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Possible Progressive Ways of Recycling Car Tires

The increase in the number of manufactured products causes an increase in production waste. The problem of excess production waste in Ukraine is acute. One of the most environmentally harmful entities that pollute the environment is rubber products. The list of products made from rubber is large: insulation for wires, gloves, household items, shoes and, of course, tires. The purpose of the article is to research of the possible methods of recycling automobile tires and establish the most rational method from the point of view of modern innovative methods of tire recycling.

One of the most common rubber products is tires. The composition of modern tires is a mixture of various components: additives, fillers, plasticizers and other special additives. The constant increase in waste tires is a problem worldwide. Since rubber is highly resistant to environmental factors, the accumulation of large volumes of used tires creates a serious environmental problem. Modern and innovative technologies for recycling used tires will help solve it. There are a number of different methods for recycling car tires. Therefore, the research presents various methods of recycling automobile tires. Particular attention was paid to modern methods. There are a number of different methods for recycling car tires. One of the common methods of recycling tires is energy recovery. Statistical data show that shredding used tires is also one of the modern methods of recycling them.

Studies using an analytical method of collecting information have established the harmful effects of landfills of used automobile tires. In this regard, the issue of tire recycling in the world is becoming extremely acute. The same situation is observed in Ukraine. The article draws conclusions about the most common methods of recycling car tires. The main methods of recycling car tires are based on the recovery of the energy that was spent on their production.

worn car tires, methods of recycling rubber crumb, pyrolysis, microbiological processes of tire recycling, energy recovery, environmental pollution, rubber products

Problem statement. The increase in the number of manufactured products causes an increase in production waste. The problem of excess production waste in Ukraine is acute. One of the most environmentally harmful entities that pollute the environment is rubber products. The list of products made from rubber is large: insulation for wires, gloves, household items, shoes and, of course, tires. With the growth of the automotive industry, the need for consumption of automobile tires is increasing.

Rubber products include a large number of items that can be used in various areas of human activity: insulation for wires, rubber gloves, hoses, tires and much more. Rubber products differ in their manufacturing methods and application. However, all such products have one common property - they contain a hydrophobic and elastic elastomer - rubber, which is vulcanized to obtain rubber. The basis of rubber production is the process of vulcanization. This is a technological process in which plastic or "raw" rubber is converted into rubber. The essence of vulcanization is the combination of linear macromolecules of rubber into a single system - a vulcanized network, using sulfur compounds [1].

One of the most common rubber products is tires. The composition of modern tires is a mixture of various components: additives, fillers, plasticizers and other special additives. The exact quantitative and qualitative composition of rubber for a particular brand of tire is a trade secret, but it is possible to determine the main set of components.

The constant increase in waste tires is a problem worldwide. Their uncontrolled burning leads to atmospheric pollution with soot, carbon monoxide, cyanide compounds, and dioxides. Since r ubber is highly resistant to environmental factors, the accumulation of large

volumes of used tires creates a serious environmental problem. Modern and innovative technologies for recycling used tires will help solve it. There are a number of different methods for recycling car tires.

Analysis of recent research and publications. The author of the article [2] notes that countries such as Turkey, Great Britain, Japan, the USA, Switzerland and many others reuse 95% of tires. The areas of utilization are different. For example, worn tires are used in civil construction, in energy recovery, etc. In addition, the author of the article notes that only 10 to 20% of waste tires are properly stored or reused. The rest remains exposed to the environment. As a result, the environment has suffered serious damage, causing health problems. The author of the work poses a real, alarming problem for humanity, which urgently needs to be solved by applying the latest methods of recycling automobile tires. This is a well-known problem related to the constant growth of the automotive industry, polluting the environment with unused tires. The author cites alarming statistics, namely: 1.4 billion tires are thrown into the environment every year. Despite the fact that the number of used tires increases annually by 13% from 300 million in 2016 to more than 1,300 million in 2020.

The author [2] describes different types of routes and types of vehicles whose tires had corresponding wear during operation. For the selection of the routes, priority was given to minimizing travel distances and collection time, and reducing the costs related to tire transportation, for which it was proposed to use three collection routes: a heavy transport vehicle with a capacity of 1.5 Ton to collect 210 tires per trip, and a total of 2 trips per route/week would collect 5040 tires per month. The details and characteristics of each route are shown in Figure 1.

Route	Distance Traveled (km) per Month	Number of Tours per Month	Number of Tires Collected	Approximate Weight (kg)
1	128	8	1320	10,560
2	168	8	1750	14,000
3	120	8	1970	15,760
Total	416	24	5040	40,320

Figure 1 – Comparison of the number of tires used on different routes

Source: developed by the authors [2]

Government and private representatives are interested in exploring new markets for recycled tire rubber. Rubber products are widely used as raw materials for processing into finished parts or semi-finished products with wide industrial applications. The author notes that such rubber is used in agricultural, recreational and sporting goods. In particular, the article notes that tire rubber can be used as boat protection, conveyor belts, vibration reduction on railway tracks, footwear industry, lawns and playground flooring [2].

The author [3] of the scientific research notes that rubbers that are not biodegradable can be used in rubber and technical products. Accordingly, tires made from such rubber cannot be easily recycled. Therefore, all this leads to certain difficulties with the disposal of such rubber products after their production and use.

European tire manufacturers provide approximately 65% of the total production of rubber products specifically for the automotive sector. The author notes that tires account for 3.5% of the mass of rubber and technical products for cars. All other types of rubber products account for only 1.6%. This suggests that end-of-life tires occupy a major place among rubber waste. Thus, the author emphasizes that by 2030 the number of used tires entering the environment will increase to 1,200 million tires per year [3].

The author [3] emphasizes that one of the common methods of recycling tires is energy recovery. The scientist notes that tires are used as an alternative fuel in cement kilns, paper mills or power plants. The article gives examples of European Union countries, in particular Norway, Serbia, Switzerland. It is in these countries that 91% of waste tires were properly disposed of by recycling materials (56.4%) or energy recovery (34.9%).

Statement of the task. The purpose of the article is to reserch of the possible methods of recycling automobile tires and establish the most rational method from the point of view of modern innovative methods of tire recycling.

Presentation of the main material. Today, in the leading countries of the world, no more than 20% of used cars are recycled from raw materials each year, but the growth of the car fleet is 3-7% per year. As you know, used tires can be buried or recycled. Therefore, a number of problems arise with the accumulation of waste tires. It is necessary to note that tire landfills are impractical and should be completely eliminated in the future. Therefore, the analysis of modern methods of recycling automobile tires is an urgent task of our time.

ETRMA statistics show that the processing of rubber and technical materials is mostly the shredding of waste tires. For example, in 2018 this method of tire recycling was the most popular method among various methods. This method is based on the production of chips, which are used as an alternative fuel. This approach allows you to recover the energy consumed [3].

The car shows data (Figure 2), which were collected from various studies. Over the past decades, research on tire recycling methods has been relevant and constantly developing. That is, the number of positions is distributed as follows: rubber recycling - 15779, ground tire rubber - 4986, devulcanization - 1001.

Known methods of recycling and using waste tires can be divided into 5 groups according to the nature of the waste [4]:

- types of use of unused tires without changing their size and shape;
- a way to complete the destruction of the primary treatment system;
- methods that damage deep waste;
- methods that lead to significant changes in the nature of drugs, due to the transfer of elastic wood to products with plastic properties (production regeneration);
- methods that do not significantly change the melting of the drug (production of rubber crumb).

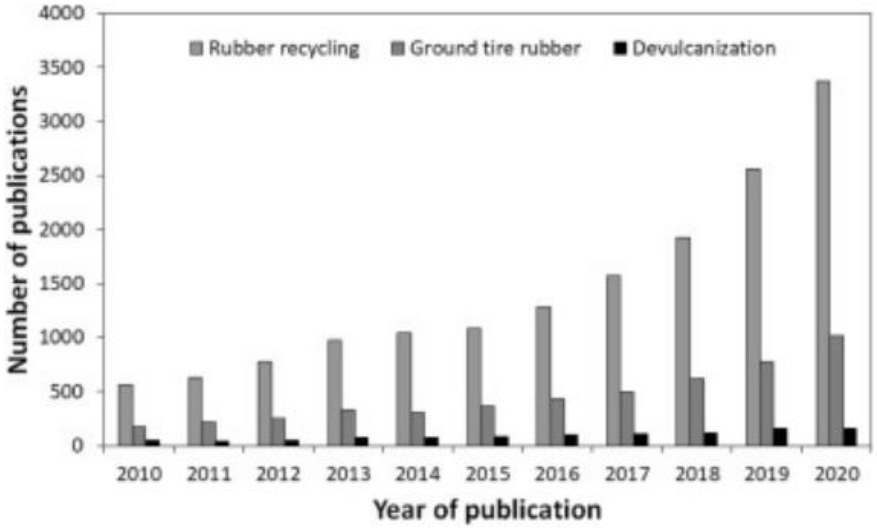

Figure 2 – Development of scientific research on tire recycling methods

Source: developed by the authors [3]

Whole tires can be used in hydraulic engineering, as reefs (spreading platforms), to protect slopes from erosion, as sound barriers, floating water and cracks. The Georgia Institute of Hydraulics and Reclamation has developed various projects for edge protection and hydraulic structures using used tires. This is a tool for protecting slopes from erosion [5], things are done with half-wheels.

In the USA, Australia, Japan, New Zealand and some other countries, hundreds of artificial spawning grounds have been created from canals used to increase marine bioproductivity [6]. The main advantages of such spawning grounds are that the seawater is unpolluted and very stable. According to some reports, the longevity of tires in the sea is 150-200 years. Therefore, breakwaters are made from tires. However, they have serious drawbacks: they do not work in strong waves and are difficult to maintain. To protect the slope from erosion, it is covered with tires, covered with soil and planted with grass [6].

To illustrate the reuse of rubber, the author successfully compares the crumb rubber market. Figure 3 shows that rubber crumb is quite widely used in various areas of human life.

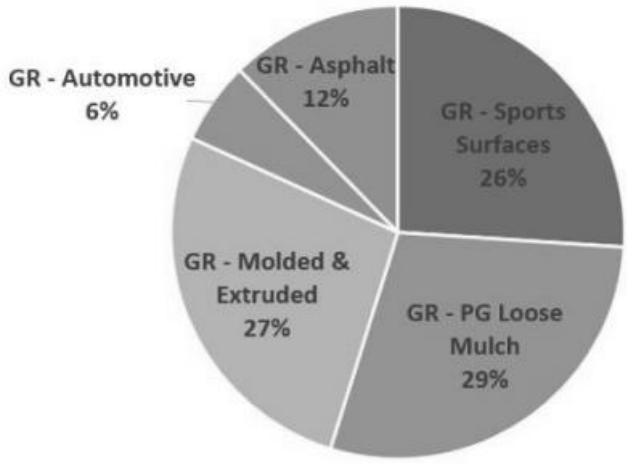

Figure 3 – Development of scientific research on tire recycling methods

Source: developed by the authors [6]

The design of noise barriers was developed by the company "Organicon" (Germany) on highways. One side is opened by the side of the tire, which is then compacted and filled with soil. The result is a slope from this structure that does not subside. In this case, the consumption of tires is 5000 per 100 m of wall length. Concrete blocks are used for the construction of roads with soft peat soils [4].

Worn tires can be used to build bridges over small rivers using concrete, streams, canals, lay pipelines under roads and railways, and build fences. These buildings are durable and the cost of construction is much lower than similar concrete buildings. The demand for tires used in engineering works ranges from a few thousand to tens of thousands of tons per year, depending on the size of the country and the scale of its business [5].

Destruction of tires by high temperatures is one of the common methods of tire disposal. Production of thermal destruction of tires containing valuable mineral oil is also quite widespread. This releases dissolved rubber, hydrocarbon condensate, gases and metals. Depending on the production conditions, such emissions can be used as raw materials for waterproofing materials, production of mastics, petrochemicals, boiler and furnace fuel, bitumen [7].

The author of article [8] presents various methods of recycling automobile tires. Figure 4 shows the mentioned tire recycling methods. The author presents a very detailed comparison of the main tire recycling methods.

Criteria	Recycling method					
	Tire recycling into reclaim	Tire recycling into crumb	Microwave pyrolysis	Classic pyrolysis	Gasification	Incineration
Further processing of processed products for sale	Necessary	Necessary	Not necessary	Not necessary	Necessary	No
Recycling of processed products after the end of their service life	Necessary	Necessary	No	No	No	No
Industrial experience	Yes	Yes	Yes	Yes	Yes	Yes
Processing speed	Low	Low	High	Medium	High	-
Environmental factors	Rubber crumb dust, organic oil, inorganic salt	Rubber crumb dust	Carbon dioxide	Carbon dioxide	Carbon dioxide, carbon monoxide	Sulfur oxide, aromatic hydrocarbon, condensed aromatic hydrocarbon, chlorine derivatives, etc.

Figure 4 – Development of scientific research on tire recycling methods

Source: developed by the authors [8]

The author of the article effectively shows various methods of recycling car tires. Table 1 shows various methods of recycling car tires, clearly showing the advantages and disadvantages of each recycling method.

Much attention in the issue of tire recycling is attracted by the use of such tires in polymer practice and composite materials. This method of tire recycling allows for the sustainable development of industrial technologies for recycling waste tires. Therefore, the use of tires as a filler for polymer composites is quite successful in reducing material costs [9].

The production of liquid and gaseous hydrocarbons, as well as carbon-rich solid materials, is achieved by the pyrolysis of rubber products. Pyrolysis is considered a progressive modern method of recycling used tires. It is a method that allows the deconstruction of polymers [9].

The explosion-circulation method of tire recycling, in comparison with others, is based on a fundamental replacement of the destruction method from the traditional mechanical to explosive with circulation of the explosion product. And the explosion, as is known, is the strongest and cheapest destroyer in nature. Without a doubt, this technology has made it possible to make a breakthrough in the field of tire recycling [10-11].

The cryogenic method is created by first freezing the tires and then destroying them. Due to freezing, the process of destruction and separation of the metal cord is simplified. This technology is widespread in the USA, and the rubber powder obtained in this way is called cryorubber [10].

Physico-chemical methods of tire recycling. Dissolution in an organic solvent is a process of thermal liquefaction of waste when starting in an organic solvent at a temperature of 280-435 oC and a pressure of at least 6.1 MPa, separation of the weak fraction into a fraction with a boiling point above 220 oC. With this liquid fraction with a boiling point up to 220 oC, catalytic reforming is provided, and part of the weak fraction is then used as the target product, and part is selected as a solvent with a new portion of waste [10].

Another method of recycling car tires is the so-called "ozone knife". Destruction of tires with ozone (the “ozone knife” technology) is based on the destruction of rubber by background ozone, which is contained in the atmosphere [10].

In addition, the method of tire recycling, which is based on microbiological processes, is of particular interest. Microbiological methods of tire disposal. One of the methods of tire disposal is microbiological, namely the destruction of solid tires by microscopic fungi [10-11].

Table 1 - Methods of recycling car tires

Recycling method	Process description	Environmental impact	Advantages
Mechanical recycling	Shredding, grinding, and separating rubber, steel, and fibers to produce crumb rubber	Low emissions; minor dust generation and waste fiber.	Simple, cost-effective, scalable
Ambient grinding	Grinding at or above room temperature	Low emissions; some heat generation.	Does not require cryogenic facilities.
Cryogenic grinding	Rubber is embrittled using liquid nitrogen before grinding	Safe, clean; energy-intensive due to cryogen.	Produces fine, clean rubber particles.
Pyrolysis	Thermal decomposition in absence of oxygen yielding oil, gas, and char.	VOCs, CO2, potential toxicants unless cleaned.	Recovers energy and oil; scalable
Gasification	Partial oxidation to convert tires into syngas.	Can be clean if controlled; ash disposal needed.	High-value syngas for energy or synthesis
Chemical devulcanization	Breaks sulfur cross-links using chemical agents.	Reagents may be hazardous; controllable if optimized.	Enables reuse of rubber compounds
Microwave devulcanization	Uses microwave radiation to selectively heat and devulcanize rubber.	Lower emissions; no chemicals; shielding required.	Energy efficient and selective.
Ultrasound devulcanization	Applies high-frequency sound waves to induce devulcanization.	Clean method; less mature commercially	Improved control; minimal chemical use.
Solvolysis	Uses solvents to depolymerize rubber into monomers or oils.	Solvent disposal/reuse challenges; less CO2 emission	Potential for selective recovery.
Hydrothermal liquefaction	Converts tires into oil using water under supercritical/subcritical conditions.	Clean if properly managed; by-product water/chemicals.	Good oil yield; minimal external solvent.
Microwave pyrolysis	Selective rubber heating via microwaves in inert atmosphere.	Lower emissions than traditional pyrolysis; faster heating	High oil yield; cleaner process.
Bio-recycling (emerging)	Utilizes microbes or enzymes to degrade rubber compounds.	Eco-friendly, but very slow and under development.	Green solution for long-term future.

Source: developed by the authors [8]

Together with Odessa companies, scientists created a steam-thermal reactor, which changes the structure of rubber in the reverse process, i.e., synthetic oil, gas, and metal cord

appear. In addition, excess heat from the thermal reaction can be used to heat hospitals, kindergartens, and schools in winter [10-11].

Conclusions. Considering all of the above, the following main conclusions should be drawn. One of the most environmentally harmful entities that pollute the environment is rubber products. One of the most common rubber products is tires. The constant increase in waste tires is a problem worldwide. Their uncontrolled burning leads to atmospheric pollution with soot, carbon monoxide, cyanide compounds, and dioxides. Modern and innovative technologies for recycling used tires will help solve it. There are a number of different methods for recycling car tires. One of the common methods of recycling tires is energy recovery. Statistical data show that shredding used tires is also one of the modern methods of recycling them. Used tires can be successfully used in various sectors of the national economy.

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Можливі прогресивні методи переробки автомобільних шин

Збільшення кількості виробленої продукції спричиняє збільшення виробничих відходів. Проблема надмірних виробничих відходів в Україні стоїть гостро. Одним з найбільш екологічно шкідливих утворень, що забруднюють навколишнє середовище, є гумотехнічні вироби. Перелік виробів з гуми великий: ізоляція для проводів, рукавички, предмети домашнього вжитку, взуття та, звичайно ж, шини. Метою статті є дослідження можливих методів переробки автомобільних шин та встановлення найраціональнішого методу з точки зору сучасних інноваційних методів переробки шин.

Одним з найпоширеніших гумотехнічних виробів є шини. Склад сучасних шин являє собою суміш різних компонентів: добавок, наповнювачів, пластифікаторів та інших спеціальних добавок. Постійне збільшення кількості відпрацьованих шин є проблемою в усьому світі. Оскільки гума має високу стійкість до факторів навколишнього середовища, накопичення великих обсягів використаних шин створює серйозну екологічну проблему. Сучасні та інноваційні технології переробки використаних шин допоможуть її вирішити. Існує ряд різних методів переробки автомобільних шин. Тому в дослідженні представлені різні методи переробки автомобільних шин. Особлива увага приділялася сучасним методам. Існує ряд різних методів переробки автомобільних шин. Одним із поширених методів переробки шин є рекуперація енергії. Статистичні дані показують, що подрібнення використаних шин також є одним із сучасних методів їх переробки.

Дослідження з використанням аналітичного методу збору інформації встановили шкідливий вплив звалищ використаних автомобільних шин. У зв'язку з цим питання переробки шин у світі стає надзвичайно гострим. Така ж ситуація спостерігається і в Україні.

У статті зроблено висновки щодо найпоширеніших методів переробки автомобільних шин. Основні методи переробки автомобільних шин базуються на рекуперації енергії, яка була витрачена на їх виробництво.

переробка гумової крихти, піроліз, мікробіологічні процеси переробки шин, рекуперація енергії, забруднення навколишнього середовища, гумотехнічні вироби

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