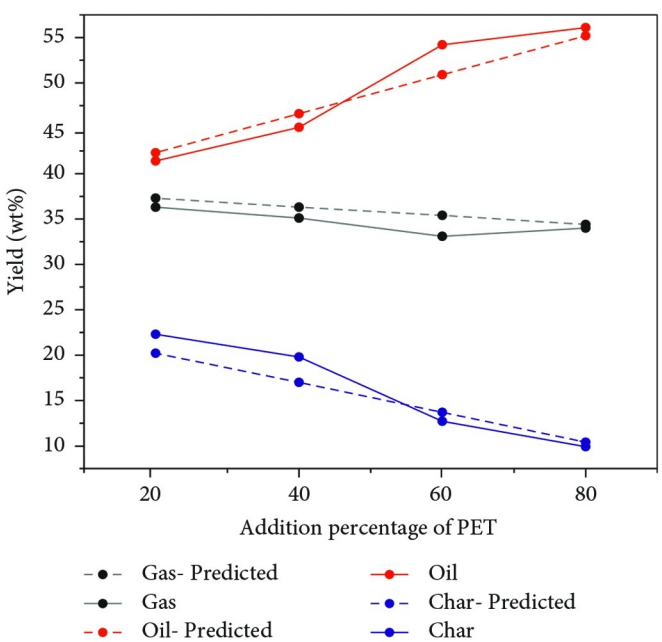

Figure 5: Effect of PET on biomass pyrolysis.

pyrolysis. The value of char decreased from 22.3 wt (%) to 9.9 wt (%) with the increment of PET from 20% to 80% of the biomass. The oil production through individual pyrolysis of PET was higher than biomass pyrolysis, which is also reflected in the co-pyrolysis reaction. In this process, the yield of oil is changed from 41.4 wt (%) to 56.1 wt (%). The oil yield enhanced with respect to the higher addition percentage of PET. The yield of oil was only 41.4 wt (%) at a 20% addition of PET. The value increased to 56.1 wt (%) with the addition of 80% PET. The increased oil yield with respect to the addition of PET is due to the existence of maximum volatiles in PET rather than biomass. According to Guo and Lua [45] and Zhou et al. [46], polyolefin polymers during pyrolysis will act as a perfect hydrogen donor and create the radical interaction to form maximum bio-oil.

3.5. Degree of Synergistic Effects. The synergistic effect on product yields during co-pyrolysis was assessed with the help of experimental and predicted yields, which are also shown in Figure 5. The experimental yield of gas throughout the co-pyrolysis process was less than the predicted value. With up to 40% addition of PET, the production of oil was lower than the predicted value and the yield of char was higher than the predicted value. For oil yield, the positive synergistic effect was identified when more than 40% of PET was added along with biomass. At 60% addition of PET, a more positive synergistic effect was identified. At that point, the liquid yield is 6.48% higher than the predicted yield. The positive synergetic effect on oil yield was attributed to radical secondary reactions, which are responsible for the condensation of noncondensable elements [47]. Furthermore, PET in the mixture acts as a biomass hydrogenation medium, potentially inhibiting polymerization and cross-linking reactions, enhancing the biomass decomposition reaction [48]. Previously, the literature [49–51] reported the synergistic effect on co-pyrolysis of various biomaterials with PET. Çepelioğullar and Pütün [52] investigated the synergistic effects of three different biomass materials combined with PET. The study produced more bio-oil and char with less gas compared to the cumulative yields obtained from individual pyrolysis. The synergistic effect of co-pyrolysis of municipal solid waste and PET was examined by Ansah et al. [53] and showed a higher synergistic effect on bio-oil yield at a 70 : 30 blend of biomass to plastic ratio. The study also concluded that when the biomass fraction was prominent in the mixture, significant interaction between biomass and PET was detected.

3.6. Physical Characterization. The physical, elemental composition, and heating value of the liquid oils acquired through individual and co-pyrolysis processes are listed in Table 2. It is noticed that the fraction of carbon and hydrogen increases with the addition of PET with biomass. The oxygen components in the bio-oil were reduced gradually from 48.45 wt (%) to 27.82 wt (%). At the same temperature, lowering the oxygen level enhanced the heating value to 28.64 MJ/kg. The findings suggest that co-pyrolysis of wood-based biomass with PET is an effective method for producing liquid oil with a higher heating value.

3.7. Chemical Analysis. For the analysis of various chemical elements in the oil, GC–MS is an important and quick technique. During pyrolysis, the three primary components of biomass, such as cellulose, hemicellulose, and lignin, were decomposed into various chemical elements such as alcohol, alkanes, alkenes, and phenolic components [54, 55]. Table 3 represents a list of chemical components determined by GC–MS. As illustrated in the table, the biomass is typically broken down into phenolic compounds. Phenols, alkyl phenols, and methoxy phenols are identified from biomass pyrolysis oil

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Table 2: Physical properties of the oils.

Properties	*Ficus benghalensis*	*Ficus benghalensis*-to-PET ratio				PET	Unit
		80 : 20	60 : 40	40 : 60	20 : 80		
Density	1010	995	965	930	915	910	(kg/m^3)
Viscosity	7.1	6.9	6.4	5.8	5.0	4.1	(cSt)
Flash point	135	130	110	92	73	58	(°C)
Carbon	43.52	46.33	50.14	54.89	59.20	63.50	(wt (%))
Hydrogen	7.10	7.10	7.31	7.72	7.90	8.10	(wt (%))
Nitrogen	0.74	0.72	0.70	0.66	0.59	0.54	(wt (%))
Sulfur	0.21	0.19	0.15	0.11	0.07	0.04	(wt (%))
Oxygen[a]	48.45	46.12	41.02	35.30	32.41	27.82	(wt (%))
H/C molar ratio	1.943	1.826	1.734	1.671	1.590	1.519	—
O/C molar ratio	0.835	0.739	0.624	0.501	0.408	0.328	—
Heating value	17.91	18.92	21.36	23.90	26.83	28.64	(MJ/kg)

[a]By difference.

Table 3: List of chemical elements identified in liquid oils through GC–MS.

Compound name	Molecular formula	A	B	C	D	E	F
2-Isopropyl-2,5-dihydrofuran	$C_7H_{12}O$	0.92	0.40	0.22			
Phenol, 2-methoxy-	$C_7H_8O_2$	1.26	1.05	0.88	0.40		
1,2-Benzendiol	$C_6H_6O_2$	2.01	1.89	1.74	0.42	0.22	
2-Furancarboxaldehyde,-5-methyl	$C_6H_6O_2$	0.91	0.25				
3-Undecene, (Z)-	$C_{11}H_{22}$					1.95	2.62
Phenol	C_6H_6O	9.12	9.01	8.24	4.20	2.11	
Furfural	$C_5H_4O_2$	0.74	0.55	0.12			
Ethisterone	$C_{21}H_{28}O_2$	0.24					
Trimethylamine	C_3H_9N					0.25	0.74
Phenol, 2-methyl-	C_7H_8O	3.44				0.11	0.19
4,5-Dimethoxy-2-methylpheno	$C_9H_{12}O_3$	1.25	1.01	0.82	0.31		
Phenol, 2-ethyl-6-methyl-	$C_9H_{12}O$	5.84	5.04	3.77	3.09	2.01	
Naphthalene, 1-methyl-	$C_{11}H_{10}$						5.22
Benzoic acid	$C_7H_6O_2$			2.55	19.81	25.14	31.24
Tridecane	$C_{13}H_{28}$			0.22	0.85	0.90	0.97
4-Ethylbenzoic acid	$C_9H_{10}O_2$	0.84	0.54	0.14			
2,4 Dimethyl pentone	C_9H_{16}			0.19	3.18	5.70	7.92
2-Methoxy phenol	$C_7H_8O_2$	5.42	3.26	1.22	0.94	0.42	
2-Acetyl furan	$C_6H_6O_2$				0.71	1.94	2.21
Phenol, 4-methyl-	$C_{21}H_{28}O$	6.01	4.10	1.25			
Tetradecane	$C_{14}H_{30}$						2.04
Benzoic acid, methyl ester	$C_8H_8O_2$	0.94	0.90	0.42	0.18		
4-Methoxy-2-methyl-1-benzene	$C_9H_{12}OS$	1.22	1.20				
Benzoic acid	$C_7H_6O_2$	1.20	1.11	0.84			
Oxirane	C_2H_4O					0.21	0.87
Pyridine 2-methyl	C_6H_7N				1.25	2.14	3.54
Cyclopentanone	C_5H_8O	1.75	0.92				
2-Phenyl-1-p-tolylethanol	$C_{14}H_{16}O$	1.25	1.05	0.81			
Naphthalene	$C_{10}H_8$	0.11					
Cyclopent-2-enethione	C_5H_6S				1.40	3.10	5.14
Butane-1,1-D2, 1-iodo	$C_{10}H_{16}O_3$	0.75	0.20				
2-Methoxy-4-methylphenol	$C_8H_{10}O_2$	2.28	1.24	0.28			
trans-1,4-Hexadiene	C_6H_{10}			0.21	1.75	2.48	4.41
Phenol, 2,6-dimethoxy	$C_8H_{10}O_3$	1.58					
Thiophene, 2,5-dimethyl	C_6H_8S						0.94
Benzenemethanol, 4-hydroxy	$C_7H_8O_2$	1.72	0.84				
3-Methoxy-2-methylphenol	$C_8H_{10}O_2$	1.88	1.55	1.31	0.74	0.14	0.10
Palustrol	$C_{15}H_{26}O$						0.45
2-Acetylcycloheptaneone	$C_9H_{14}O_2$					0.21	0.94
2,4-Dihydroxy-6-methoxyacetophenone	$C_9H_{10}O_4$	1.85	1.22	0.73			
2-Methyl-5-methoxy-6-hydroxybenzofuran	$C_{11}H_{14}O_3$	1.79					
2-Furanmethanol	$C_5H_6O_2$	2.56	2.12	1.84	1.02	0.74	

Source: Hindawi, Journal of Chemistry, Volume 2022, Article ID 3699076

Table 3: Continued.

Compound name	Molecular formula	A	B	C	D	E	F
Vanillin	$C_8H_8O_3$	2.40	1.26				
1-Methyl-1,3,3-triphenylindan-2-one	$C_{28}H_{22}O$	0.97					
10-Chlorodanuphylline	$C_{24}H_{25}ClN_2O_8$					0.12	0.78
3,4-Dimethylthiophene	C_6H_8S					0.85	2.47
9-Octadecenamide	$C_{18}H_{35}NO$	0.82	0.24				
Benzhydryl vinyl ether	$C_{15}H_{14}O$	0.86	0.25				
Oleic acid	$C_{18}H_{34}O_2$	1.25	1.02	1.00	0.78	0.54	0.24
4-Ethyl-2 methoxy-phenol	$C_9H_{12}O_2$	5.62	5.04	4.44	1.87	0.97	
Dibenzo[a,e]cyclooctene	$C_{16}H_{12}$			0.97	2.47	3.22	5.41
2-(2,4,6-Trimethylphenyl)butylamine	$C_{13}H_{21}N$					2.14	3.05
Phenol, 3-amino	C_6H_7NO	1.25	0.82	0.11			
Pyridine, 2-propyl-	$C_8H_{11}N$			0.54	0.99	1.25	2.41

A, biomass; B, 80 : 20; C, 60 : 40; D, 40 : 60; E, 20 : 80; F, PET.

under various proportions. The amount of these chemicals varies depending upon the amount of biomass material in the feedstock. The components identified in PET pyrolysis oil, on the other side, are completely different from biomass pyrolysis oil. The chemical components identified in PET oil are mostly hydrocarbon elements with some oxygenated elements. In contrast to the biomass pyrolysis, half of PET was decomposed into a majority of benzoic acid (31.24%). It is well known that pyrolysis oils with an acidic nature can cause corrosion difficulties in reactors and handling devices. In addition to that, the acidic properties may cause environmental issues during its natural degradation. Apart from these drawbacks, it is well recognised that benzoic acid can be utilized as a significant feedstock for a variety of chemical industries. From this perspective, pyrolysis of PET can be used to transform PET into valuable chemical feedstocks for industrial applications.

4. Conclusion

Fixed-bed pyrolysis of wood-based biomass obtained from *Ficus benghalensis* and waste PET was used in this study for the production of liquid oil. The maximum yield of pyrolysis oil was obtained from biomass and PET at 450°C and 500°C, respectively. The co-pyrolysis of biomass and PET was performed in four stages. Among different blends, the highest positive synergy for liquid oil production was obtained at a 60% addition of PET. In parallel with these results, the physical and chemical properties of the obtained liquid oil were determined to find the basic characteristics. Physical characterization demonstrates that the amount of plastic in the feedstock has a direct correlation with the heating value of the oil. The hydrogen and carbon-rich compositions were found in co-pyrolysis due to the interaction of plastics. In conclusion, it can be inferred that co-pyrolysis of *Ficus benghalensis* and waste PET could be an environmentally benign approach of converting biomass-plastic mixtures into useful products for a variety of applications.

Data Availability

The data used to support the findings of this study are included within the article.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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Abstract of Selected Research Article:

Experimental investigation on the combustion, performance and emission characteristics of 1-pentanol blended waste plastic oil in a CRDI engine with EGR:

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Faster exhaustion of fossil fuels and escalation of pollution levels have increased the requirement for alternate fuels to fulfil the energy demand of the fast growing world. The present work attempts to use waste plastic oil added with 1-Pentanol in a CRDI engine to achieve comparable performances of pure diesel with significantly reduced hazardous emissions. The experiments were carried out with 10, 20 and 30% of 1-pentanol blended with waste plastic oil on volume basis. The experiments were conducted at constant speed of 2000 rpm with load varying from 20 to 80% and exhaust gas recirculation by 10 and 20%. The fuel blend with 30% 1-pentanol exhibited 3.3% lower efficiency, 0.02 kg/kWh higher brake specific fuel consumption, 74 ppm of lower nitrogen oxide and 2.3 ppm of higher hydrocarbon emissions correlated to pure diesel. The use of exhaust gas recirculation reduced nitrogen oxides in the exhaust gas with slightly aggravated emissions of carbon monoxide. Considering the different combustion, performance and emission parameters, the fuel blend containing 30% of 1-pentanol and 70% waste plastic oil can be a potential alternate to pure diesel.

Highlights:

- Impact of blending 1-pentanol with waste plastic oil on engine characteristics of a CRDI engine is investigated.
- 1-pentanol is a potential additive for the waste plastic oil to enhance the engine characteristics.
- The BTE increases and BSFC decreases with addition of 1-pentanol with waste plastic oil.
- The NOx emission reduces significantly for the 1-pentanol/WPO blend with EGR approach.

Microbial fermentation of polyethylene terephthalate (PET) plastic waste for the production of chemicals and electricity:

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Abstract:

Ideonella sakaiensis (I. sakaiensis) can grow on polyethylene terephthalate (PET) as the sole carbon and energy source.

Previous work has shown that conversion of the hydrolysis products terephthalic acid (TPA) and ethylene glycol (EG) under aerobic conditions released carbon dioxide and water while yielding adenosine triphosphate (ATP) through oxidative phosphorylation.

This study demonstrates that under anaerobic conditions I. sakaiensis ferments PET to the feedstock chemicals acetate and ethanol while co-producing ATP by substrate-level phosphorylation. In addition to PET, maltose, EG, and ethanol can also serve as fermenting substrates.

Co-culturing of I. sakaiensis with electrogenic Geobacter sulfurreducens produced electricity from PET or EG. This newly identified plastic fermentation process by I. sakaiensis provides a novel biosynthetic route to produce high-value chemicals and electricity from plastic waste streams.

Latest News on Plastic Waste Management

from www.thedailystar.net

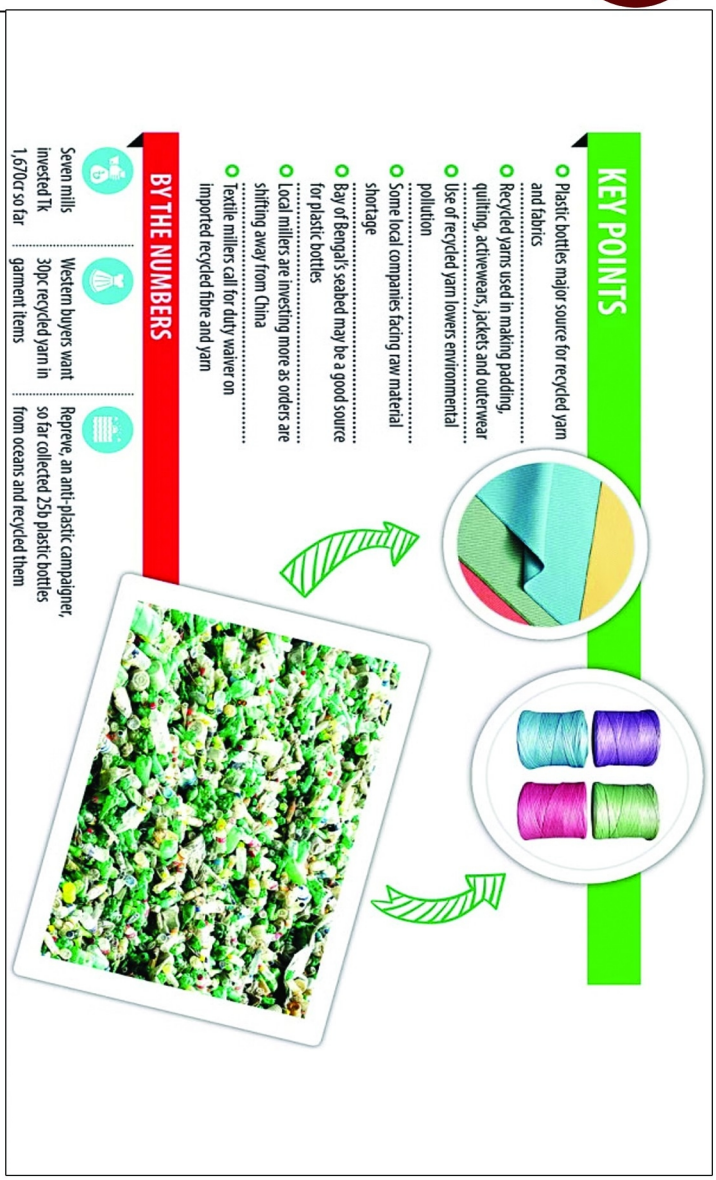
From garbage to fashion!

An amazing way to beat plastic pollution:

It is pretty amazing that Bangladesh is on its way to becoming a major source of recycled yarn and fabrics made from plastic bottles. Reportedly, some Bangladeshi companies have already set up plants investing hundreds of crores of taka to make flakes from waste plastic bottles, which will be used to make yarn and fabrics. Recycled yarns are used to make some high value-added garment items such as jerseys, jackets, quilts, padding and outerwear. It is a growing global trend now to make yarn from recycled plastic bottles, as Western consumers are becoming increasingly conscious about saving the environment from plastic pollution. As the demand for such garment products is increasing worldwide, Bangladesh can take this opportunity to become a major producer of yarn and fabric made from plastic.

Reportedly, international retailers and brands are asking suppliers to add 25-30 percent of the raw material made from plastic to the finished garment items. Bangladeshi companies mostly import these recycled yarns from China. But the price of the yarn has increased a lot in the international market, which has led some Bangladeshi companies to plan for producing their own plastic flakes and yarns.

It is good to know that already seven local mills have set up plants to produce flakes from waste plastic bottles. While some of them have already started their production, they are struggling to get the required raw material for production. The problem is that plastic waste and bottles are usually collected in an informal way. If this process could be formalised and incentivised, the collection would definitely increase. Also, the seabed of the Bay of Bengal could be explored to extract plastic bottles currently polluting its waters.



Being the 10th most plastic-polluting country in the world (according to the Earth Day Network, 2018), it should be our priority to invest more in setting up recycling facilities. The National Action Plan for Sustainable Plastic Management has set a target of recycling 50 percent of plastic by 2025. In order to fulfil that target, more companies should come forward to make plastic flakes to be used to make garment products. Besides, recycled plastic can be used to produce many day-to-day household products. While reducing our consumption of plastic is very important, it is equally vital to reuse and recycle them. And we believe that more Bangladeshi companies will come forward to set up recycling plants to beat plastic pollution in the country.

Latest News on Plastic Waste Management

from www.greaterkashmir.com

Plastic roads in Kashmir soon? J&K Govt exploring option to use plastic waste for road construction:

To appropriately utilise the material, which would otherwise not be recycled, the central government has been using plastic garbage in road construction. Special arrangement

Srinagar: The Jammu and Kashmir administration is now exploring using plastic waste in road construction and has started the process to study the potential after the central government built over 1 lakh kilometres of roads using plastic garbage.

According to the officials, the initiative aims to preserve biodiversity and reduce carbon footprints in the ecologically-vulnerable region of J&K, which has recently suffered from several natural disasters.

To analyse and create a plan for the use of waste plastic in the Public Activities (Roads and Building) Department's macadamisation operations, the General Administrative Department (GAD) established an Inter-Departmental Committee.

According to a directive from Secretary to the Government Piyush Singla, the creation of an inter-departmental group to create a roadmap for the use of waste plastic in PW (R&B) Department macadamisation projects starting in the following fiscal year has been authorised. Official sources said that the committee was in charge of properly taking into account environmental concerns while investigating the feasibility of employing waste plastic in road construction.

To appropriately utilise the material, which would otherwise not be recycled, the central government has been using plastic garbage in road construction. One lakh kilometres of roads have already been built out of plastic waste. Nine tonnes of bitumen and one tonne of plastic debris were needed for every kilometre of road building. This indicates that one tonne of bitumen, which costs roughly Rs 30,000, is saved for every kilometre of road. Six to eight percent of the material in plastic roadways is plastic whereas 92 to 94 percent is bitumen.

In 2016, Union Minister Nitin Gadkari said that plastic waste would be used in road construction. Since then, one lakh kilometres of roads in 11 states have been built using plastic garbage. The amount would double in the current fiscal. For the first time in 2018, the Municipal Corporation of Gurugram (MCG) put plastic waste on its roads. The MCG now requires the use of plastic debris in arterial road development.

Plastic waste has also been used on the 270-km Srinagar-Jammu National Highway. About 1.6 tonnes of plastic waste was used in the 2-km stretch of Delhi-Meerut highway news UP Gate. It has also been used in constructing the road connecting Dhaula Kuan to the airport in Delhi.

Know Your Polymer

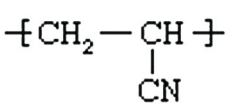
Polyacrylonitrile (PAN)

Polyacrylonitrile (PAN), a synthetic resin prepared by the polymerization of acrylonitrile. A member of the important family of acrylic resins, it is a hard, rigid thermoplastic material that is resistant to most solvents and chemicals, slow to burn, and of low permeability to gases.

Most polyacrylonitrile is produced as acrylic and modacrylic fibre, a common substitute for wool in clothing and home furnishings.

Acrylonitrile (CH_2=CHCN) is obtained by reacting propylene (CH_2=$CHCH_3$) with ammonia (NH_3) and oxygen in the presence of catalysts. It is a flammable liquid that is highly toxic if ingested and is a known carcinogen; strictly regulated procedures are required for its handling and disposal.

Acrylonitrile monomers (single-unit molecules) are suspended, almost always in combination with other monomers, as fine droplets in water and are induced to polymerize to PAN through the action of free-radical initiators. The acrylonitrile repeating unit of the polymer has the following structure



PAN has none of the hazardous properties of the monomer. Owing to the formation of strong chemical bonds between the nitrile (CN) groups, the polymer molecules resist most organic solvents and do not melt without decomposing. In most cases the polymer is dissolved in special solvents and spun into acrylic fibres, which are defined as fibres that contain 85 percent or more of PAN. Because PAN is difficult to dissolve and is highly resistant to dyeing, very little fibre is produced containing PAN alone.

On the other hand, a copolymer containing 2 to 7 percent of a vinyl comonomer such as vinyl acetate can be solution-spun readily to fibres that soften enough to allow penetration by dyestuffs. Acrylic fibres are soft and flexible, producing lightweight, lofty yarns. Such properties closely resemble those of wool; hence, the most common use of acrylics in apparel and carpets is as a wool replacement—for example, in knitted wear such as sweaters and socks. Acrylics can be sold at a fraction of the cost of the natural fibre, and they offer better sunlight resistance, mildew resistance, and resistance to attack by moths.

Acrylic fibres are also used as precursors for the production of carbon and graphite fibres, as replacements for asbestos in cement, and in industrial filters and battery separators.

Acrylics modified by halogen-containing comonomers such as vinyl chloride or vinylidene chloride are classified as modacrylics. (By definition, modacrylics contain more than 35 percent and less than 85 percent PAN.)

The presence of chlorine imparts a notable flame resistance to the fibre—an advantage that makes modacrylics desirable for products such as children's sleepwear, blankets, awnings, and tents.

However, they are not as widely used as the simple acrylics because of their higher cost and because they are somewhat prone to shrinkage in clothes dryers.

Although the polymerization of acrylonitrile had been known since the 1890s, commercial production of PAN fibre did not begin until the 1940s, after Ray C. Houtz of E.I. du Pont de Nemours & Company (now DuPont Company) discovered spinning solvents that could dissolve the polymer.

DuPont introduced its trademarked Orlon acrylic fibre in 1948; Orlon was soon followed by the Monsanto Chemical Company's Acrilan, American Cyanamid's Creslan, Courtaulds' Courtelle, and others.

The decade of the 1950s also saw the introduction of modacrylics such as Eastman Kodak Company's Verel and Monsanto's SEF.

Infographics

from www.lessplastic.co.uk

Infographics

from www.lessplastic.co.uk

9 WAYS TO TRAVEL WITH LESS PLASTIC

9 MORE TIPS FOR LIVING WITH LESS PLASTIC

3 REASONS PLASTIC STRAWS SUCK

3 WAYS TO STOP SUCKING PLASTIC

9 IDEAS FOR GIFTS WITH LESS PLASTIC

5 Ways to Teach Waste Management to Your Child

1. Upcycling with Art

Children are naturally curious and creative, so gearing them towards craft is a great way of teaching them about waste management. First and foremost, you need to keep a carton where your child can put single-use plastic bottles, old tins, paper towel tube and cereal boxes. Instead of merely discarding these everyday waste items, encourage your children to get creative and upcycle waste materials.

You can drill tiny holes in these plastic bottles, fill it with soil and plant a seed to make a hanging pot. You can use paper towel tubes and cereal boxes to cut up and make into a periscope or a kaleidoscope. These small upcycled items will help them think creatively and innovate more, besides ensuring that they do not simply discard material as waste!

2. Effective Disposal of Household Waste

A major component of teaching your child about waste management is learning waste management yourself. Children learn by example, so if they see you making wise, environmentally-conscious decisions, they will be motivated to emulate your example. There is more you can do that simply separating recyclable and non-recyclable waste, such as effective solvent disposal.

Your household produces ecologically-damaging solvent waste—in the form of polishes, cleaning fluids and fertilizers. This solvent waste often goes untreated, damaging the freshwater sources it is dumped in.

3. Use of High-Grade and Alternative Material

Besides setting good examples of waste disposal to your kid, you can also sensitize your child to good environmental practices by using eco-friendly alternatives to disposable plastics. There are simple switches you can make.

Instead of using polythene bags that choke the seas, use cloth bags for groceries. Instead of buying single-use plastic bottles for drinking water, carry science bottles made of high-grade plastic when you are on the move. Another way of cutting down on your plastic use is by buying vegetables from farmers' market, instead of purchasing vegetables that are wrapped in plastic, like you find in chain stores.

4. Organize Neighbourhood Clean-Up Drives

Another activity that is bound to solidify the importance of waste management while instilling the virtue of doing in your child is organizing or participating in neighbourhood clean-up drives. It is fairly easy to organize one. Contact your local school or club to gather motivated young people on a weekend. Provide them with gloves and other equipment required for picking trash off the streets.
In small groups, go around your neighbourhood collecting litter. Once collected, sort them according to its recyclability and have it suitably treated. This activity train children against littering, and make the importance of waste management apparent to them

5. Teaching through Games

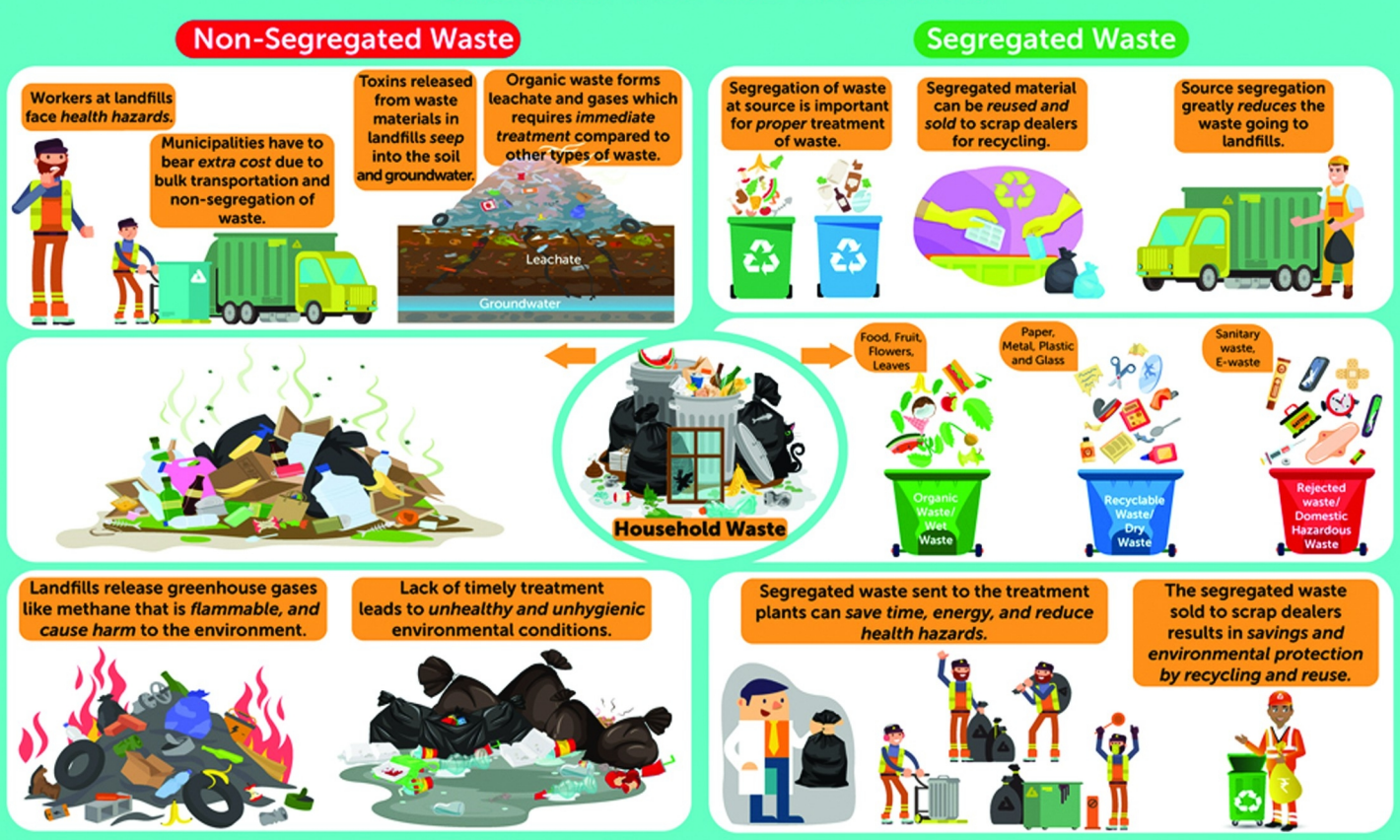
Waste management for kids does not have to be boring. Environmental care immediately concerns us, so its importance can be palpably felt through a number of fun games.
Take the Air+Water Power Experiment Kit. While building small machines, your child can learn about the laws of Physics and alternative resources. Or you can create beautiful art using recycled paper through the Spin Art Revolution Craft Kit. Through these games, your children will learn to be sensitized towards the environment, while having fun!

Kids Corner

Educate the Kid to Segregate Your Waste

WASTE: SORT AND SEGREGATE

To Segregate or Not Segregate: Shouldn't be the Question!



Highest Ocean Plastic Waste Polluters

(annual estimation in metric ton)

It is estimated that 1 million metric tons of plastic waste enters the ocean every year, out of a total of 67.5 million metric tons

This is particularly prevalent in tropical archipelago regions, which have a higher waste emission due to their relatively small land surface compared to the length of their cosatline and high precipitation rates, which increase the likelihood of plastic waste being washed into the ocean

Source: More than 1000 rivers account for 80% of global riverine plastci emission into the ocean. Lourens J. J. Meijer et al (2021) via science.org