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Pyrolysis of Tyre Waste: A Sustainable Waste Management Approach

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ABSTRACT

Tyre waste is produced in large amounts and demands proper management as its disposal is associated with concern for the environment and public health. Proper management of tyre waste can result in material recovery, energy recovery and other value added products. This chapter discusses about the problems associated with waste tyre disposal, waste tyre pyrolysis products and application of pyrolysis products in circular economy. Pyrolysis of the tyre can be considered one of the most suitable due to the possibility of maximum benefits regarding economy circulation, environment, and sustainability. Through waste tyre pyrolysis, we can produce quality products such as oil, char, steel, and gas that have high commercial demand in industrial applications and have societal impact. With this, it is possible to circulate economy and there are almost negligible waste products by ultimately ending the life of tyre with a positive impact on the environment and society. Therefore, the end life of waste tyre through pyrolysis resulting in sustainable waste tyre management with minimum environmental impacts and maximum economic benefits.

Keywords: Waste tyre, pyrolysis, value-added products

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1. INTRODUCTION

Dumping of the waste tyre has been a serious concern globally due to its aesthetic, environmental and health issues. Almost 1.6 billion new tyres per year are produced, and at the same time, 1.5 billion scrap tyres per year are generated [1]. Because of non-biodegradability, the scrap tyre can persist in the environment for many years and can potentially impact the environment and human health. Accidental fire hazards, toxicants leaching, vector breeding and associated epidemics and wastage of land, are the common problems associated with waste tyre disposal. Therefore, for environment and human health safety, disposal of scrap tyre should be replaced with other alternative routes to mitigate these issues. Different methods have been adopted to manage the scrap tyre, including reducing or reuse, recycling (civil engineering applications and thermochemical treatments (combustion, gasification and pyrolysis)) and landfilling.

According to waste tyre management global statistics- 2011, 77% of the waste goes to dump sites illegally, 7% for recycling and 11% treated for fuel production. But the above statistics are drastically changing due to rigid environmental policies and standards and also innovations in the technologies even though all these methods (reduce, reuse and recycling) have some economic and non-economic barriers. Majority (25-60%) of the waste tyre is sutilised for energy recovery, 5-23% is reused, 3-15% is recycled and 20-30% goes to landfills [2]. Recycling is the most recommended feasible way of waste tyre management, which mainly include recovery of materials (for civil engineering applications), energy (by thermochemical treatments) and value-added products (through pyrolysis) in a sustainable way. In this economy-oriented world, among these options again, the most appropriate route for obtaining the maximum benefits concerning circular economy, environment and sustainability from the waste tyre is the recovery of the value-added products. These products have high commercial demand in various industrial and societal applications. This main objective of this chaptr is to discuss about problems associated with waste tyre disposal, application of pyrolysis process for management of tyre waste and the uses of waste tyre pyrolytic products.

2. SCHARACTERISATION OF WASTE TYRE

Before using any process for managing scrap tyre, it is crucial to understand the composition and characteristics of the tyre. The material composition of tyre mainly contain natural rubber (NR), synthetic rubber (SR) (BR: butadiene rubber and SBR: styrene-butadiene rubber), carbon black, additives like sulphur and zinc oxide, steel, textiles and fillers. This composition varies depending upon the type of tyre and ranges in between 14-48% of NR, 10-27% of SR, 11-28% of carbon black, 14-25% of steel, and 12-17% of fabric, fillers and accelerators [3]. Various materials are added to the tyre to enhance its properties. For example use of natural rubber improves the cracking resistance, synthetic rubber improves the rolling resistance, carbon black increases tire resistance against abrasion and improves the strength, steel improves wear performance and tire handling and sulphur and zinc oxide are used for rubber svulcanisation [4, 5]. According to elemental composition, the tyre contains carbon, hydrogen, nitrogen, sulphur, oxygen and other metals, and this composition also varies depending on the type of tyre [4, 5].

3. PROBLEMS ASSOCIATED WITH WASTE TYRE DISPOSAL

Due to non-biodegradability, longer life span and chemical composition of the waste tyre, disposal is associated with various serious problems such as fire hazards, leaching, vector-borne diseases and large space requirements creating negative impacts on both environment as well as public health.

3.1. Fire Hazards

Many studies have revealed that tyre fires are the most dangerous than any other problems associated with tyre waste as the tyre fires can pollute the environment at every stage in tyre fire dynamics [6].

3.1.1 Air pollution

Tyre fires release more toxic air pollutants that include particulates, carbon monoxide (CO), sulfur oxides (SO_X), oxides of nitrogen (NO_X), and volatile organic compounds (VOCs); hazardous air pollutants (HAPs), such as polycyclic aromatic hydrocarbons (PAHs), dioxins, hydrogen chloride, benzene, polychlorinated biphenyls (PCBs); and metals such as arsenic, cadmium, nickel, zinc, mercury, chromium, and vanadium into the environment [7, 8]. The potential health impacts can be short term or long term and include cancer, asthma, lung and heart diseases, respiratory effects, and irritation to skin, eye, nose and throat [7, 6].

3.1.2 Water pollution

During tyre combustion, high internal temperature of around 2000^0C can lead to oil runoff into surface water and other areas depending upon the location of the tyre fire [7]. Various combustion residues like zinc, cadmium and lead can also be carried into the water.

3.1.3 Soil pollution

Tyre fires can leads to soil pollution in two ways. The oil from the tyre fire may penetrate into the soil and the ash left after the tyre fire can enter into the soil through rainfall or any other means [9].

3.2. Leachate

Another most prominent problem with tyre waste is the leaching of chemicals and heavy metals into the ground. The leachate from the scrap tyre contains both organic and inorganic compounds and contaminates the groundwater and the soil. The organic compounds from the tyre leachate include polycyclic aromatic hydrocarbons (PAH), nitrogen and sulphur containing organic compounds, aromatic compounds (ketones) and volatile organics (benzene, toluene, carbon disulphide and methyl ethyl ketone), whereas the inorganic compounds (like metals) include arsenic, barium, cadmium, calcium, chromium, iron, lead, manganese, selenium and zinc . These toxicants can get transported to other locations that can potentially harm the animals and human health when they contact these toxicants through various means [10]. The quality (contaminants) and quantity (concentration) of the tyre leachate in the soil and water (ground and surface) depends upon various factors, which include the type of tyre (based on size: scrap or whole tyre; based on composition: low vehicle, medium vehicle or heavy vehicle tire), chemical conditions (acidic or basic: under acidic environment leaching of metals is quick whereas in alkaline environment leaching of organic compounds is faster), soil characteristics (like soil permeability), and horizontal distance from tyre storage site to the downstream direction and vertical distance to groundwater table [9].

3.3. Vector breeding

The whole tyre can hold the rain water inside the tyre space and can retain the temperature for a longer period that provides a better environment for mosquitoes to breed [11]. In addition to this, the leaves filled in the tyre provide energy for mosquitoes. These mosquitoes can seasily spread the diseases, such as malaria, Zika virus, West Nile virus, and Encephalitis [12].

3.4. Large space requirement

For any waste to be disposed , compaction is a crucial factor to be considered due to land scarcity. Scrap tyre are difficult to compact and therefore its disposal demands larger space requirement. On the other hand, its size reduction for disposal is not cost-effective. Another concern about storing waste tyres in large quantity can cause injury to workers or even death.

4. WASTE TYRE PYROLYSIS

The term pyrolysis defines the thermal degradation of carbonaceous waste material under certain operating conditions, mainly in the absence of oxygen by heating resulting in the conversion of waste material into liquid, solid and gaseous phases. Although, the pyrolysis process seems to be a straightforward phenomenon, but involves several complex, simultaneous on-going reactions. Initially, moisture present in the waste material is evaporate and then de-volatilisation takes place. The non-volatile fraction will be left as a solid residue. Further, the volatiles convert into lighter molecules depending upon the residence time. These volatiles further condense into liquid and the non-condensed volatiles leave the system as gases.

The product distribution in terms of quality and the quantity will mainly depend on temperature, residence time (RT) and reactor pressure. Also, feed material composition, size of feed material, heating rate (HR) and gas flow rate influence the product distribution. The variation of the optimum yield of tyre pyrolytic products with the various operating conditions are listed in Table 1. For example, in case of waste tyre pyrolysis, depending upon type of tyre products, distribution varies for the same operating conditions. Smaller particle size leads to faster heat transfer inside the material, resulting in more gas yield whereas for larger particles yield of char is more because of slower heat transfer. For higher heating rate accelerates the process and producemore volatile fraction than less heating rates . The higher temperature inside the reactor leads to a higher gaseous fraction, and less char than the lower temperature. If the pressure inside the reactor is vacuum condition, then the yield of liquid fraction is more and requires less pyrolysis temperature than the atmospheric pressure inside the reactor. If the residence time for volatiles inside the reactor is large, more gaseous products are produced due to further disintegration of volatiles into lighter molecules whereas less volatile residence time results in more liquid yield. Also, the flow rate of carrier gas influences the residence time for volatiles which inturn influence the yield distribution.

Different types of reactors and various technologies in pyrolysis process have shown significant variation in the distribution of the product. Fixed bed reactor, fluidised bed reactor, moving bed reactor, conical spouted bed reactor, rotary kiln reactor, and microwave reactor are the different reactors used in the waste tyre pyrolysis process. Thermal pyrolysis, catalytic pyrolysis, microwave pyrolysis and vacuum pyrolysis are the different type of pyrolysis technologies used for the waste tyre pyrolysis process. Each of these reactor types and technologies targeted to improve the process for optimum quality and quantity of the products. All the three products (oil, char and gas) resulting from the waste tyre pyrolysis can be sutilised for various applications as shown in Figure 1, which indicates that pyrolysis process is nearly zero waste products discharge. Based on the quality of the product the process can be scommercialised, and multiple uses of these products are detailed below. Also, pyrolysis process can provide employment opportunities for plant operation and maintenance.

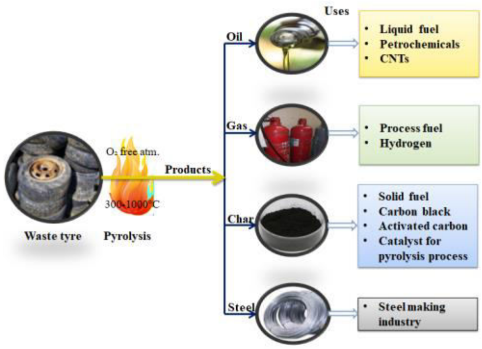

Fig. 1. Uses of products obtained from pyrolysis of waste tyre

4.1. Tyre pyrolytic oil

The tyre derived pyrolytic oil contains both lighter and heavier fractions known as gasoline-like fuels and diesel-like fuels, respectively [22]. These have properties (density, viscosity, calorific value, carbon and hydrogen content) almost similar to standard commercial fuels such as diesel and petrol [13, 14]. Therefore it is suitable to blend this oil with conventional diesel [24] or may be used as alternative fuel [14]. But more than 50% blending is not recommended for direct use in a diesel engine as it releases more CO, HC, SO_2 and smoke emissions [25]. The presence of sulphur restricts the direct use as diesel fuel or oil for direct combustion in standard engines without changes in engine configuration, but this can be possible after its quality improvement [13, 15]. The use of suitable catalysts can reduce the sulphur and ash content in the oil fraction [17, 18]. Tyre pyrolytic oil is a complex mixture of compounds largely aromatics and aliphatic and small amounts of nitrogenated and benzothiazol [27]. The high aromatics content in pyrolytic oil makes it suitable for industrial purposes [20, 21]. Improvements in technology, mainly catalytic pyrolysis, can improve the oil quality by increasing the lighter hydrocarbons content due to catalytic activity [29]. Benzene, toluene, xylene, ethylbenzene and styrene which are mostly used in the production of petrochemicals and plastics and in chemical industries can also be extracted from high quality pyrolysis oil [23, 24]. Tyre pyrolytic oil can also be suitable for the production of quality Carbon Nano Tubes CNTs [32].

Table 1. Optimum yield production by varying operating conditions in tyre pyrolysis

Sr. No.	Sample	Feed size	Amount	Reactor type	HR (^{0}C/Min)	RT	Temp. (°C)	Optimum yield (wt%)			Ref.
								liquid	gas	solid	
1	Passenger car, truck, airplane & motor cycle tire	5-20 mm	7.51 kg	Rotary kiln	20 & 60	10 min	450-600	43.0	21.5	35.5	[13]
2	Bicycle tyre	1cm²	20 g/run	Semi batch	20	N/A	450-700	49.6	12.5	44.5	[14]
3	Tyres from dump sites	2-10 mm	10g/batch	Fixed Bed	15	30 min.	375-750	34.4 ± 2	38.85	59.58 ± 7	[15]
4	Motorcycle tyre	2-12 cm³	750 ± 2 g	Fixed bed	10-60	50 min	375-575	49 ± 1.3	N/A	41 ± 1.5	[16]
5	Tyres from recycling plants	4 mm	5g/10 min	Pilot plant	N/A	N/A	450	37.8	N/A	35.2	[17]
							750	10.87	N/A	37	
							1000	<0.01	N/A	37.7	
6	Used tyre	20×20 mm	300g	Batch reactor	12	gas: 1-1.5 min	400-700	30.0-42.8	2.4-4.4	64.0-51.3	[18]
7	Car & truck tyres	1-3 cm²	15g	Batch reactor	16.5, 9 & 7.5	N/A	450	42.6	11.1	46.3	[5]
							570	50	9.3	40.7	
8	Passenger car tyres	1×1×1 & 6×5×1 cm³	1500g	Fixed bed	1.81	30 min	500	40.51	N/A	N/A	[19]
					7.14			53.49	N/A	N/A	
					16.31			50.86	N/A	N/A	
9	Waste tyre	1-4 mm	10g	Fixed bed	5.0- 35.0	1 hr	350-600	38.8	33.8	35.1	[20]
10	Passenger car tyre	3cm×1.5cm	3Kg	Batch	5	90 min	450-600	58.2	8.9	38.3	[21]

4.2. Tyre pyrolytic solid residue

The solid residue in the tyre pyrolysis products comprises steel and char. The recovered steel can used by steel industries for metal recycling. Char has fixed carbon, ash, sulphur and other impurities. Because of high fixed carbon content this char can be used as a raw material for category-A briquettes production [33]. The char can also be used to manufacture various rubber items (footwear, conveyor belts, dock fenders etc.), which requires even low-quality carbon black [27]. Because of the reasonable amount of energy content, it is suitable to use as a solid fuel. It may also use in the manufacturing of new tyre [34]. The produced char with the high surface area can be comparable with commercially available activated carbons. With further treatments, the char can be used as an activated carbon catalyst for wastewater treatment [28, 18]. It can also be used as a pigment in printing inks [33]. The pyrolytic tyre char can also be suitable as a catalyst in the tyre pyrolysis process to produce petrochemicals [36].

4.3. Tyre pyrolytic gas

The tyre pyrolysis gas consists of CO, CO_2, hydrocarbons (HC), H_2, and sulphur and nitrogen compounds [37]. Because of its high energy content it can be used as fuel in the pyrolysis plant processes [19, 31] and also suitable as liquefied petroleum gas (LPG) [34]. The pyrolysis gas has high energy content but its sutilisation as a fuel require equipment to control SO_X and other emission [39]. Selection of optimum process conditions and suitable catalyst to minimize sulphur content in the gas phase can result in less polluting flue gas emissions. Using of suitable catalyst can result in more H_2 production [25, 33]. Higher temperature can result in higher gas yield but can affect the economy of the pyrolysis process [37]. Therefore, to recover maximum energy at viable conditions, it is recommended to target more than one product type [41].

5. CONCLUSION

Literatures suggest that pyrolysis of the waste tyre can significantly reduce the mass and volume of the waste and recover energy and value–-added products. Energy production through waste tyre pyrolysis can decrease energy demand from fossil fuels. End of life of tyre can be possible through the pyrolysis process to completely eliminate the problems associated with waste tyre . The pyrolysis process emits less pollutant than burning and the gas obtained in the process can be used as fuel to fulfil the energy demand. Among all three tyre pyrolytic products, oil and solid products have significant advantages. Oil recovered in the process has several applications mainly as a liquid fuel because of its high calorific value after adequate purifications. Also, tyre pyrolytic oil comprises chemicals used for synthesis of petrochemicals and plastics and even carbon nano tubes. Solid residue from the tyre pyrolysis can be used as a solid fuel, and the carbon present in the soot can be converted into activated carbon. Hence all these products have high commercial applications. Pyrolysis process itself demand the human resources for plant operation and maintenance, which ensures new employment opportunities. Therefore, from the literatures it can be concluded that waste tyre pyrolysis can be considered a sustainable approach for circular economy for waste tyres. However, an in-depth research is still required to soptimise the process to produce maximum benefits.

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