

PRODUCTION OF ACTIVATED CARBON FROM WASTE RUBBER TYRE

CP301

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ABSTRACT

This report elucidates the transformative process of converting waste rubber tires into activated carbon, a valuable material with diverse industrial applications. The production method outlined herein emphasizes sustainability and resource efficiency, offering a promising solution to mitigate environmental burdens associated with tire disposal while concurrently addressing the demand for activated carbon. The flowchart provides a comprehensive overview of the sequential steps involved, from tire collection and preparation to pyrolysis and activation stages, culminating in the creation of high-quality activated carbon. Each stage of the process is then examined in detail, explaining the purpose, factors affecting efficiency, and potential challenges. Through thorough analysis and optimization, This report highlights the potential of this technology to address the growing problem of waste tire disposal while creating a valuable resource for various applications, thereby contributing to the circular economy and fostering environmental stewardship.

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0.1 INTRODUCTION

India's booming automotive industry, a symbol of progress, presents a hidden environmental threat: waste rubber tires. These essential components for safe transportation have a major drawback – their near-indestructible nature in landfills. Taking centuries to decompose, they create a growing environmental burden. India discards an estimated 1.5 billion waste tires annually, contributing a significant portion to the global problem ([India Today, 2023])[1]. This translates to roughly 6 % of the total global waste tire generation. With limited land resources, India struggles to manage its ever-increasing landfill burden. Waste tires occupy significant space and pose a risk of leaching harmful chemicals into the environment.[2]



Figure 1: Tyre Dump-yard

The ever-growing number of vehicles in India necessitates effective solutions for managing waste rubber tires. Tires in landfills create socio-economic and environmental issues and are visually unappealing to local communities [8][9]. Due to their durable composition, tires decompose slowly [7], occupying a large volume of landfill space due to their incompressibility. Moreover, tire stockpiles can become breeding grounds for

disease-carrying vectors [11]. When these stockpiles catch fire, extinguishing them is not only costly [10] but can also lead to temporary health issues due to impaired visibility and environmental pollution. The smoke from tire fires is particularly concerning, as it emits large quantities of harmful gases [12][13]. The accumulation and improper disposal of tires pose significant challenges that need urgent attention to mitigate their adverse impacts.

0.2 LITERATURE SURVEY

0.2.1 Already existing methods of waste tire management

Here's an overview of current methods and potential alternatives for recycling waste tyre:

1. **Rubber Asphalt:** Incorporating rubber powder into asphalt improves road performance by enhancing cracking and rutting resistance. Research by the Indian Road Congress shows that rubberized asphalt can extend road life by up to 50%, reducing maintenance costs and environmental concerns.

Problem: However, challenges include higher material costs and concerns about the leaching of chemicals into the environment.

2. **Rubber Mulch:** Rubber mulch, made from shredded or pelletized tires, is used in landscaping for its shock absorption and low-maintenance qualities.

Problem: Despite its benefits, there are concerns about long-term environmental impact due to the potential leaching of chemicals and limited biodegradability.

3. **Rubber Products:** Waste tires can be transformed into various products due to their durability and elasticity.

Problem: Challenges may arise related to market demand, product quality, and scalability of production, especially for niche rubber products.

4. **Concrete Use:** Adding crumb rubber to concrete can enhance flexibility, damping properties, and resistance to fatigue cracking.

Problem: Challenges include ensuring proper bonding between rubber and cement, potential reduction in compressive strength, and additional testing required for structural applications.

0.2.2 Activated carbon

Activated carbon, also known as activated charcoal, is a highly porous form of carbon with a vast internal surface area and a network of microscopic pores. This unique structure gives activated carbon exceptional adsorption properties, making it highly effective in capturing and retaining a wide range of contaminants and impurities from gases, liquids, and solutions[5].

Uses of activated Carbon:

1. Water Purification: Activated carbon is widely used in water purification processes to remove contaminants, byproducts, chlorine, and volatile organic compounds (VOCs) from drinking and wastewater. It also removes odors and tastes.
2. Air Purification: Carbon filters are used in air purification systems to capture pollutants such as volatile organic compounds (VOCs), ozone, sulfur dioxide, and particulate matter. It helps improve indoor air quality and reduce the risk of respiratory problems.
3. Gas Purification: Activated carbon is utilized in gas purification applications to adsorb impurities, such as hydrogen sulfide, ammonia, and sulfur compounds, from natural gas, biogas, and industrial gases.
4. Environmental Remediation: Activated carbon is used in environmental remediation projects to mitigate soil and groundwater contamination caused by hazardous substances, including heavy metals, pesticides, and industrial chemicals.
5. Pharmaceutical and Medical Applications: Activated carbon is employed in pharmaceuticals and medical products for its adsorption properties. It is used in gas masks, respirators, and wound dressings, and as an antidote for poisoning by adsorbing toxins and drugs in the gastrointestinal tract[5].

0.3 PROCESS FLOW DIAGRAM

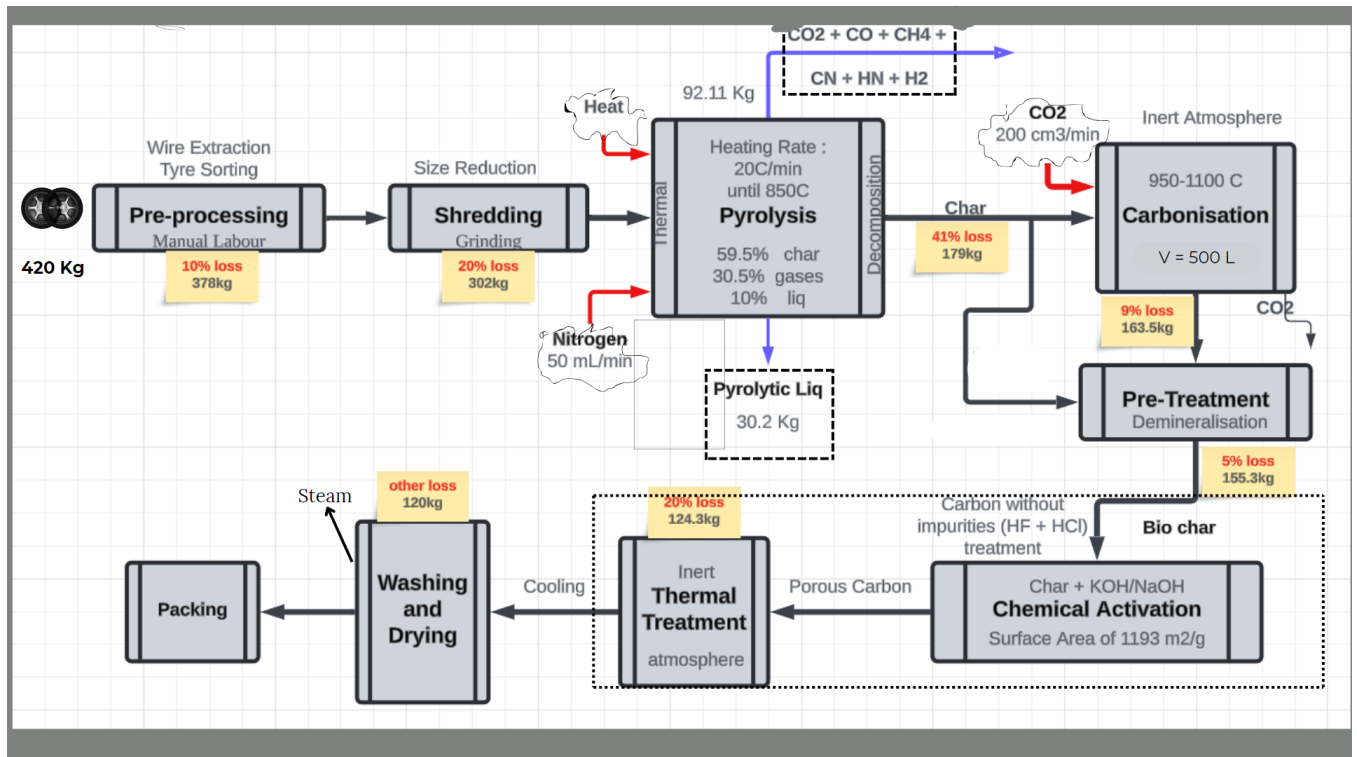


Figure 2: Process flow diagram

0.4 METHODOLOGY

0.4.1 Collection and Sorting

The first step in the pre-processing of rubber tires is the collection of used tires from various sources such as automobile repair shops, tire retailers, and waste management facilities.

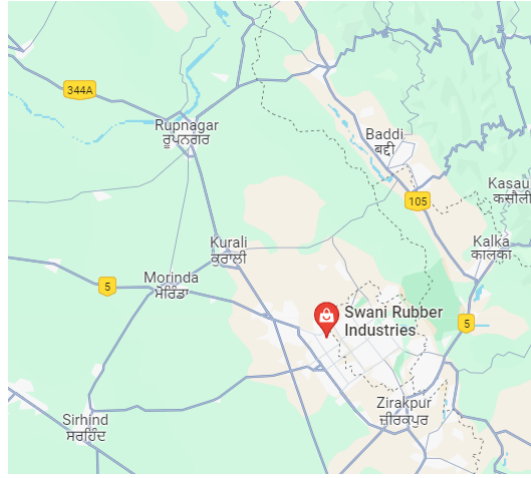


Figure 3: Tyre collection point near Ropar

0.4.2 Pre-treatment

- Removal of foreign objects: Before shredding, any metal bands, wires, or other foreign objects remaining on the tires are removed manually or mechanically. This is important to prevent damage to the shredding equipment and ensure a cleaner feedstock for pyrolysis.
- Shredding: Large tire pieces are fed into a primary shredder. This machine typically uses cutting blades or heavy-duty rotating hammers to break down the tires into large chunks, often ranging in size from 250mm to 500mm (10 to 20 inches). Depending on the specific pyrolysis requirements, the large chunks from the primary shredder may undergo secondary shredding. This stage uses similar equipment to further reduce the particle size to a more uniform range, typically between 10mm and 50mm (0.4 to 2 inches).



Figure 4: Pre-processing of tyre

0.4.3 Pyrolysis

Thermochemical conversion of organic biomass into gaseous or/and liquid fuels at extremely high temperature in the absence of halogen (mainly oxygen) is termed as pyrolysis. It is a thermal decomposition process that converts organic materials into valuable products such as pyrolysis oil, carbon black, and syngas. Operating at a temperature 850°C and atmospheric pressure, the process occurs in the absence of oxygen to prevent combustion.

Key reactor conditions include controlled residence time and the introduction of nitrogen (N_2) at a flow rate of 50ml/min to maintain an oxygen-free environment. The sample was heated at a rate of $20\text{ }^{\circ}\text{C/min}$ until the maximum temperature of 850°C was reached and maintained. The composition of the primary pyrolysis products is influenced by process operating parameters such as the feed size, temperature and pressure, residence time, heating rate, and reactor configuration, as well as the presence of a catalytic medium. As shown in the flow chart, after pyrolysis we get 51 % char, 30% gas and 10% pyrolytic oil.

A flow diagram of tire pyrolysis process, including the proposed thermal decomposition model, is presented in Figure below. The three types of arrows in the flow diagram indicate three decomposition reactions. The higher weight or color deepness of the arrows indicates the decomposition of the corresponding tire material in the higher temperature regions.

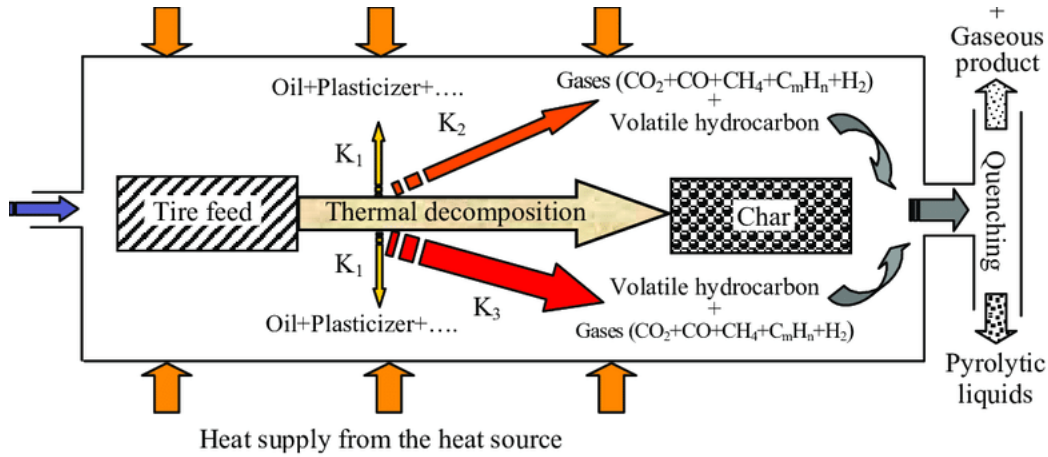


Figure 5: Pyrolysis of rubber

Thus, the global pyrolysis reaction that takes place into a reactor can be described in the following manner:

1. Tire wastes volatile hydrocarbon + gases + solid residues
2. Tire wastes, fed into the pyrolysis reactor undergoes a thermal cracking, by cleaving themselves into volatile hydrocarbon, gases and solid residue.
3. Volatile hydrocarbon can be cooled and condensed into a liquid fraction
4. Gaseous fraction remains uncondensed during quenching
5. Solid residues wait in the reactor chamber for their removal

Normally, the process provides:

- A gaseous fraction (30.5 wt%) is essentially composed of CH_4 , and higher hydrocarbons C_mH_n , H_2 , CO_2 , CO etc.
- A liquid fraction (10wt%), composed of water, tar, and oils (organic compounds);
- Solid residues containing steel cord (10 wt%) and char (59 wt%), containing fixed carbon and ashes (metals, oxides, and inert matter).

0.4.4 Carbonization

Physical activation is a two-step process. Carbonization of carbonaceous materials comes first, then activation of the resulting char at high temperatures in the presence of CO₂ serving as oxidizing gases.

Tyre rubber was heated to 700 °C in nitrogen, when this temperature was reached, the gas was substituted by carbon dioxide at a flow rate of 500 ml/min and further heated to 950 °C. For the activation agent, CO₂(purity of 99.99%), the flow rate was maintained at 200 cm³/min. In the steam runs, water flow rates of 0.6 and 0.05 g/min at activation temperatures were maintained by a syringe pump. Initial carbonization 500–600 °C gives char yield in the range of 33–42 % with very limited porosity development (307 m²/g). The product was prepared in 1 atm CO₂ at 900 °C with a surface area of (813 m²/g) at 10% burn-off

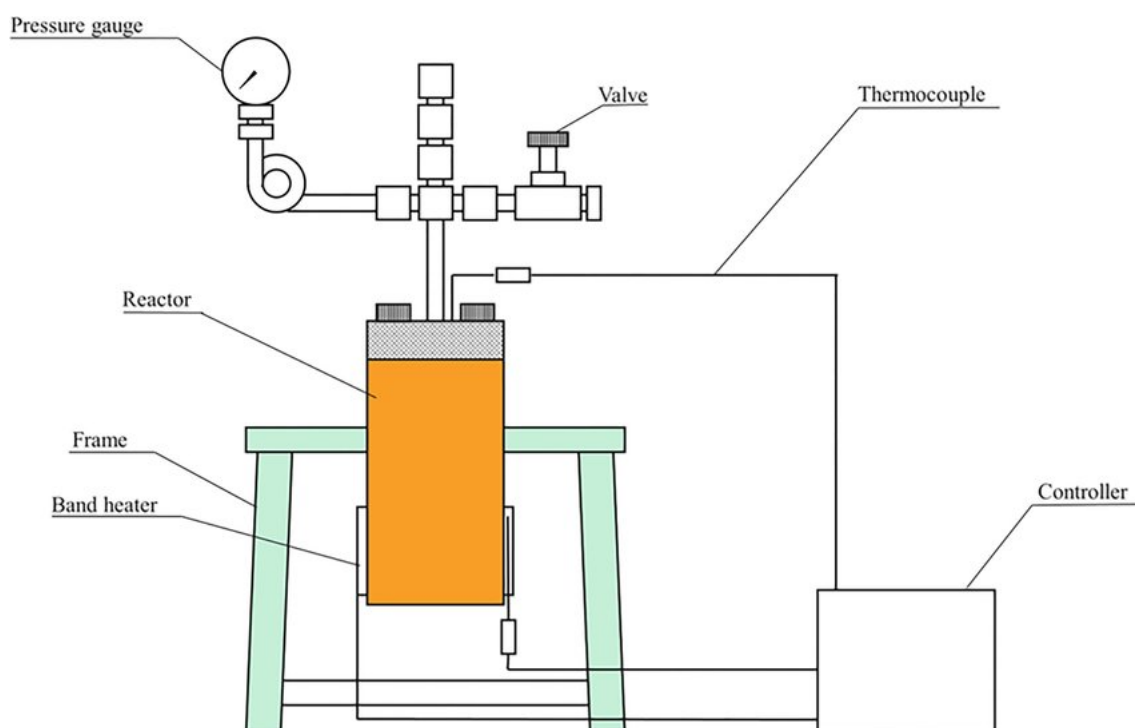


Figure 6: Carbonisation Chamber

0.4.5 Demineralisation

The tire industry relies on a diverse range of compositions to produce highly durable and reliable products. The process of manufacturing tires involves *vulcanization*, wherein untreated soft rubber is heated with sulfur and initiators to create cross-links between polymer chains, forming a robust three-dimensional chemical network. These additives are essential for achieving specific performance characteristics in tires.

The resulting *char* from waste tire rubber pyrolysis exhibits a high carbon content (>80 wt%), with sulfur content reduced to less than half of its initial amount (<3 wt%), primarily functioning as a cross-linking agent between elastomer chains. In post-treatment *demineralization* of tire-derived char, the use of strong acids has proven effective in removing a significant portion of inorganic minerals.[14]

This demineralization process is critical for enhancing the purity and quality of the derived char, which may find applications in various industries such as energy production or material synthesis. By selectively removing inorganic contaminants, the char's potential value as a sustainable resource is further enhanced, contributing to the circular economy objectives within the tire recycling sector.

0.4.6 Chemical activation

Activation using potassium hydroxide (KOH) is a key process to enhance the surface area and modify the chemical properties of carbon materials derived from waste tires. In KOH activation, the carbon precursor is treated with KOH and then subjected to thermal treatment. The success of this method depends mainly on two factors: the treatment temperature and the ratio of KOH to carbon (impregnation ratio).

Operating at temperatures typically between 600°C , the process occurs in the presence of the activating agent, which facilitates the development of a porous structure within the carbon matrix. This porous structure enhances the surface area and ad-

sorption capacity of the activated carbon. When mixed with waste tire material and subjected to high temperatures it leads to extensive pore development, including the creation of micropores (<2 nm) and mesopores (2-50 nm), resulting in a high surface area.

The treatment temperature plays a crucial role in determining the final properties of the activated carbon. Higher temperatures lead to increased activation and pore development, resulting in higher surface area. However, excessively high temperatures can damage the structure of the carbon. Therefore, optimizing the treatment temperature is essential to achieve the desired balance between surface area and structural integrity.

Similarly, the KOH: char ratio, which refers to the amount of KOH relative to the carbon precursor, significantly influences the activation process. The right impregnation ratio is key to maximizing surface area and pore volume while maintaining mechanical strength and stability.

By carefully controlling these activation parameters, the properties of activated carbon for specific applications such as adsorption, energy storage, and environmental remediation can be tailored.

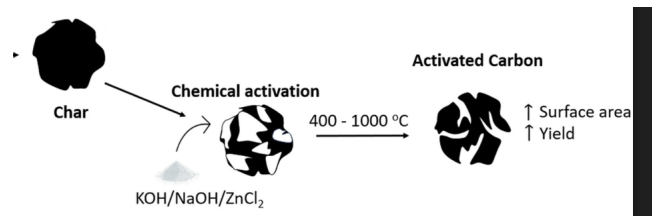


Figure 7: Chemical activation Process

0.4.7 Post-Processing

This includes the washing drying and processing the char through mills and packing of the final product

0.5 RESULTS AND DISCUSSION

0.5.1 Pyrolysis

	After pyrolysis	C%	density	Conc C	$k \cdot 10^{-4}$	Cp
		(w%)	(Kg/m ³)	(Kmol/m ³)		
Rubber Tyre	302 Kg	84.2	1100	77.425		1.9
Char	59.5 % 179 Kg	82.1	1590	108.857	556.6	2.3
Pyrolytic Oil	10 % 30.2 Kg	86.64	935	67.71	236.1	2.2
Gases	30.9 % 92.11 Kg	74.2	0.7	0.0433	131.3	6

Figure 8: Property table before and after Pyrolysis

Mass Balance

Input: 302 Kg

Output :

char = 179Kg

liq = 30.2Kg

gases = 92.11Kg

We assume :

- There is no loss.
- Pyrolysis chamber is ideal thus complete rubber is burnt

Energy Balance

Input

$$T = 25^{\circ}\text{C}$$

$$Q = (302 * 1.9 * (273 + 25)) = 473.385 \text{ MJ}$$

Output

$$\text{char} = (179 * 2.3 * (273 + 850)) = 349.945 \text{ MJ}$$

$$\text{liq} = (30.2 * 2.2 * (273 + 850)) = 56.474 \text{ MJ}$$

$$\text{gas} = (92.11 * 6 * (273 + 850 - 25)) = 455.944 \text{ MJ}$$

After using $Q = m * Cp * (T)$

$$\text{Difference} = 388.978 \text{ MJ}$$

Therefore heat supplied by the pyrolysis Chamber

Reactor design

We applied the Coats-Redfern method to design a batch reactor for a first-order kinetic reaction.

Given Parameters:

- Volume of reactor, $V = \frac{M}{\rho} = 0.5 \text{ m}^3$
- Temperature, $T = 850^{\circ}\text{C} = 1123.15 \text{ K}$
- Reaction rate constant, $B = 20 \text{ k/sec} = 20 \times 10^3 \text{ s}^{-1}$
- Activation energy, $E_a = 65.6 \text{ kJ} = 65.6 \times 10^3 \text{ J}$
- Pre-exponential factor, $A = 5.1 \text{ min}^{-1}$

Calculation of Reaction Rate Constant, k : The reaction rate constant k is calculated using the Arrhenius equation:

$$k = Ae^{-\frac{E_a}{RT}}$$

Substituting the values:

$$k = 5.1 \times e^{-\frac{65.6 \times 10^3 \text{ J}}{8.314 \text{ J/mol/K} \times 1123.15 \text{ K}}}$$

$$k \approx 4.53 \times 10^{-3} \text{ min}^{-1}$$

Determination of Conversion, X : Using the Coats-Redfern method, the equation for X is:

$$\ln(1 - X) = \frac{A}{B} \frac{(1 - 2RT)}{E_a} RT^2 e^{-\frac{E_a}{RT}}$$

Substituting the values and solving for X :

$$X \approx 0.837$$

Batch Reactor Design Equation: The batch reactor design equation relates conversion X to time t :

$$\frac{dX}{dt} = \frac{-r_a V}{N_{a0}}$$

where $r_a = kC_a$ and $C_a = C_{a0}(1 - X)$.

Integrating with respect to time:

$$\ln(1 - X) = kt$$

Substituting X and k values:

$$t \approx 400 \text{ min}$$

Therefore, the required time t for achieving the specified conversion X in the batch reactor is approximately 400 minutes.

0.5.2 Carbonisation

Mass Balance

Assumptions: **Assumptions:**

Ideal behavior

Constant composition

Negligible pressure changes

Constant specific heat capacities

Input:

Mass of feed 179 kg

Output:

Biochar 163.3 kg

Gases 15.7 kg

Loss Calculation:

Assumed loss	9%
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Desired conversion efficiency (X_a) 0.98

Assumption:

- Steady-state conditions
- Ideal behavior
- No heat losses
- Constant composition
- Constant reaction rates
- Negligible pressure changes
- Constant specific heat capacities

Input : 179 Kg

Output :

Biochar = 163.3 Kg

Gases = 15.7 Kg

We assume that there is 9% loss

$$X_a = 0.98$$

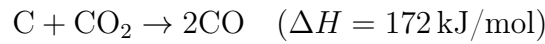
Energy Balance

We conducted an energy balance analysis based on the Boudouard reaction involving the gases released during the activation of pyrolyzed char to produce CO₂-activated char.

Given Parameters:

- Mass of gases released = 15.5 kg

Boudouard Reaction: The Boudouard reaction is given by:



Number of Moles of CO Produced: The number of moles of CO produced from the gases released is calculated as:

$$\text{Moles of CO} = \frac{15.5 \times 1000 \text{ g}}{28 \text{ g/mol}} = 553.5 \text{ mol}$$

Energy Balance Calculation: The energy change (ΔH) for the Boudouard reaction is endothermic and can be calculated based on the moles of CO produced:

$$Q(\text{endothermic reaction}) = \frac{\text{Moles of CO}}{2} \times \Delta H = \frac{553.5}{2} \times 172 \text{ kJ/mol}$$

$$Q(\text{endothermic reaction}) = 23803 \text{ kJ}$$

Therefore, the energy balance for the Boudouard reaction, considering the gases released during the activation process, results in an endothermic heat requirement of approximately 23803 kJ.

Reactor design

We designed a batch reactor for the carbonization process with first-order kinetics.

Given Parameters:

- Volume of reactor, $V = 0.5 \text{ m}^3$

- Desired conversion, $X_a = 0.98$
- Reaction rate constant, $k = 7.58 \times 10^{-3} \text{ min}^{-1}$

Batch Reactor Design Equation: The batch reactor design equation for a first-order reaction is given by:

$$\frac{dX}{dt} = \frac{-r_a V}{N_{a0}}$$

where $r_a = kC_a$ and $C_a = C_{a0}(1 - X)$.

Integration of the Design Equation: Substituting $r_a = kC_a$ and $C_a = C_{a0}(1 - X)$ into the reactor design equation and integrating with respect to time t :

$$-\ln(1 - X_a) = kt$$

Calculation of Time for Desired Conversion: To find the required time t to achieve the desired conversion $X_a = 0.98$, substitute $X_a = 0.98$ and $k = 7.58 \times 10^{-3} \text{ s}^{-1}$ into the integrated equation:

$$-\ln(1 - 0.98) = (7.58 \times 10^{-3} \text{ min}^{-1}) \times t$$

Solving for t :

$$t = \frac{\ln(0.98)}{7.58 \times 10^{-3} \text{ min}^{-1}}$$

$$t \approx 123.2 \text{ min}$$

Therefore, the required time t for achieving a conversion $X_a = 0.98$ in the batch reactor under the given conditions of first-order kinetics and fixed volume is approximately 123.2 minutes.

0.5.3 Demineralization

Demineralization of char is performed after pyrolysis using hydrochloric acid.

Parameters:

- Amount of char after pyrolysis = 163.5 kg

Calculation of Acid Requirement: To demineralize the char, hydrochloric acid is used. The amount of acid needed is calculated based on the mass of char as well as the concentration of the acid:

Sample	Acid/char ratio (mL/g)	Demineralisation time (h)	Acid concentration (M)
C5	5	6	3

Figure 9: Data about demineralisation[6]

$$\text{Amount of acid needed} = 163.5 \text{ kg} \times 5 \text{ L/kg} = 817.5 \text{ L}$$

Therefore, approximately 817.5 liters of hydrochloric acid is required for the demineralization process.

We have included screenshots of relevant research papers detailing the demineralization process using hydrochloric acid for the treatment of char. After this process about 66% of Sulphur is removed.[6]

0.5.4 KOH needed for chemical activation

Parameters:

- Amount of char to be treated = 155.3 kg

Activating Agent Used: The activating agent used for the treatment is potassium hydroxide (85% pure, Carl Roth).

Calculation of KOH Requirement: The amount of KOH required for treating the char is calculated based on the mass of char:

Sample	Activation conditions		Y ^b (wt.%)
	T (°C)	W ^a (g KOH/g TPC)	
CK.700.2	700	2	81

Figure 10: Data about chemical activation taken from research paper[15]

$$\text{Amount of KOH required} = 155.3 \text{ kg} \times 2 = 310.6 \text{ kg}$$

Therefore, approximately 310.6 kilograms of potassium hydroxide (KOH) is needed for the treatment of 155.3 kilograms of char.

0.6 CONCLUSION

Tire waste poses a major environmental problem in India. Traditional disposal methods such as landfilling and incineration create new problems and highlight the need for urgent solutions. This report explores various recycling methods for waste tires, each with their advantages. Production of activated carbon from waste rubber tires via pyrolysis holds promise against the dual challenges of waste management and scarce resources. Waste tires can be transformed into valuable products that provide many economic benefits through appropriate methods such as pre-treatment, pyrolysis and activation processes. India can contribute to the future by transforming waste tires into valuable resources by completing this process and supporting research and development.

0.7 FUTURE SCOPE

Despite significant progress in the production of carbon monoxide from waste tires, many avenues remain to be explored for future research and development. It is important to create a good market for rubber products. By recycling rubber into the manufacturing process, India can reduce its reliance on virgin materials and create a closed loop. Promoting research and development, establishing a collection and processing system, and establishing business support for recycled rubber products are important steps.

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