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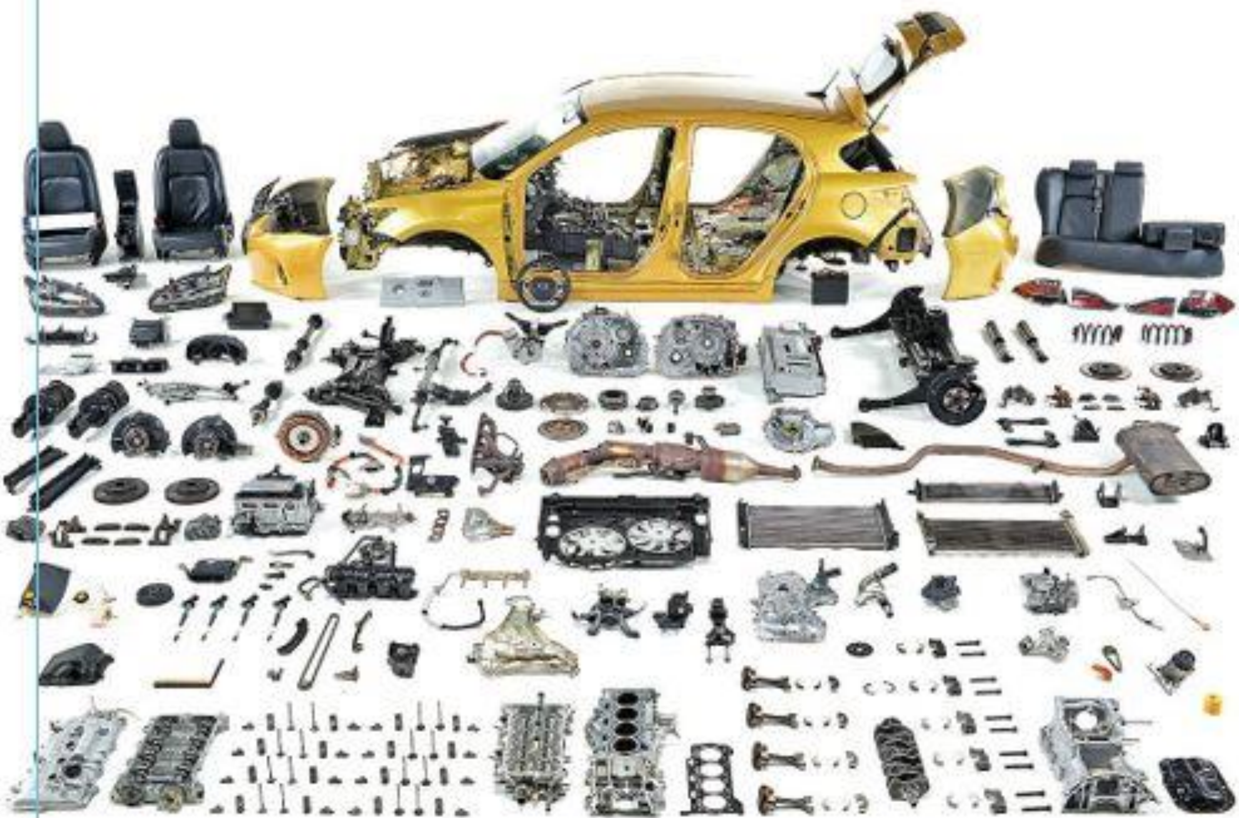
SLOVAK UNIVERSITY OF
TECHNOLOGY IN BRATISLAVA

SMART TECHNOLOGIES FOR WASTE PROCESSING FROM THE AUTOMOTIVE INDUSTRY

Editor

Dr.h.c. prof. Ing. Ľubomír Šooš, PhD.



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UNIVNET – University and Industrial Research and Education Platform of the Recycling Society

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ÚMMS SAV - ÚMMS SAV - detached workplace Inoval, Žiar nad Hronom, (SK)

Technical adaptation: **Mgr. Henrich Hipča, ZAP SR**
Automotive Industry Association of the Slovak Republic

Cover design: **Ing. Tibor Dzuro, PhD.**,
Technical University of Košice, Faculty of Mechanical Engineering,

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Smart technologies for waste processing from the automotive industry, Scientific Monograph of UNIVNET 2021

Contents

Introduction

Dear readers, waste management specialists and students,

This is another issue in the series of books prepared by the UNIVNET association – University and Industrial Research and Education Platform of the Recycling Society. The publication sums up the results of activities related to the assessment of state, waste generation forecasting and development of new technologies for material and energy recovery of the selected types of waste from the automotive industry in 2021.

The UNIVNET association was established upon an agreement between the Ministry of Education, Science, Research and Sport and the leader of the association – Slovak University of Technology in Bratislava (STU BA). In addition to STU BA, the association includes four other universities and the Automotive Industry Association of the Slovak Republic (ZAP SR).

The EU waste management policy focuses on the reduction of negative impacts of waste on the environment and human health and, at the same time, on the improvement of waste recovery efficiency in the form of secondary raw materials and energy. In order to switch over to circular economy it is necessary to implement changes in the entire value chain, from the product design up to new business and market models, including the new methods of waste conversion into resources, up to the change of consumer behaviour. This foresees a complete systemic change and innovation not only in the field of technologies, but also in organization, society, financing methods and formulation of policies.

The Slovak Republic is currently facing many environmental challenges. We have problems with air quality, low level of waste recycling and also with the protection of ecosystems. The basic vision defined in the Strategy of the Environmental Policy of the Slovak Republic through 2030 is to achieve better environmental quality and a sustainable circular economy.

The publication we present to you is divided into eight logically related chapters. Individual chapters are devoted to the analysis of waste quantities, processing capacities, forecasting of the waste change in relation to the launch of electromobility, waste preparation for reuse, design of technology for the recovery of laminated glass, recycling of metal-bearing waste from accumulators, waste from sound-proofing and thermal insulation, recycling of rubber, natural rubber and plastics, and finally the possibilities for energy recovery from waste.

I believe that this publication will provide you with the necessary information on the state and issues of waste management in the automotive industry and becomes an inspiration for those who deal with the minimization and recovery of waste generated in their production, operation, and processing of old vehicles.

Dr.h.c. prof. Ing. Ľubomír Šooš, PhD.
Editor

Analysis of the quantities and processing capacities of waste generated in the automotive industry

Research team:
Automotive Industry Association of the Slovak Republic (ZAP SR)

Principal researcher:
prof. Ing. Ľubomír Šooš, Dean of the Faculty of Mechanical Engineering of STU BA

Researchers:
Ing. Ján Pribula, ZAP SR
Mgr. Henrich Hipča, ZAP SR
Mgr. Viktor Marušák, ZAP SR

1 Analysis of the quantities and processing capacities of waste generated in the automotive industry

1.1 Introduction

The Automotive Industry Association of the Slovak Republic (ZAP SR) is one of the partners of UNIVNET – University and Industrial Research and Education Platform of the Recycling Society, an association recognized by the Ministry of Education, Science, Research and Sport of the Slovak Republic, the Ministry of Economy of the Slovak Republic and the Deputy Prime Minister's Office for Investments and Informatization of the Slovak Republic as the national platform for the area of recycling and waste recovery with its application outputs in industry sectors. The study "Analysis of the quantities and processing capacities of waste generated in the automotive industry" **contributes to the execution of prognostic and research and development activities in the search for new technologies and methods for the maximum efficient recovery of waste, especially in the automotive industry**, with the aim to minimize negative impacts on the environment and save the primary resources of energy and raw materials. In the long term, ZAP SR perceives the deteriorating situation in the area of processing waste from industrial production and end-of-life vehicles and the issue of wastes is gradually becoming one of the pillars of competitiveness. The results of studies should assist in the search for solutions in cooperation with all competent and involved parties. ZAP SR is prepared for further cooperation and discussion about this issue, especially with the responsible officers of the Ministry of Economy, Ministry of Environment, Ministry of Education and professional organizations. Data from the study mapping the needs of industry and processing capacities of individual types of waste provide a more realistic perspective of the issue of waste processing from the automotive industry and represent an important source of information in the search for solutions and improvement of the waste management situation.

1.2 Main objectives of the study and methods

The main objective of the study was **to map the needs of industry** and **processing capacities** within waste management in Slovakia. An analysis of the waste quantity was carried out on the basis of waste reports for 2019 and 2020. Members of ZAP SR were addressed by letter. Groups of waste types were determined after examination of delivered waste reports and missing data were again requested from the manufacturers from the relevant groups of waste types. At the same time, an analysis – **mapping of processing capacities** – was performed. Mapping the needs of the automotive industry could be carried out with the use of data from the relevant ministry which receives annual Reports on waste generation and management.

Since the information contained in these reports is not further analyzed, there is no available study concerning the reported quantities and future projections. We have decided to proactively respond to this situation by requesting the necessary data directly from the **waste producers** – production companies in the automotive industry.

Electromobility, circular economy, structural effects of automotive on the economy of the Slovak Republic, science, research and their barriers in the automotive value chain

Research team:
University of Economics in Bratislava

Principle researcher:
prof. Ing. Pavol Ochotnický, CSc. [1] (editor and co-author)
Dr.h.c. prof. Ing. Rudolf Sivák, CSc. [1] (coordinator and co-author)

Researchers:
doc. Ing. Martin Lábaj, PhD.[1]
Ing. Erika Majzlíková, PhD.[1]
Ing. Marek Engel[1]
doc. Ing. Stanislav Zábojník, PhD.[2]
doc. Ing. Viera Kubičková, PhD.[2]

1 Faculty of National Economy of the University of Economics in Bratislava, 1x doctoral candidate.
2 Faculty of Commerce of the University of Economics in Bratislava.

2 Trends of structural effects of electromobility on the economy of the Slovak Republic and the potential of waste for the circular economy

2.1 Introduction

The intention to gradually transfer the structure of the car "fleet" in Europe towards the use of electric vehicles is one of the biggest technological challenges for the operators involved in the entire life cycle of cars (LCC). A time-lag in bringing about **electromobility** will affect the entire LCC in the Slovak Republic (hereinafter SR): from production, operation, up to processing of end-of-life vehicles (ELV). Under the influence of the growth of scarce raw materials and their prices, but especially for the purpose of emission reduction in the entire LCC and under the influence of EU regulation, it is generally expected that electrically powered vehicles will become a dominant type of so-called light vehicles by 2050. If we strip out the emissions related to power production in the use of such cars, electric cars, as compared to vehicles with petrol, diesel or hybrid drive, will have a significant impact on the reduction of the total volume of greenhouse gases.

Future production of these vehicles represents a big challenge, especially in terms of **technology, ecology, raw materials and economy**. It will have significant effect on the innovations in the entire LCC. The transition to electromobility, as well as other changes towards the new material structure of cars, will fundamentally change the supplies of components. In professional circles, it is generally expected that the number of components will fall by approximately one third and they also expect changes in the structure of suppliers and the overall structure of economies. This is especially true in relation to the intensification of supplies for the producers of electronic components and batteries.

Electromobility will "strengthen" the area of science, research and innovations especially in the two above-mentioned fields. It will gradually eliminate the consumption of fossil fuels and petroleum products and be the incentive in the development of new "fuel" infrastructure and energy consumption growth. It will also be the source of a new structure of waste generated during the use of vehicles and also in the phase of processing of end-of-life vehicles (ELV). Electromobility will bring new impulses for all phases of LCC. Early adaptation will be the prerequisite for the involvement in the creation of added value within the global and changing value chains.

Europe and its individual countries in 2020 recorded a **boom in the demand for electric cars** – battery electric vehicles (BEV) and plug-in hybrid electric vehicles (PHEV). The Nordic countries, followed by Luxembourg and Germany, lead the ranking of "fleet" penetration by electric cars. The share of registration of these vehicles in the SR compared to Europe is negligible.

SR lags behind Europe even in the current volume structure of cars in SR. This is caused especially by the growing importation of second-hand cars (earlier years of manufacture) which appeared during pandemic. Without the acceleration of action steps towards the increase of the share of BEV (Battery Electric Vehicle) – pure electric vehicle, and PHEV (Parallel Hybrid Electric Vehicle), fulfilling European obligations for the future will be endangered, and thus there will be insufficient reduction of the carbon footprint from the use of cars registered in the SR. At the same time, such composition will become the source for the processing of secondary raw materials, as well as for the generation of such waste during operation that will, for several years, copy the current structure of waste as well as the existing technologies for their processing in the SR or in Europe.

Despite the pandemic, in 2021, Slovakia maintained its leadership position with regard to the **number of produced cars per capita** (Press release of ZAP: Alexander Matušek, Chairman of ZAP SR: Slovakia lags behind in the country's green transformation. How to fulfil the EU's commitments? Bratislava, 13.1.2022). **The share of electric car production in the SR gradually increases.** Based on publicly available data, the share of electric and plug-in hybrid vehicles represented almost quarter of the production (23%) of Volkswagen Slovakia. The percentage of electrified car production of Stellantis Slovakia was 10% in 2020, and 13.5% in 2021. Production of petrol engines also prevailed in the production of Kia Slovakia in the previous year (eight out of ten engines were petrol aggregates).

In the following text we will be focusing on the major trends influencing the production inputs, material composition of cars and waste, changes and trends of impacts of the technological changes in the production of cars in the SR on the structure of SR economy and on science and research as a source of innovation potential of subcontractors in the automotive industry in the SR – the chapter presents the main findings of the study by Ochotnický, P. et al. (2021).

SmartOdpady III. – Integrated information and innovation platform of recycling technologies

Research team:
Slovak University of Technology in Bratislava
Faculty of Mechanical Engineering

Principal researcher:
prof. Ing. Marcela Pokusová, CSc.

Researchers:
prof. Ing. Ľubomír Šooš, PhD.
doc. Ing. Juraj Úradníček , PhD.
doc. Ing. Miloš Matúš, PhD.
doc. Ing. Juraj Beniak, PhD.
doc. Ing. Peter Križan, PhD.

3 SmartOdpady III. – Integrated information and innovation platform of recycling technologies

3.1 Introduction

Change in the EU's economic structure in terms of greening the economy is not feasible without the transition to cutting-edge technologies which use materials on the basis of critical strategic raw materials. It is therefore inevitable to mobilize and separate the waste containing the specific strategic raw materials, and their significant source in Slovakia are things such as electric waste, waste from the processing of end-of-life vehicles, etc. In order to achieve the globally set objectives it is necessary to more strictly promote and observe the binding hierarchy of the waste management to increase the rate of waste recycling.

The concept of the digital platform "SmartOdpady" integrates the fundamental principles of two strategic documents in the field of waste management in Slovakia. The primary document is the Waste Management Plan of the Slovak Republic. However, if we perceive waste as a long-term significant source of secondary raw materials and energy, it is legitimate to also accentuate the innovation strategy of the SR "Through knowledge towards prosperity – Research and Innovation Strategy for Smart Specialization of the Slovak Republic (RIS3)" which, within the economic specialization of the economy, identified the automotive industry and engineering as one of the priorities and has defined these development tendencies:

- increasing the added value of domestic products, especially through an efficient transfer of technologies and results of the science and research into the production process,
- development of manufacturing procedures focusing on more effective use of available resources, higher rate of recycling and use of environmentally friendly materials through the use of scientific and technological development and innovations.

The philosophy of the SmartOdpady platform is based on the fundamental principles applied in the modern waste management:

- The recycling society using waste as a source of raw materials, moving away from waste disposal especially through landfills.
- Life cycle thinking, taking into consideration the entire life cycle of materials and products and not just thinking about the waste phase. This approach is reflected most notably in the definition of waste hierarchy.
- Waste hierarchy defines the order of priorities of waste management according to what is best for the environment, taking into consideration the precautionary principle, sustainability, technical feasibility, economic viability and environmental protection.
- Expanded producer responsibility as a means to promote the development and production of products which take into account and facilitate the effective use of resources during their entire life cycle, including repair, re-use, dismantling and recycling.

- Using waste as a resource, when the sorting of waste directly at its source and its subsequent separate collection will ensure the increase of economic value of the waste as a source of secondary raw materials.
- End-of-waste, which determines the conditions under which the waste is no longer waste and may be regarded as material freely tradable on the market.
- Circular economy, which preserves the value of products and materials as long as possible in order to minimize the quantity of waste and the use of new resources, and thus promotes the separation of economic growth from the need to extract the primary raw materials. In practice, this approach is implemented through savings on materials, re-use, change of the eco-design of products and development of new products and services with reduced material intensity, or re-use in the circular cycle.

Recycling of laminated glass
Construction of line modules for the decomposition of multilayer laminated glass

Research team:
Slovak University of Technology in Bratislava
Faculty of Mechanical Engineering of the Slovak University of Technology

Principal researcher:
prof. Ing. Ľubomír Šooš, PhD.

Researchers:
prof. Ing. Marcela Pokusová, CSc.
Ing. Iveta Čačková, PhD.
Ing. Ondrej Chlebo, PhD.
Ing. Viliam Čačko, PhD.
Ing. Jozef Babics

4 Recycling of laminated glass – Construction of line modules for the decomposition of multilayer laminated glass

4.1 Introduction

The content of the presented third report follows the report of 2019 and 2020. The **content of the report from 2019** [5] was the mapping of the quantities of waste from the multi-layer laminated sheets of glass and the analysis of available technologies for the decomposition of the specified glass, the possible uses of individual secondary raw materials from these wastes, as well as the economy of recycling and recovering of these wastes. The analysis of waste quantities from the multi-layer laminated sheets of glass has shown that based on estimates of ZAP SR, there are approx. 3 600 tonnes in Slovakia and the total annual available waste of flat glass from construction is approx. 13 200 tonnes, [1]. The analysis also pointed out the fact that the recovery of such sheets of glass is currently very problematic. Although approximately 40% of the total amount is recovered, the extractability with the use of current technologies is only 60 – 65%. This means that from the waste in a total amount of 16 800 tonnes, only approx. 6 700 tonnes are processed and only 4 000 – 4 400 tonnes of secondary raw materials are gained from this amount. This corresponds only to 26% of the total amount of waste. The rest, 12 400 tonnes of such waste, is deposited at landfills.

The second report from 2020 [6] focused on the verification of known analyzed principles from the report drawn up in 2019 and experimental verification tests. The aim of this part of the research was the comparison and SWOT analysis of the available technologies. There are a range of various types of technologies in the world. These technologies are mainly dry, wet, chemical combined thermal/chemical. Based on literature references, in order to achieve perfect separation and extraction of pure laminate phases, only the wet method of glass layer separation from the foil is suitable, as it uses a reverse effect of the bonding technology – the adhesion to the glass increases with the decreasing humidity of the foil. However, these technologies are very expensive. Moreover, their applicability on damaged windshields is significantly complicated.

The results of analysis have shown that the classic mechanical technology for the disintegration of glass and subsequent separation of individual commodities of the laminated glass is cheap, but the currently known technologies are very noisy, dusty, and not very effective. Even though there is demand for the foil and glass fragments, glass and chemical plants do not want secondary raw materials that are incompliant for the required purity criteria. The extractability of clean glass fragments and foil with the use of the specified technologies is only 50 – 60%. The remaining non-separated waste is deposited at landfills.

The second most important result of the report from 2020 was the experimental laboratory verification of the known technologies. Based on the results of laboratory tests, the conclusion of the paper includes an outline of the authors' own affordable technology for small and medium-sized outputs with a yearly capacity of 1 000 – 2 000 kg. The working hypothesis of the decomposition of multiplayer sheets of glass in such way as to eliminate disintegration of the glass waste within the decomposition process, is crucial. Within this process the glass should be separated by its breaking and subsequent stripping and scraping off of the glass fragments in such way that the foil remains intact, if possible, [7].

The aim of the present third report from 2021 is the presentation of production documentation, production of individual modules and the overall variant concept of the line for the decomposition of waste laminated glass. The designed modules, as well as the variant solutions, are the result of laboratory tests. The proposed variant solutions are affordable and designed according to the exact requirements of the client for various types, layers, and dimensions of the processed waste glass.

Extraction of valuable components from the discarded lithium accumulators from electric vehicles

Research team:
Technical University of Košice
Faculty of Materials, Metallurgy and Recycling
Institute of Recycling Technologies

Principal researcher:
prof. Ing. Tomáš Havlík, DrSc

Researchers:
prof. Ing. Andrea Miškufová, PhD.
doc. Ing. Dušan Oráč, CSc.
Ing. Jakub Klimko, PhD.

5 Extraction of valuable components from the discarded lithium accumulators from electric vehicles

5.1 Introduction

The activity of the UNIVNET association – University and Industrial Research and Education Platform of the Recycling Society, focuses on the condition and vision of the recovery of selected types of waste especially from the Slovak automotive industry. The main aim of the association consists of prognostic and research and development activities in the search for new technologies and methods for the maximum efficient recovery of waste, especially in the automotive industry, with the aim of minimizing negative impacts on the environment and to save the primary resources of energy and raw materials.

One of the most important challenges of the waste industry within the dynamically developing sector of electric vehicles is the management of discarded traction lithium accumulators (LiA). They represent a potentially very dangerous waste, but, on the other hand, they are the source of very important materials that must be recycled with regard to their price and scarcity. It is not negligible that some components, such as cobalt, graphite, and lithium, contained in LiA belong among the critical raw materials for the European Union. Recycling of LiA is an important way to gain these critical raw materials, but, on the other hand, it is a complicated and demanding process, since it is a complex composite material and its character as well as electrical and chemical properties pose a serious risk in terms of safety and the protection of health.

Within the activities of the UNIVNET association, the Institute of Recycling Technologies, Faculty of Materials, Metallurgy and Recycling, Technical University of Košice, deals with this issue and the results of their work in this field for 2021 are presented in this paper.

Development of materials and products with sound and thermal insulating and other properties on the basis of waste from the automotive industry

Research team:
Technical University of Košice, Faculty of Mechanical Engineering, Institute of industrial engineering, management and environmental engineering, Department of environmental engineering

Principal researcher:
Dr.h.c. mult. prof. Ing. Miroslav Badida, PhD.

Researchers:
doc. Ing. Lýdia Sobotová, PhD.
Ing. Tibor Dzuro, PhD.
Ing. Marek Moravec, PhD.
Ing. Miriama Piňosová, PhD.
doc. Ing. Ružena Králiková, PhD.

6 Development of materials and products with sound and thermal insulating and other properties on the basis of waste from the automotive industry

6.1 Introduction

The study of the research team follows up the research executed in 2019 and 2020. The researchers have focused on the selection of suitable materials from the components in the end-of-life vehicles. For the further detailed research, the research of sound insulating materials, we have selected materials such as various fractions of recycled waste tires, various fractions of textile materials from the automotive industry and also glass fractions from car glass. The basic objective of the research is the idea to use bulk materials, that is, those specified fraction types of the selected materials for use as sound insulating products. The study was focused on the comparison of the same fractions of materials in compact form and in bulk form. For the purpose of the research of bulk materials, we have developed and produced special testing cartridges and special test cartridge filling equipment. Attention was given to a wide range of scientific experiments which were analyzed and evaluated. The researchers have also focused on the specific products characterized by good sound insulating properties.

Research of new wooden composites containing waste polymers from cars

Research team:
Technical University in Zvolen
Faculty of Technology
Department of Environmental and Forestry Machinery

Principal researcher:
Prof. Ing. Jozef Krilek, PhD.

Researchers:
Doc. Ing. Iveta Čabalová, PhD.
Doc. Ing. Marek Potkány, PhD.
Doc. Ing. Helena Hybská, PhD.
Prof. Ing. Dagmar Samešová, PhD.

7 Research of the properties or new wooden composites containing waste polymers from cars

7.1 Introduction

The constant industrial development as well as the consumption lifestyle result in the growth of produced waste including the plastic waste. Plastic products currently form an indispensable part of people's daily lives and are applied in various industry sectors, such as construction, agriculture, automotive industry, etc. By 2015, a total of about 6,300 Mt of plastic waste was produced, out of which around 9% was recycled, 12% was incinerated and 79% was accumulated at landfills or in the nature. It is estimated that by 2050 there will be about 12,000 Mt of plastic waste at landfills or in the environment if current trends of production and waste management are to continue (Geyer et al. 2017). Plastics increasingly become the first choice in the automotive sector leading to the enhancement of safety, output and fuel efficiency (Pradeep et al. 2017). Plastics, such as polyethylene (PE), polypropylene (PP), polyvinyl chloride (PVC), acrylonitrile butadiene styrene (ABS), polyurethane (PUR) or thermosetting composites, such as plastics reinforced with carbon fibres (CFRP), or plastics reinforced with glass fibres (GFRP), are most often used in cars (Tranchard 2015). Like plastic waste, waste rubber (insulation, carpets, etc.) and used tires are still a global problem, and their volume is still much higher than the amount of waste which can be reasonably recovered. About 1,000 million of waste tires are disposed of in the world every year and according to Formel et al. (2019), this amount will reach 1,200 million per year in 2030. Tires are made from synthetic polymers (46 – 48%), such as polyamide, butyl rubber, butadiene rubber and styrene-butadiene rubber (Carmo-Calado et al. 2020, Bulei 2018). Carbon black is added to rubber during vulcanization in order to improve its abrasion resistance (Larsen et al. 2006). Together with silicone dioxide and following the rubber polymer, carbon black is the second major component in tires (Bockstal et al. 2019). Based on the paper of Danon and Gorgens (2015), the most common components of tires are natural rubber (14 – 27%), synthetic rubber (14 – 27 %), fillers such as carbon and silicon dioxide (26 – 28 %), extender oils and resins (5 – 6 %), sulphur (5 – 6%), and metals for reinforcement (16.5 – 25%). There is no recovery process that could recover the original rubber or other rubber raw materials from the rubber waste. Tires as the secondary material are only used in two ways: material conversion (floors, noise barriers, etc.) (Bulei 2018), and energy recovery (Bulei 2018, Demirbas et al. 2016). The thermochemical conversion processes, such as pyrolysis, gasification and liquefaction, offer alternative solutions for the reduction of the high level of global dependence on oil. These processes can be used for the provision of energy, fuel and products with high added value (Nkosi et al. 2021, Čabalová et al. 2021). Demirbas et al. (2016) have carried out the catalytic pyrolysis of the waste tire. The liquid product was produced at high temperature (up to 600 °C) with the use of sodium carbonate (Na_2CO_3) as the catalyst. The thermophysical properties of the liquid samples produced have shown that up to 85% of the produced oil can be used in the combustion engines. Wang et al. (2019) have achieved direct conversion of waste tires to 3D graphene by an alkaline single-stage pyrolysis process without the use of expensive chemical agents and complex equipment. Experimental work of Buss et al. (2019) indicates that there are possible practical applications of rubber waste from end-of-life tires, resulting in a new product which is harder and contains 60% share of rubber particles, as indicated by the tests, with a smooth surface that requires no polishing.

In addition to the production of energy or graphene, another way of re-use of the waste rubber is material recycling. The main course for the recovery of used plastic and rubber waste is: re-use in the same quality as the original products; for the production of other products; recycling, as material re-used in regenerated elastomeric compositions; and as specified above: a source of different chemicals (carbon black, pyrolysis oils), a source of heat and as forms of different materials; as construction material (Fazli, Rodrigue 2020, Bulei 2018, Baričević et al. 2013); powder from the waste tire/polypropylene composite (Ong et al. 2021); wood-rubber composites from waste tires (Zhao et al. 2010, Ayrilmis et al. 2009); wood-plastic composites (Rajan et al. 2021). Shalbafan et al. (2016) in their study have compared the effect of different quantities of expanded polystyrene filler (5, 10, and 15%) on the properties of particle boards. The results have shown that the use of polystyrene fillers has a significant impact on bending properties, internal bonds, edge screw withdrawal resistance, swelling in thickness, and water absorption. Xu et al. (2020) have prepared fiberboard composites with powder from waste tires as functional fillers. This research has shown that it is possible to produce fiberboard composites with rubber filler resulting in added value and satisfactory properties. Test results of the research by Zhao et al. (2010) have shown that the sound insulating properties of a composite wood-rubber panel from waste tire is better than the properties of the commercial composite wooden flooring and particle board. Moreover, the acoustic insulation of these composites is significantly affected by the amount of crushed rubber and binder used in the composite. Increased usage of recycled crushed rubber and dosage of binder significantly improve the sound insulating properties of the composite.

There is information about the material recycling of waste tires, but the information about the use of rubber materials from cars is lacking. Therefore, the objective of this research task is:

- to reduce the volume of tires, other rubber materials and plastics as waste from the automotive industry;
- to reduce the consumption of raw materials, especially those that come from non-renewable resources and use waste rubber and plastics as secondary raw material;
- to reduce the enormous environmental burden represented by waste rubber and plastics;
- to prepare new composite materials containing the waste rubber (tires, carpets, insulation);
- to evaluate the properties of composites and possibility of their use as construction material in the exterior and/or interior;

- to create a concept of business investment plan for the production of new composites;
- to produce composites on a commercial basis.

Implementation of the pyrolysis reactor for energy recovery of waste from the automotive industry

Research team:
University of Žilina
Faculty of Mechanical Engineering
Department of Power Engineering

Principal researcher:
Ing. Marek Patsch, PhD.

Researchers:
prof. Ing. Jozef Jandačka, PhD.
Prof. RNDr. Milan Malcho, PhD.
Ing. Peter Pilát, PhD.

8 Implementation of the pyrolysis reactor for energy recovery of waste from the automotive industry

8.1 Introduction

The current objective of modern society is to implement the circular economy, which is based on maximum possible long-term utilization of objects and on their disassembly into individual components after the end of their life cycle. These components will be afterwards sorted to re-usable ones, either as individual parts or as a secondary raw material, and to parts that cannot be used further. The aim is to minimize the unusable waste. Since the automotive industry generates large quantities of waste, either from the production or after the end-of-life cycle of the cars, this issue is highly topical.

However, not all materials can be re-used in production. A large part of the waste cannot be used for other than energy purposes. The most common method of energy recovery is incineration, for example, in incineration and cement plants. This method is the simplest and is widely applicable. It results in the generation of energy, reduction of the waste volume, chemical stability of residues after incineration, and their safety with regard to the environment.

However, our aim is to gain another quality fuel with much broader use from these energy efficient raw materials. The recovery of such waste with the use of pyrolysis seems the most suitable. The result is pyrolysis gas and pyrolysis oil. Pyrolysis gas can be used directly at the site as fuel for the pyrolysis reactor, and pyrolysis oil can be used as liquid fuel in other various processes, as a fuel for combustion engines to take one example.

Therefore, at the Department of Energy, Machines and Equipment, Faculty of Mechanical Engineering at the University of Žilina, we have started to deal with the development of a small pyrolysis reactor the use of which we could verify the suitability of individual input materials and the quality of the resulting product.

In the first phase, we have designed a small pyrolysis reactor with discontinuous operation. Within the second phase, based on the dimensions of the proposed equipment, we have prepared space for this installation – an extended platform with a shelter in the exterior of a building adjacent to the laboratory of the Department of Energy Machines and Equipment. Later on, due to the unexpected growth of prices, we had to modify and simplify the structure of the reactor in order to achieve the objectives of the research. The designed pyrolysis reactor is constructed and ready for use in a trial operation.

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Smart technologies for waste processing from the automotive industry

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