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Unveiling the Potential of Tyre Pyrolysis Oil – A Sustainable Solution for Energy and Environmental Challenges: A Mini Review

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Abstract

Pyrolysis is a technology to recover energy from the end-of-life tyre or scrap tyres by converting into various useful products like tyre pyrolysis oil (TPO), pyro-gas and solid char or carbon sooth also known as raw recycled carbon black. Tyre pyro oil is a dark brown/black colored liquid and used as a fuel in compression ignition (CI) engines, industrial furnaces and power plants etc. The TPO like other fuels contains different hydrocarbons ranging from C_5-C_{20} and can be used as an alternate source of energy and will greatly help in reducing the consumption of petroleum fuels. In addition, the potential energy content of TPO possesses many advantages like the possibility of recycling carbon dioxide (CO_2) which will lead to significant fall in greenhouse gas emissions (GHGs), relatively much lesser environment pollution as compared to burning of waste tyres in open atmosphere, and recovery of value added chemicals etc. It was also documented that TPO contains some phenolic compounds which can be used as an antioxidant when blended with bio-diesel. In this review article, conversion of waste tyre into useful and value-added form of energy by pyrolysis process i.e. Tyre pyrolysis oil [TPO] and its potential applications are discussed.

Keywords: Pyrolysis, tyre pyrolysis, TPO, recycled carbon black, end of life tyres

INTRODUCTION

In continuous need of sustainable energy and environmental management, innovative solutions are constantly being explored globally. Tyre pyrolysis oil (TPO) is being considered as a potential contender, which offers an effective route towards efficient resource utilization and pollution reduction. This article briefly describes TPO, its production process, applications, advantages, challenges, and its key role in developing a greener future [1].

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Understanding Tyre Pyrolysis Oil: Tyre pyrolysis is a thermochemical decomposition process that converts scrap tyres into valuable products, including TPO, through heating in the absence of oxygen. The process typically occurs in a reactor, where the tyres undergo thermal degradation, yielding a range of by-products, with TPO being a key output.

PRODUCTION PROCESS: TYRE PYROLYSIS INVOLVES SEVERAL STAGES

Pre-Treatment

Tyres are shredded, grinded or processed to suitable sizes for feeding into pyrolizer continuously.

Pyrolysis

The shredded tyres are continuously fed into a reactor called rotary Pyrolizer with a controlled rate and subjected to high temperatures zones (around 400–600°C) in the absence of oxygen. There are 4 zones and temperatures are maintained in increasing order from 400°C to 600°C maximum. In these zones degradation of tyre rubber takes place.

Fractionation

Up to 250°C, pyro gas is generated which is recycled for the heating of pyrolizer. From 250°C to 450°C, resulting pyrolysis gas is condensed to obtain tyre pyrolysis oil [TPO] and at the last by-products like carbon black and steel wires are obtained.

Refining of By-Products

Resulting TPO is separated from water layer and suspended particles are separated by filtration and raw carbon black is sieved, micronized or pelletized for end applications.

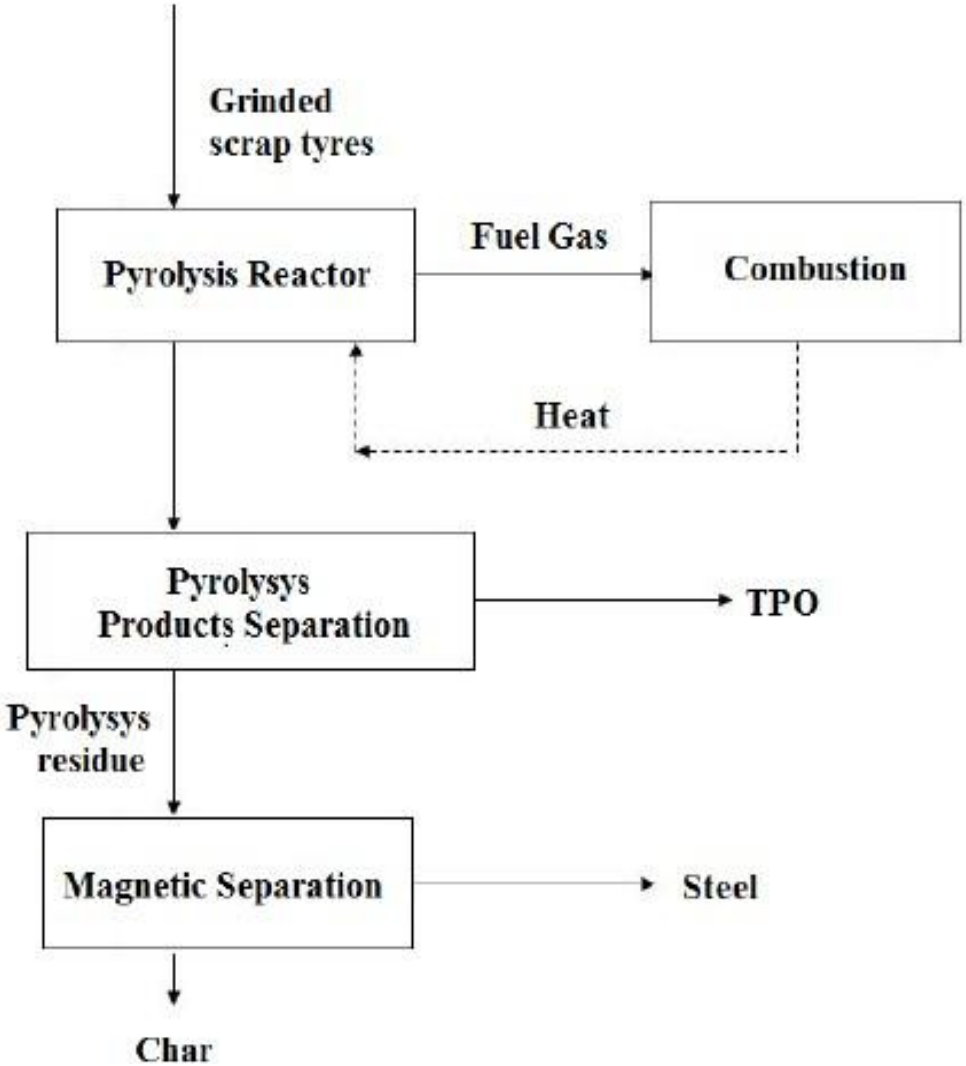

Figure 1. Process flow diagram of scrap tyre pyrolysis process [2].

Operating Facilities for a Continuous Pyrolysis Plant

Following facilities are required for smoothly running a continuous pyrolysis plant,

1. Feed to reactor should be in crumbs form with 10 to 50 mm size free of metals and fibres.
2. Feeding system must have an airlock system to prevent air entry into pyrolysis reactor during feeding.
3. Initial heating of pyrolysis reactor should be done using diesel and flue/pyro gas should be released through a chimney having 30-meter height.
4. After initial heating, pyro gas generated in reactor to be used as fuel for heating of the reactor.
5. Suitable instrumentation and safety interlock systems to be installed to continuously monitor and control temperature and pressure in all the zones. It should be ensured that reactor is under positive pressure all the time.
6. Tyre Pyrolysis Oil [TPO] collected through condensers must be done in closed vessels and storage tanks with suitable venting system. There should be pumping system to transfer of TPO and manual handling should be avoided.
7. There should be a mechanized system to separate suspended carbon black particles in pyro oil. Oil spillage must be avoided during the entire operations.
8. Collection of raw recovered black should be done with a mechanized system with further provision of contamination removal and micronizing and pelletizing.

PROPERTIES OF TYRE PYROLYSIS OIL

Table 1. Properties of diesel, TPO and distilled TPO [3].

Characteristics	ASTM Standards	Diesel Fuel	Tire Pyrolysis OIL (TPO)	Distilled (TPO)
Density (kg/L) at 15 °C	ASTM D4052	0.82–0.86	0.9563	0.8355
Gross calorific value (MJ/kg)	ASTM D240	44−46	42.00	43.56
Pour point (°C)	ASTM D97	−42 to −30	−3.00	< (−6)
Kinematic viscosity (cSt) at 40 °C	ASTM D7042	2.00	16.39	0.89
Flashpoint, °C	ASTM D93	> 55	50.00	<10
Carbon (wt.%)	ASTM D4530	87	85.67	87
Sulphur (wt.%)	ASTM D4294	0.16	1.12	0.43

Applications of Tyre Pyrolysis Oil: TPO Finds Diverse Applications Across Various Sectors

Fuel Production

TPO is further refined to produce diesel, gasoline, or fuel oil, serving as a sustainable alternative to conventional fossil fuels. TPO can also be used as rubber process oil either alone or in combination with other rubber processing oils [4].

Industrial Feedstock

Tyre pyrolysis oil can also be used as a feedstock in industrial processes, such as heating furnaces, boilers, and kilns [5].

Chemical Synthesis

TPO is being considered as a precursor in the synthesis of chemicals and polymers, contributing to the circular economy [6].

Asphalt Modification

It can be blended with bitumen to enhance the performance and sustainability of asphalt pavements [7–9].

Advantages of Tyre Pyrolysis Oil

Resource Utilization

TPO harnesses the energy potential of discarded tyres, mitigating waste accumulation and conserving valuable resources.

Environmental Benefits

By converting waste tyres into useful products, TPO helps reduce landfill pressure and curbs environmental pollution associated with tyre incineration or dumping.

Energy Efficiency

TPO contributes to energy security by offering an alternative energy source, thereby reducing reliance on finite fossil fuels.

Circular Economy

It promotes the principles of a circular economy by closing the loop on tyre waste, transforming it into valuable commodities (Table 1).

Challenges and Limitations: Despite Its Potential, TPO Faces Certain Challenges

Quality Variation

The quality of TPO can vary based on factors like feedstock composition, pyrolysis conditions, and post-processing methods, affecting its usability and market acceptance.

Regulatory Hurdles

Regulations regarding the use and disposal of TPO vary across regions, posing challenges to its widespread adoption.

Economic Viability

The economic viability of TPO production depends on factors, such as feedstock availability, processing costs, and market demand for derived products.

Technology Optimization

Continuous research and development are needed to optimize pyrolysis technology, enhance process efficiency, and improve product quality.

Current Market Landscape

The tyre pyrolysis oil market has been experiencing steady growth driven by several factors.

Environmental Concerns

With growing environmental awareness, governments and industries are increasingly seeking eco-friendly alternatives to traditional fossil fuels. Tyre pyrolysis oil presents itself as a viable option due to its potential to reduce greenhouse gas emissions and dependency on non-renewable resources.

Energy Demand

The escalating demand for energy worldwide has propelled the search for alternative energy sources. Tyre pyrolysis oil, derived from waste tyres, offers a sustainable solution to meet part of this demand.

Regulatory Support

Many governments are implementing regulations to encourage the adoption of renewable energy sources and promote waste management practices. Subsidies, tax incentives, and renewable energy targets are driving investments in technologies like tyre pyrolysis.

Technological Advancements

Ongoing research and development efforts are enhancing the efficiency and scalability of tyre pyrolysis processes. Innovations in reactor design, catalysts, and purification techniques are making the production of high-quality pyrolysis oil more economically viable.

The future of the tyre pyrolysis oil market appears promising, with several factors contributing to its growth potential:

Circular Economy Initiatives

The concept of a circular economy, where resources are recycled and reused to minimize waste, is gaining traction globally. Tyre pyrolysis aligns with this ethos by converting discarded tyres into valuable products, thereby closing the loop in the tyre lifecycle.

Energy Transition

As the world transitions towards cleaner energy sources, tyre pyrolysis oil can play a crucial role in the energy mix. Its potential to replace conventional fuels in industrial applications, power generation, and transportation presents a significant opportunity for market expansion.

Waste Management Solutions

With the proliferation of waste tyres posing environmental challenges, tyre pyrolysis offers an effective waste management solution. By converting tyres into valuable products like pyrolysis oil, it not only reduces waste but also mitigates environmental pollution associated with tyre disposal.

Investment and Collaboration

Continued investment in tyre pyrolysis technology and collaborations between governments, industries, and research institutions are expected to drive innovation and market growth. Strategic partnerships can accelerate the commercialization of pyrolysis oil and expand its applications across various sectors.

Estimated global market for tyre pyrolysis oil was USD 340.10 million in year 2023 and projected to be around 567.90 million in year 2030 with CAGR of 5.26% from 2024 to 2030 [10].

Asia Pacific region is showing rapid pace to expand usage of tyre pyrolysis oil for the period under the forecast period. Countries like India, Japan, and China have implemented strict regulations for tire disposal and supporting to an increased focus on clean energy generation as an eco-friendly option to conventional fossil-based fuels. These eco-friendly resources can greatly ease energy shortage problems and create huge economic benefits.

The growth of the tire pyrolysis oil market is seeing surge due to favourable regulations by government regulations and incentives aimed at promoting environmental practices and reducing carbon emissions. In addition, companies are highly investing in continuous waste tire pyrolysis plants as a profitable business, and partnerships and collaboration among government agencies, industry players, and research institutions are likely to supplement the market growth in this region.

Waste management is one of the rising concerns across the globe and requires attention or else it can affect the future immensely. According to the study, between 1 billion and 1.8 billion used tyres are discarded every year worldwide.

This accounts for about 2% to 3% of all waste materials collected in Europe. Key application of rubber derived unrefined pyrolysis oil is in vehicle tyres; more than 70% of all rubber in the world ends wrapped it around the wheels of cars, bicycles, and lorries.

Moreover, tires composed of around 80% rubber compound, steel, and textiles are built to last, making them a difficult product to recycle. Further, waste-derived pyrolysis oil production process contributes effectively toward waste management [11].

Through such processes, global waste production concerns can be reduced and generate desired petroleum outputs. Pyrolysis oil is expected to be used to generate electricity and energy to cater to the growing demand for diesel and gasoline.

Future Perspectives [12, 13**]: The Future of TPO Hinges on Technological Advancements, Regulatory Support, and Market Demand. Key Areas for Development Include**

Technological Innovation

Research efforts should focus on optimizing pyrolysis processes, enhancing product quality, and exploring novel catalysts for improved yields [13].

Policy Frameworks

Governments should formulate supportive policies, such as incentives for TPO production and regulations to encourage its use in various sectors.

Market Integration

Collaboration between industry stakeholders is crucial to establish TPO as a viable alternative fuel and industrial feedstock.

Public Awareness

Increasing public awareness about the benefits of TPO and the importance of tyre recycling can foster consumer acceptance and drive market demand.

CONCLUSIONS

Tyre pyrolysis oil represents a valuable resource in the quest for sustainable energy and waste management solutions. With its potential to convert waste tyres into useful products, TPO offers a pathway towards a circular economy and reduced environmental impact. Pyrolysis of scrap tyres enables separating of the rubber hydrocarbons of tires components (natural rubber and synthetic rubbers like SBR and polybutadiene rubber and carbon black), creates favorable conditions for a circular economy [14–16]. The resulting products are considered as energy commodities. Both, the tire pyrolysis oil and the tyre pyrolysis gas, are combustibles and can be used as replacement of fossil fuels. However, addressing challenges, such as quality control, regulatory frameworks, and economic viability is essential to unlock the full potential of tyre pyrolysis oil in different industrial applications.

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