Chemical Science International Journal

Volume 33, Issue 6, Page 26-31, 2024; Article no.CSIJ.124803
ISSN: 2456-706X
(Past name: American Chemical Science Journal, Past ISSN: 2249-0205)

The Environmental and Economic Impacts of Tire Recycling Technologies

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

Article Information

DOI: https://doi.org/10.9734/CSJI/2024/v33i6921

Open Peer Review History:
This journal follows the Advanced Open Peer Review policy. Identity of the Reviewers, Editor(s) and additional Reviewers, peer review comments, different versions of the manuscript, comments of the editors, etc are available here: https://www.sdiarticle5.com/review-history/124803

Original Research Article

Received: 13/08/2024
Accepted: 15/10/2024
Published: 19/10/2024

ABSTRACT

Aims: Study of physical and chemical characteristics of technical carbon obtained by pyrolysis of worn automobile tires. Development of carbon-containing filler of composite elastomer materials for obtaining products based on them with a given structure, physical, mechanical and dynamic properties.

Study Design: The physicochemical characteristics of carbon black obtained by pyrolysis of worn-out automobile tires were studied, and its composition was determined using modern physicochemical methods.

Place and Duration of Study: Sample: Navoi State Mining and Technological University, Faculty of Chemical Technology Navai in the period from June 2023 to July 2024.

Methodology: The density, ash content, pH and granulometric composition of the obtained technical carbon were studied using standardized methods and its qualitative and quantitative composition was determined using X-ray phase and IR spectroscopic methods.

Results: The physicochemical characteristics of carbon black obtained by pyrolysis of worn-out automobile tires were studied. The bulk density, ash content, pH, mass fraction of moisture and

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Cite as: *Shokhrukh, Juraev, Sodiqov Bobir, Tilloyeva Nilufar, and Temirov Uktam. 2024. "The Environmental and Economic Impacts of Tire Recycling Technologies". Chemical Science International Journal 33 (6):26-31. https://doi.org/10.9734/CSJI/2024/v33i6921.*

granulometric composition of crushed carbon black were determined. It was found that a decrease in the particle size of carbon black leads to an increase in bulk density, acidity, humidity and has virtually no effect on ash content. X-ray phase analysis showed that carbon black mainly consists of amorphous carbon (88.4%), calcite (7.59%), ankerite (1.21%), zinc oxide (1.14%) and other components. Based on the results of thermal analysis, the temperature range of decomposition of carbon black residues was determined to be in the range of 150-900^{0}C.

Conclusion: The physicochemical characteristics of technical carbon obtained by pyrolysis of worn-out automobile tires were studied. The bulk density, ash content, pH, mass fraction of moisture and granulometric composition of crushed technical carbon were determined. It was established that a decrease in the particle size of technical carbon leads to an increase in bulk density, acidity, humidity and has virtually no effect on ash content.

Keywords: Pyrolysis; carbon black; rubber; bulk density; ash content; moisture; X-ray phase analysis; derivatography; IR spectroscopy; microscopy.

1. INTRODUCTION

Tires are a powerful source of environmental pollution. At the same time, worn-out tires are a valuable source of secondary raw materials: rubber, carbon black, metal cord, etc. Recycling worn-out tires will significantly reduce the consumption of some scarce natural resources. There are three conventional categories of commercial recycling of tires: crushing, pyrolysis (high- and low-temperature), decomposition using chemical solvents [1]. One of the areas of recycling worn-out tires is regeneration, aimed at producing a substitute for part of the new rubber used in the production of rubber products. However, the amount of worn-out tires used to produce regenerate does not exceed 20% of their total amount [2]. The use of used tires that have fallen into disuse as a raw material is relevant from an economic and environmental point of view. Automobile tire is a valuable secondary raw material containing rubber: about 65-70%, carbon black-15-25%, wire rope-10-15%. To date, only one pyrolysis distillate is obtained in Uzbekistan based on NSMC, but the pyrolysis residues are not treated. Rubber crumb can be obtained from worn-out tires, which can be used as a component of polymer mixtures, in rubber asphalt mixtures for road construction, for partial replacement of bitumen, for the production of construction and technical materials and products. In many countries, burning tires to generate energy and heat, as well as fuel in the cement industry, is considered a promising solution to the problem. This method can significantly reduce the volume of used tires [3]. However, burning is not profitable from either an economic or environmental point of view, mainly due to the high content of total sulfur. One of the most environmentally friendly methods of recycling used tires is pyrolysis (thermal decomposition). The advantage of pyrolysis is its economic efficiency and environmental safety. However, in addition to useful products, pyrolysis produces a solid residue - a low-quality carbon-containing substance that makes up 85% of the original mass of tires and has practically no direct application [3-6].

2. METHODOLOGY

Carbon black obtained by pyrolysis of worn-out car tires was selected as the objects of research. Some physico-chemical characteristics were determined, such as bulk density (Ph)-GOST 16190-70; pH was determined by the method, ash content (Ad)-GOST 1022-95; mass fraction of moisture (Wa)-GOST 52917-2008; Granulometric composition-GOST 2093-82. Diffractograms were obtained on a powder X-ray diffractometer of the brand "ShimadzuXRD-6100", equipped with a copper (Cu) tube (K ∞1=1.5406, K ∞2=1.5443, K ∞2/K ∞1=0.5. The detector is a scintillation detector. Microscopic analysis was performed on a Diotox1500 device [7].

3. RESULTS AND DISCUSSION

The solid residue most often has an ash content unacceptable for direct use (Vdaf = 6-8 wt.%) due to additives in rubber, a high sulfur content, and can be very toxic due to violations of the technological regime. The problem of recycling the solid residue of tire pyrolysis is relevant. Table 1 presents data from laboratory studies of solid residue from tire pyrolysis. The goal research is development technologies receipt commodity products from solid carbon-containing remainder pyrolysis car tires [8].

IN under development technologies original stage processing solid carbon remainder pyrolysis car tires is process enrichment by the oil agglomeration method, as other enrichment methods not acceptable in view of their low selectivity at enrichment finely dispersed particles. Liquid fuel is used as a reagent fraction pyrolysis car tires at enrichment solid carbon remainder [9].

From low quality carbon-containing remainder was received low ash concentrate. Concentrate has next characteristics (Table 2).

After enrichment received concentrate is subject to granulation and application on surface granules waterproof, absorbing smell coatings from oil products (For example, paraffin) [10].

Analogue composite fuel on basis solid carbon-containing remainder pyrolysis car tires is pressed coal small change (Table 3).

As for the collection of tires and their delivery: if abroad when selling new tires are subject to recycling fees, but this doesn't work for us yet. In developed countries, the recycling fee goes to the state treasury, then is distributed V view translations those, Who is engaged collection tires And their processing. The advantage of pyrolysis is its cost- effectiveness and ecological safety.

However besides useful products at Pyrolysis produces a solid residue - low-quality carbon-containing a substance that makes up 85% of the original weight of tires and is virtually non-existent Maybe find your own applications directly. The environmental impact of tire recycling. Recycling of car tires, including pyrolysis and incineration methods, has a significant impact on the environment. The main components of rubber, such as styrene butadiene rubber (SBR), carbon black, and acetone extract, affect the type and amount of emissions generated during the recycling process. Unlike PAHs, the concentration of PCDD/F in the solid phase reached a maximum during the shutdown phase, which is mainly related to temperature. The results of the study provide recommendations for reducing pollutant emissions and recycling pyrolysis products.

Table 1. Laboratory studies of solid carbonaceous residue

Test object	Defined component	Component content
Low quality th technical carbon	Content moisture	2.17%
	Ash content: A^d	11.7%
	Volatile release substances: V^{daf}	8.6%

Table 2. Characteristics concentrate

A^d, % (ash content)	W^a, % (humidity)	V daf , % (exit volatile substances)	Q^r, kcal/kg S (heat combustion)	$S^d{}_t$, wt . % (sulfurous there is)
4.0-5.5	8.5-10.5	6.0-8.0	7500-8800	0.2

Table 3. Comparison molded fuel with analogue

Technical and economic indicators (name and units measurements)	Names analogues innovative products	Name innovative products
	Coal small change	Composite fuel
Strength on abrasion, % content of pieces size >25 mm	22-48	80-99
Strength on drop, % content of pieces size >25 mm	42-74	85-99
A, % mass. (ash content)	10.0-12.0	5.4-10.0
Q, kcal/kg (heat combustion)	6200-8250	7500-8800
S, % mass. (sulfur content)	0.4-0.5	0.025-0.4
Price products	33 -35 dollars. for 1t	22 dollars . for 1t

Table 4. Distribution of pyrolysis waste from 10 kg of tires by weight

Air pollutant	Percentage of total mass (%)	Approximate weight of 10 kg tires (kg)
Pyrolysis gas	10-15	1.0 - 1.5
Pyrolysis oil	40-50	4.0 - 5.0
Pyrolysis carbon	35-45	3.5 - 4.5
Metals and ash	5-10	0.5 - 1.0
Polycyclic aromatic hydrocarbons (PAHs)	1-5	0.1 - 0.5
Polychlorinated dibenzodioxins and dibenzofurans (PCDD/F)	0.1-1	0.01 - 0.1
Volatile organic compounds (VOCs)	5-10	0.5 - 1.0
Soot	1-5	0.1 - 0.5
Sulfur compounds	0.5-2	0.05 - 0.2
Nitrogen oxides (NOx)	0.5-2	0.05 - 0.2
monoxide (CO)	0.5-3	0.05 - 0.3

Table 5. Distribution of pyrolysis waste 1,000,000 kg of car tires per year

Component	Percentage of total mass (%)	Approximate weight (kg)
Pyrolysis gas	10-15	100,000 - 150,000
Pyrolysis oil	40-50	400,000 - 500,000
Pyrolysis carbon	35-45	350,000 - 450,000
Metals and ash	5-10	50,000 - 100,000
Air pollutants:		
Polycyclic aromatic hydrocarbons (PAHs)	1-5	10,000 - 50,000
Polychlorinated dibenzodioxins and dibenzofurans (PCDD/F)	0.1-1	1,000 - 10,000
Volatile organic compounds (VOCs)	5-10	50,000 - 100,000
Soot	1-5	10,000 - 50,000
Sulfur compounds	0.5-2	5,000 - 20,000
Nitrogen oxides (NOx)	0.5-2	5,000 - 20,000
monoxide (CO)	0.5-3	5,000 - 30,000

Table 6. The amount of emissions released during the pyrolysis of a 3825 tyre 250 °C temperature

No.	Measured temperature, °C	Name of pollutants	MPC m.r. mg/ m^3	Result mg/ m^3	Condition above normal
1	250	(SO_2) sulfur oxide	0.5	26,448	52 , 9
		ardor	0.5	0, 0 30	0.06
		(CO) carbon monoxide	5.0	78,380	15.7
		(CH_2O) formaldehyde	0.035	0.6280	17.94
		(NO_2) nitric oxide	0.085	0 , 0000	-
		(NH_3) ammonia	0.2	5,5497	27.7
		(CO_2) carbon 4 oxide	250	0.0 000	-
		(H_2S) hydrogen sulfide	0.008	17,700	2212.5
		CH_4 methane	60	17,35	0.29

During pyrolysis of car tires, various air pollutants are formed (Table 4).

This table provides approximate data on the distribution of air pollutants from the pyrolysis of 10 kg of car tires. To calculate the actual masses of pollutants on a larger scale, it is necessary to multiply the approximate values by an appropriate coefficient reflecting the total volume of tire recycling.

Here is a table that shows the waste distribution of pyrolysis of 1,000,000 kg of car tires per year, including both the main components (pyrolysis gas, oil, carbon, metals and ash) and air pollutants.

This table helps to estimate the distribution of waste and air pollutants when scaling up the tire pyrolysis process to large volumes.

This analysis shows how the scaling effect on the mass of pollutants and other products in tire pyrolysis increases the absolute amount of waste and pollutants proportional to the input quantity of tires.

Significant excesses of maximum permissible concentrations for sulfur oxide, carbon oxides and hydrogen sulfide are recorded in the atmospheric air. This may pose a danger to public health and requires urgent measures to reduce emissions of these substances into the environment.

4. CONCLUSION

The physicochemical characteristics of carbon black obtained from the pyrolysis of worn-out car tires have been studied. The bulk density, ash content, pH, mass fraction of moisture and granulometric composition of crushed carbon black were determined. It has been found that a decrease in the size of carbon black particles leads to an increase in bulk density, acidity, humidity and practically has no effect on ash content. The study of the physico-chemical properties of products obtained from recycled car tires highlights the complexity and relevance of the problem of tire waste disposal. Despite the fact that tires contain valuable components such as rubber, soot and metal cord, recycling involves a number of challenges, including high ash content (11.7%) and volatile substances (8.6%). It is important to note the significant environmental risks associated with the release of harmful substances into the atmosphere with imperfect processing technologies. The presence of SO_2, CO, NO_2 and NH_3 in significant concentrations poses a serious threat to human health and ecosystems. Therefore, it is necessary to continue research and development in the field of pyrolysis and other tire recycling methods in order to create more efficient and environmentally friendly technologies. The goal is to turn tire waste into a valuable resource and reduce the environmental burden of its disposal.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that generative AI technologies such as Large Language Models, etc have been used during writing or editing of this manuscript. This explanation will include the name, version, model, and source of the generative AI technology and as well as all input prompts provided to the generative AI technology.

Details of the AI usage are given below:

1. We did not use artificial intelligence technologies.
2. We tracked the relevance of news only with the help of artificial intelligence technologies.
3. AI gas formulas verified to be accurate.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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Peer-review history:
The peer review history for this paper can be accessed here:
https://www.sdiarticle5.com/review-history/124803