

# Hydrothermal Carbonization (HTC) Technology for Tire Pyrolysis: A Comprehensive Review

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## Abstract

*Hydrothermal Carbonization (HTC) is an innovative technology that mimics natural coal formation processes to convert wet biomass into valuable carbon-rich materials known as "biochar". This process involves subjecting organic matter, like agricultural waste, food residues, or sewage sludge, under high-pressure and moderate-temperature conditions (around 180–250°C and 2–4 MPa) in the presence of water. HTC technology accelerates process of the dehydration and carbonization of biomass, thus producing a solid product with improved energy density, which can find various applications such as fuel, soil amendments, and a precursor for activated carbon production. HTC process is a sustainable solution to effectively manage biomass waste including waste tires and creating value-added products. The biochar produced through HTC has high surface area, and can be customized for specific applications. HTC is an effective means of carbon sequestration, helping mitigate climate change by locking carbon in solid form and significantly reducing greenhouse gas emissions. Moreover, HTC technology reduces the volume of waste material, leading to waste-to-energy strategies and promoting a circular economy. HTC technology's versatility offers to process a wide range of feedstocks, including those that are too wet or difficult to handle with other biomass conversion technologies. HTC's integration with existing waste management and energy systems holds great potential for addressing global challenges related to waste disposal, renewable energy generation, and sustainable agriculture. As research and development progress, HTC technology has the potential to play a significant role in future energy and environmental solutions. This review briefly describes basic HTC technology, its usage in Tire Pyrolysis, superiority as compared other recycling technologies and challenges and limitations.*

**Keywords:** Hydrothermal Carbonization (HTC), tyre pyrolysis, hydrochar, pyrolysis oil, carbon black

## INTRODUCTION [1, 2]

In the pursuit of sustainable waste management, tyre pyrolysis is a promising solution for dealing with the ever-growing massive number of used/end of life tyres generated globally. Typically, tyre pyrolysis involves the thermal decomposition of tyres in the absence of oxygen to valuable products such as oil, gas, carbon black, and steel wire. Among the current technologies used to further enhance

the efficiency and effectiveness of tyre pyrolysis, HTC (Hydrothermal Carbonization) is emerging as a game-changer. HTC technology, used for the treatment of organic materials such as biomass, is currently being explored for its potential adaption in tyre pyrolysis.

HTC technology is considered as a relatively new process in the field of waste-to-energy and material recycling. HTC operates under mild conditions of temperature (180–250°C) and pressure (up to 30 bar) in an aqueous environment to convert the organic material into solid carbon product called hydrochar. Although HTC has been primarily

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applied to biomass processing, its application to tyre pyrolysis presents huge potential for improving the efficiency and environmental performance of the pyrolysis process. This review aims to explore the role of HTC technology in tyre pyrolysis, its advantages, challenges, and potential for scaling up. We will examine the principles behind HTC, its integration with pyrolysis processes, the products, and environmental impact of combining these technologies.

### The Need for Sustainable Tyre Waste Management [3]

The disposal of used tyres is a growing concern due to their severe environmental hazards globally. According to the European Tyre and Rubber Manufacturers' Association (ETRMA), millions of tyres are discarded worldwide every year. Tyres, made primarily from synthetic rubber, steel, and carbon black, which all are non-biodegradable, and if improperly disposed of, they create severe environmental risks. It may be highlighted that, traditional disposal methods, like landfilling and incineration, are not sustainable due to space limitations, pollution concerns, and the release of harmful emissions.

Tyre pyrolysis is considered as an innovative disposal method to address these issues. In general, the pyrolysis process decomposes the tyres at high temperatures in the absence of air, to produce value added byproducts such as:

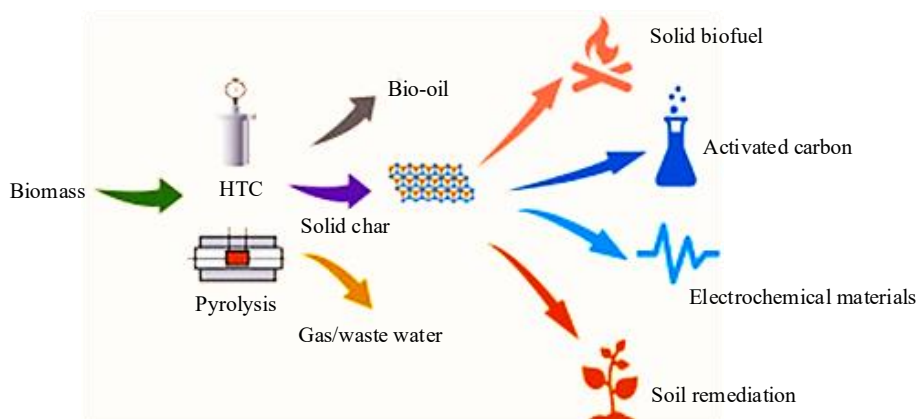
- *Pyrolytic Oil*: A liquid fuel that can be used for various industrial applications.
- *Pyrolytic Gas*: A gaseous product that can be used as a fuel to power the pyrolysis reactor itself.
- *Carbon Black*: A high-value material used in the manufacturing of new tyres, rubber products, and inks.
- *Steel Wire*: Recovered from the steel-belted tyres, which can be recycled.

However, despite its advantages, the traditional tyre pyrolysis process faces several challenges, including high energy consumption, low efficiency, and significant environmental impact. The introduction of HTC technology into tyre pyrolysis offers the potential to improve these aspects significantly.

## HYDROTHERMAL CARBONIZATION (HTC) TECHNOLOGY: INTRODUCTION

### Principles of HTC [4]

HTC is a process that involves the conversion of organic material into carbon-rich products (hydrochar) in a hot, pressurized water (aqueous) environment. The process takes place at temperatures ranging from 180 to 250°C and under high pressure (up to 30 bar), in the presence of water, which is used as a solvent and also as a medium for heat transfer. The key mechanism of HTC is the breakdown of complex organic polymers into simpler low molecular weight structures, with the formation of hydrochar as the primary product [5]. The hydrochar is a high carbon content and can be used as a solid fuel or further processed for applications in various industries. In addition to hydrochar, the HTC process also produces liquid (Pyro Oil) and gaseous byproducts (Pyro gas), which can be used in energy recovery applications (Figure 1).



**Figure 1.** Process flow of HTC and pyrolysis technology [6].

The HTC process involves the following key steps [7]:

- *Hydrolysis*: The organic material is partially broken down by water into smaller compounds.
- *Dehydration*: Water helps to remove moisture from the organic material and facilitating carbonization.
- *Reactions/ Carbonization*: The smaller organic molecules undergo several reactions resulting into the formation of complex carbon structures in the hydrochar.

HTC has been mainly used for the processing of biomass, such as agricultural residues and food waste, due to its relatively low temperature requirements and high efficiency. Its application to tyre pyrolysis is of great significance because of the possibility of improving the carbon yield, reducing energy consumption, and enabling the recovery of additional valuable byproducts at relatively lower temperature.

### **HTC'S ROLE IN TYRE PYROLYSIS [8]**

The integration of HTC technology into tyre pyrolysis involves modifying the traditional pyrolysis process to introduce water as a medium for heat transfer as well as carbonization. In this hybrid technical approach, tyres are first subjected to HTC conditions, where the organic components of the tyres undergo partial breakdown in the presence of water at elevated temperatures and pressures. The hydrochar produced during HTC can be further processed in a pyrolysis reactor to produce oil, gas, and carbon black.

### **Key Benefits of Combining HTC with Tyre Pyrolysis Include [9]**

*Improved Carbon Yield*: HTC may increase the carbon content of the pyrolyzed material, leading to a higher yield of carbon black, a valuable product used in the manufacturing of new tyres and other rubber products.

- *Lower Energy Consumption*: HTC operates at lower temperatures than conventional pyrolysis, thus reducing the energy required significantly for the process and therefore improving its overall efficiency.
- *Enhanced Fuel Production*: The integration of HTC can result in higher-quality pyrolytic oils with a higher energy density and can find usage as a more efficient green fuel.
- *Water Recovery*: The water used in the HTC process can be recovered and recycled, which will reduce overall water consumption and minimizing the environmental impact due to waste water discharge.

### **ADVANTAGES OF HTC VS. TYRE PYROLYSIS [10]**

#### **Energy Efficiency [11]**

One of the primary advantages of incorporating HTC into tyre pyrolysis is its potential to enhance energy efficiency. Current tyre pyrolysis requires high processing temperatures (typically around 400–500°C), which requires significant energy input. By using HTC to pre-treat the tyres, the need for such high temperatures can be reduced drastically. Since HTC operates at lower temperatures (180–250°C), hence it requires less energy for the carbonization process as compared to pyrolysis.

Furthermore, studies indicated that byproducts of HTC, such as hydrochar and pyrolytic oil, have higher energy densities compared to raw tyres. This means that the overall process becomes more efficient in terms of energy conversion, reducing reliance on external energy sources and making the process more sustainable.

#### **Reduction in Emissions [12]**

HTC technology can also contribute to the reduction of harmful emissions during tyre pyrolysis. Traditional tyre pyrolysis (which operates at higher temperature) can release volatile organic compounds (VOCs), sulfur, and other pollutants into the atmosphere. However, by introducing HTC into the process, the breakdown of the tyres can be more controlled, leading to the formation of fewer

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harmful byproducts. The water environment in HTC also helps to capture and neutralize some of the potentially harmful gases in water itself that might otherwise be released during pyrolysis.

### **Higher Quality Byproducts [13]**

By incorporating HTC, the pyrolyzed products, particularly the carbon black and pyrolytic oil, can be of higher quality. The hydrochar produced through HTC can be further processed into a more valuable form of carbon black with better properties for use in industrial applications. The pyrolytic oil produced in this enhanced process can also have a higher calorific value, making it a more efficient and versatile fuel.

The oil and gas produced from HTC-assisted tyre pyrolysis are often cleaner, with fewer impurities, which makes them more suitable for industrial use, including as a fuel in cement kilns or as a feedstock for chemical processes.

### **Environmental Benefits [14]**

One of the main driving forces behind the adoption of HTC in tyre pyrolysis is its potential to reduce the severe environmental impact of the waste tyre disposal process. By combining these technologies, it is possible to convert waste tyres into valuable resources, such as fuel, carbon black, and steel, while minimizing the environmental impact associated with traditional disposal methods. The process also promotes resource recovery and reduces the need for raw materials, contributing to a circular economy.

HTC's ability to use water as a medium also ensures that the process is safe and environmental footprint of the process is minimized. In addition, the recovery and reuse of water used in the process further offers the sustainability of the technology.

### **CHALLENGES AND LIMITATIONS [15]**

While the combination of HTC and tyre pyrolysis holds great promise, several challenges are road blocks in its implementation. These include:

1. *Cost of Technology:* The cost of setting up an HTC-based pyrolysis system is relatively higher as compared to traditional pyrolysis technology due to the complexity of the HTC process which needs specialized equipment to handle high-pressure water systems.
2. *Material Handling:* Tyres are difficult to process due to their tough, rubbery nature. The presence of steel wires and other non-organic components makes the processing challenging.
3. *Scale-up Issues:* Scaling up the HTC-enhanced tyre pyrolysis process for commercial applications may require significant optimization, particularly in terms of maintaining the required temperature and pressure conditions in large commercial production plants.
4. *Product Quality Variability:* The quality of the hydrochar and other byproducts can vary depending on the specific parameters of the HTC process, like temperature, pressure, and water composition. Ensuring consistency in processing parameters, to obtain good finished product quality is essential for commercial viability.

### **CONCLUSION AND FUTURE TRENDS [16–20]**

As dedicated research and development efforts in HTC technology progress, it could play a pivotal role in making tyre pyrolysis a more sustainable and attractive, efficient, and environmentally friendly process, aligning with the ever-growing demand for cleaner recycling technologies globally.

HTC technology presents an exciting opportunity to improve the efficiency, sustainability, and environmental performance of waste tyre pyrolysis. With the unique advantages of HTC, such as energy efficiency, enhanced product quality, and reduced emissions, the combination with conventional tyre pyrolysis technology has great potential to revolutionize the waste tyre management and recycling industry.

Although challenges in commercial implementation of HTC remain, particularly in terms of cost and scalability, the continued research and development of HTC-assisted tyre pyrolysis systems has great promise in future. With growing awareness and concerns over waste tyre disposal and the increasing demand for sustainable solutions, HTC technology could play a critical and pivotal role in transforming the tyre recycling industry to next stage and contributing to a circular economy.

As the technology matures and more pilot projects are implemented, it is likely that we will see broader adoption of HTC-enhanced tyre pyrolysis systems in coming years, leading to more efficient and environmentally friendly tyre recycling practices in the near future.

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