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Recycled Carbon Black Manufacturing and Its Commercialization

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Abstract

Recycled Carbon Black (rCB) has emerged as a sustainable alternative to virgin carbon black in the manufacturing of tires, non-tyre rubber products, and various other industrial applications. The increase in demand for this environmentally friendly material is due to the growing issue of waste/scrap tyre management, which has driven the development and commercialization of rCB. This study explores the various processes involved in the production of recycled carbon black, including pyrolysis and advanced chemical treatments, which help to convert waste/used tires and plastics into valuable carbon black. The study also discusses the commercial viability of rCB, focusing on the technological advancements, economic factors, and market opportunities for its industrial adoption. Despite current challenges i.e. inconsistent product quality and relatively higher processing costs, the growing awareness of environmental impacts and regulatory pressure for recycling are propelling the demand for rCB in industries to minimise their carbon footprint. The study highlights case studies of companies that have successfully implemented rCB technology, showcasing their efforts to scale up production and establish a market presence. Additionally, it examines the potential for rCB to serve as a key ingredient of a circular economy by closing the loop on carbon black production. Finally, the study identifies key trends and innovations that may shape the future of rCB manufacturing and its commercialization, offering insights into how it can contribute to a more sustainable and resource-efficient industrial ecosystem.

Keywords: Carbon black, recycled carbon black, pyrolysis, end of life tires, hydrothermal carbonization

INTRODUCTION

In recent years, sustainability has become a key area of innovation across industries, particularly in manufacturing. One such area where sustainable innovation is making significant strides is the production of carbon black [1]. Traditionally, Carbon Black is derived from fossil fuels in processes that contribute to significant environmental degradation, has now found itself as the centre of an evolving green revolution. Recycled carbon black (rCB) manufacturing is a new frontier in this transformation, which offers both economic and environmental benefits.

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WHAT IS CARBON BLACK? [2, 3]

Carbon black is a fine, black powder made from the incomplete combustion of hydrocarbons, mainly derived from oil or natural gas. It is used as a reinforcing filler in rubber products, in tires, non-tires, plastics, coatings, inks, and batteries applications. In finished rubber production, carbon black significantly improves durability, wear resistance, and weathering properties. In plastics and coatings, it imparts colour and UV stability.

Carbon black is produced by the furnace black process, where a hydrocarbon fuel (such as oil or gas) is partially combusted at a high-temperature, oxygen-limited environment. This process results in the formation of carbon black particles, which are further processed into different grades based on particle size and structure.

However, as industries are now focusing for development of more sustainable practices, concerns about the environmental impact of producing carbon black have arisen. The manufacturing process of Carbon Black generates greenhouse gases (GHGs), and the raw materials are fossil-based, which is contributing to resource depletion. In order to overcome these problems, alternative approaches such as the recycling of carbon black have gained considerable attention in recent years.

RECYCLED CARBON BLACK: A SUSTAINABLE ALTERNATIVE [4]

Recycled carbon black (rCB) is carbon black that is produced by recovering the material from used/scrap/End of Life Tires (ELTs), rubber and plastic waste. This process allows to reuse carbon black that has already served its purpose in the marketplace, effectively creating a closed-loop recycling system. The recycling of carbon black reduces waste generation, lower carbon footprints, and decrease dependency on fossil fuels.

SOURCES OF RECYCLED CARBON BLACK [5]

End-of-Life Tires (ELTs)

ELTs represent the largest source of carbon black waste globally. According to the European Tyre & Rubber Manufacturers' Association (ETRMA), more than 1.6 billion used tires are scraped every year worldwide, many of which are used in landfills or incinerators [6]. As tires contain up to 30% carbon black, they are rich and readily available feedstock for rCB production.

Waste Rubber

Other rubber waste, like conveyor belts, rubber mats, and automotive parts, are also valuable sources of carbon black that can be recycled. Rubber wastes are efficiently processed through various recycling technologies to recover both carbon black and other valuable components like pyro gas and Pyrolysis Oil.

Plastics and Other Products

Carbon black is also used in plastics and coatings industries. As the demand for recycled plastics is increasing, carbon black recovery from post-consumer plastic waste can contribute to a more sustainable and circular economy.

MANUFACTURING PROCESS OF RECYCLED CARBON BLACK [7]

The process of recycling carbon black starts with the collection, segregation and pre-treatment of waste materials, and then the recovery and refining of carbon black. The technology used for rCB production has developed significantly in recent years, and a range of processes are now available and being used commercially. These processes mainly focus on devulcanization (breaking down the cross-links in rubber), carbon black recovery, and purification. Following are some of the common methods:

Pyrolysis (Thermal Decomposition) [8]

Pyrolysis is one of the most widely used methods for producing recycled carbon black. In this process, waste tires or rubber are indirectly heated in a controlled, oxygen-free environment at temperatures between 400 and 600°C [9]. This heat causes degradation polymers into the organic materials to break down into gases, liquids, and solid carbon black. The gaseous products are typically condensed into oils (Pyrolysis Oil), which can be further processed into fuels or chemicals, and the solid carbon black is recovered and refined into free-flowing powder or pellets.

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The key advantages of pyrolysis process are as follows:

- *High yield:* Pyrolysis process produces a high percentage of carbon black from waste materials, normally exceeding 40% by weight.
- *Energy recovery:* This process also generates energy in the form of oil and gas, which is used to power the pyrolysis plant itself.
- *Reduced environmental impact:* Pyrolysis process reduces the waste going to landfills and eliminates the need for incineration.

It may be highlighted that, the quality of recycled carbon black produced via pyrolysis depends on the type of feedstock and processing conditions during the pyrolysis. Further refinement is necessary to meet the specifications for different industrial applications.

Solvent Extraction and Mechanical Processing [10]

The carbon black is also recovered from waste rubber or plastic through solvent extraction [11]. This method involves using solvents to dissolve the rubber or plastic matrix, leaving behind the carbon black. The carbon black is then purified through mechanical processes such as grinding, sieving, washing, drying & palettization prior to application.

Solvent extraction method is more selective than pyrolysis and may result higher-quality recovered carbon black, but it is more expensive and less environmentally friendly due to the use of chemicals, especially organic solvents.

Hydrothermal Carbonization (HTC) [12]

A less common but promising method under development of carbon black recycling is hydrothermal carbonization (HTC). HTC typically involves heating organic waste materials in a high-pressure water environment at temperatures between 180 and 250°C. This process converts the organic waste into a solid carbon-rich material known as hydro char, which is subsequently processed to obtain carbon black.

HTC is still being explored as a commercial technology for Recovered Carbon Black (rCB) production, but it has shown good potential due to lower temperature requirements and relatively simple equipment required (Figure 1) [13].

Plasma Arc Technology [14]

Plasma arc technology uses high-temperature plasma generated by an electric arc to break down rubber waste into its constituent components [15]. The carbon black is recovered from the plasma arc reactor, and the gaseous by-products are used as a source of energy.

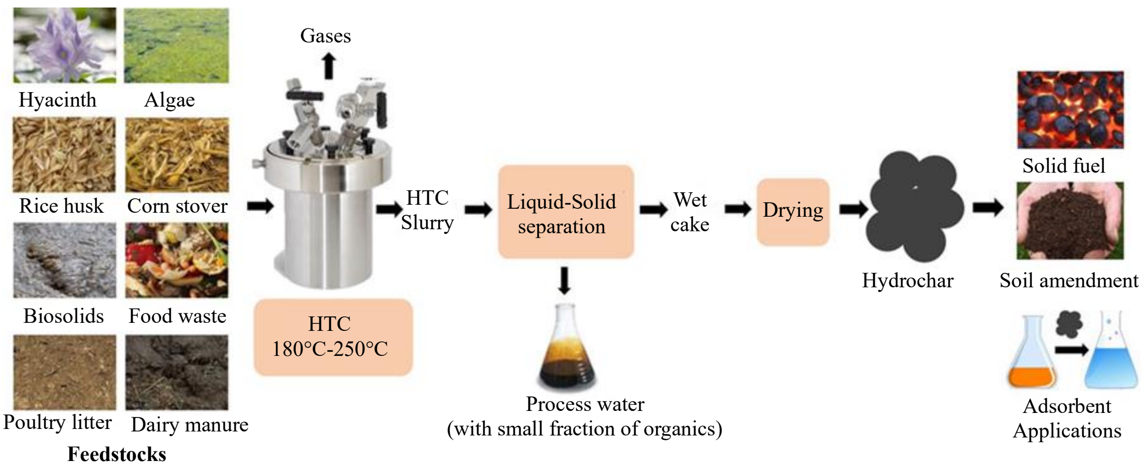

Figure 1. HTC process illustration diagram [13].

Plasma arc technology is still in its early stages, but it holds promise and is capable of producing high-quality recycled carbon black. It is particularly suitable for recovering carbon black from complex waste materials, like mixed plastic and rubber waste.

REFINEMENT AND PURIFICATION [16]

After the initial recovery of carbon black from waste materials, the product often needs to be refined to meet the stringent quality specifications as per the requirement of various industrial applications. This may include:

- *Purification [17]:* The removal of contaminants such as sulphur, oils, and ash is necessary to improve the quality and performance of the recycled carbon black in certain commercial applications.
- *Grinding and sizing (Size Reduction):* The carbon black particles need to be ground and sized to specific ranges, as different applications require different particle sizes.
- *Palletisation [18]:* In order to minimize dusting problem, Recovered Carbon Black after sieving can be converted to pellets form for easy to handle, transport and use.
- *Surface modification [19]:* The surface of the recycled carbon black is modified to improve its dispersion characteristics in rubber and plastic compounds. This step is especially important when the recycled carbon black is used for improvement in reinforcing properties in high-performance applications such as automobile tires.

COMMERCIALIZATION OF RECYCLED CARBON BLACK [20, 21]

The commercialization of recycled carbon black has gained momentum in recent years, due to both regulatory pressures and growing demand for sustainable products. Several companies have made significant strides in establishing scalable production processes for rCB and integrating the material into the supply chain.

Challenges in Commercialization of Recovered Carbon Black [22]

1. *Quality Control [23]:* One of the primary challenges of recycled carbon black is ensuring that it meets the quality consistency and performance standards required by industries like tire manufacturing. Recycled carbon black may have variations in particle size, structure, and purity, which can very much impact its performance in different applications.
2. *Economic Viability [24]:* The cost of producing recycled carbon black must be competitive with traditional carbon black, which is produced at large scale from petroleum-based feedstocks. Generally, recycling process reduces raw material costs; however, additional steps required for purification and surface modification can lead to increased cost of production of rCB. Overcoming these cost barriers is must for wider adoption and commercialization of Recovered Carbon Black.
3. *Lack of Standardization:* Currently, there is a lack of established standards for recycled carbon black (standards are being designed ASTM commission D36) which complicates its acceptance in various industrial applications [25]. Standardization of the quality and performance parameters for rCB will be key parameters to its commercialization and wider applications.
4. *Supply Chain Integration [24]:* For companies to adopt rCB for regular commercial production, they need a reliable, regular and consistent supply of high-quality recycled carbon black. This requires big investment in infrastructure, such as recycling facilities with regular supplies of RM (Scrap Tires) and logistics networks, to ensure a steady flow of feedstock from waste rubber and plastic sources.

SUCCESSFUL CASE STUDIES

Several companies have emerged as leaders in the recycled carbon black industry. Some of the notable players include:

1. *Black Bear Carbon [24]:* Based in the Netherlands, Black Bear Carbon has developed a proprietary pyrolysis technology to recycle carbon black from end-of-life tires. Their process not

only recovers carbon black but also produces oil and gas, which can be used to power the plant. The company has commercialized its technology and is working with several major tire manufacturers to incorporate recycled carbon black into their products.

2. *Pyrolyx AG [24]:* Pyrolyx, a German company, operates one of the first industrial-scale plants for producing recycled carbon black from waste tires. Pyrolyx has established a strong position in the European market, providing rCB to major tire manufacturers, automotive companies, and plastic producers.
3. *Bolder Industries [24]:* This company focuses on producing high-performance rCB from used tires and other rubber waste. Bolder's rCB is used in a variety of applications, including rubber, coatings, and plastics.

These companies demonstrate that there is a growing market for recycled carbon black, and as technologies continue to improve and costs decrease, the commercialization of rCB is expected to expand.

MARKET TRENDS AND FUTURE OUTLOOK

The market for recycled carbon black is growing rapidly as the global emphasis on circular economies and sustainable manufacturing practices is on forefronts and intensifies. According to recent market research reports, the global recycled carbon black market is expected to grow at a compound annual growth rate (CAGR) of over 30% from 2020 to 2027.

Several trends indicate bright future of rCB manufacturing and commercialization:

1. *Growing Demand for Sustainable Products:* Consumers and businesses are increasingly focusing on sustainability. As regulations around waste and emissions become stricter, companies are seeking affordable and easily available alternatives to virgin carbon black and adopting to recycled solutions in their production.
2. *Investment in Recycling Infrastructure:* Governments are encouraging private companies for investing in infrastructure to support the recycling of carbon black. These investments are essential and crucial for scaling up rCB production and integrating it into global supply chains.
3. *Collaborations and Partnerships:* Many tire manufacturers, rubber producers, and plastic companies are forming partnerships with rCB producers to secure a steady supply of consistent quality of recycled material and to meet their sustainability goals. These collaborations are the need of the hour for driving the widespread adoption of rCB in various industrial sectors.
4. *Technological Advancements:* Continuous research and development activities are under way for improvising existing recycling technologies, such as pyrolysis, solvent extraction, and plasma arc technology, to improve the efficiency and cost-effectiveness of commercial production of rCB.

CONCLUSION

The recycled carbon black industry represents a promising opportunity for sustainable manufacturing, offering a comprehensive solution for the ever-growing problem of waste management as well as reducing dependence on fossil resources. Through innovative recycling technologies and commercial partnerships, recycled carbon black is poised to become a promising and key material in industries such as tire manufacturing, rubber production, plastics, and coatings. However, challenges such as quality control, economic viability, and supply chain integration must be addressed to ensure the widespread adoption of rCB with full pace.

As the demand for sustainable products continues to rise, recycled carbon black will certainly play a pivotal role in helping industries to meet their environmental goals while supporting a circular economy. With ongoing advancements in recycling technologies and growing investment in infrastructure, the future of recycled carbon black seems to be absolutely bright, offering a path toward a more sustainable and circular future for industrial materials.

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