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Innovative technologies for the recovery of platinum group metals from catalysts – a case study of selected projects

Introduction

One of the basic spheres of human activity is road transport, which on the one hand is necessary to meet many social needs but on the other hand can be counted as a sector that causes a nuisance to modern civilization. The greatest threat of the development of motorization which is directly perceptible by the environment is the emission of toxic substances such as carbon oxides, nitrogen oxides, sulfur oxides, aromatic hydrocarbons, aldehydes, petroleum hydrocarbons and heavy metals (cadmium, zinc, chromium, iron, lead, copper,

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nickel, vanadium and manganese). With the introduction of catalytic exhaust-gas converters in the mid-1970s in the US and Japan, and in the early 1980s in the European Union countries (Moldovan 2007; Ravindra et al. 2004), the level of harmful emissions associated with the road transport sector fell significantly (by 24–35%). Currently, two basic types of catalysts can be distinguished: oxidation-type catalysts (coupled to diesel engines); trifunctional catalysts (used in gasoline engine vehicles). The process of the conversion of toxic compounds in converters is catalyzed by a specific group of elements, which are metals of the platinum group (Pt, Pd, Rh and, less frequently, Ru and Ir). Unfavorable operating conditions of the catalyst (too high exhaust-gas temperature , mechanical and chemical impact on its surface) result in the emission of platinides into the environment. Precious metals, entering the environment as a result of road transport, are deposited in suspended matter, street dust, soil and water.

The automobile industry is one of the most significant sectors of the world economy. The peculiarity of the passenger car market in Poland, as in other countries of Central and Eastern Europe, is due, among other things, to the fact that until 1990, it developed under the conditions of a centrally planned economy, different from a market economy. In fact, until the 1970s, the supply of cars was severely limited. The political transformation made it possible to integrate the country's economy into globalization and integration processes, which significantly influenced the formation of the market. The car market went through three critical moments in a relatively short period of time (political transformation, EU accession and the 2008–2010 global crisis). Each time, they fundamentally changed the situation in this market.

Over the past two decades, the governments of most countries around the world have been developing and implementing solutions to minimize the environmental impact of the growing number of cars. One of the solutions contributing to this is the organization of end-of-life car recycling (ETC) networks, which is now an integral part of the functioning of the automotive sector worldwide. The main stimuli for the development of the design of the recycling network were the introduced legislation and economic and business conditions. The basis for solving the problems of end-of-life car waste management in European Union countries is Directive 2000/53/EC on end-of-life vehicles (Directive 2000/53/EC), it developed common rules for the handling of end-of-life car waste. The directive led to the implementation of recycling and recovery solutions that did not exist before. Among other things, it introduced the principle of expanded producer responsibility for recycling vehicle waste. It brought about a change in the percentage of materials and components used in the construction of cars to the point of increasing the amount of materials that can be recycled or recovered as well as the use of the recycled materials.

Meeting the conditions of the European directive on end-of-life cars is contingent on the development and implementation of new improved recovery and recycling methods. The development process of the car and the EoF waste-recycling network depends on the internal ability to change the organization of the network. The implementation of a new recovery technology must be met with recognition and readiness to change by the entity acquiring the technology itself, as well as the external environment: other EoF network entities, competitors, society. The purpose of this article is to analyze the modern catalyst reprocessing technologies in Poland and Europe based on selected projects.

1. The role of platinum in the automotive industry

The main role of a catalytic reactor, commonly referred to as a car catalytic converter, is to minimize air pollution during car operation. This device significantly reduces the amount of dangerous chemicals emitted into the air, namely nitrogen oxides (NOx), hydrocarbons (CH) and carbon monoxide (CO). This is due to the use of the properties of platinum (platinum, rhodium and palladium) used in the construction of the automotive catalyst, such as its high melting point and resistance to chemical attack, and in particular, its catalytic properties. Since stricter regulations were introduced to equip every new car with an automotive catalytic converter to reduce air pollution, there has been a significant increase in the demand for platinums. This fact entailed an increase in the importance of platinums in the market in the first decade of this century. Currently, the demand for platinums exceeds their supply.

In addition to other sources of platinides, the emission of these metals from exhaust gas converters deserves special attention, as according to the literature, it currently represents the most serious source of this group of pollutants in the environment (Helmers 1997; Zimmermann and Sures 2004). The exhaust-gas converter is a component located in the front part of the exhaust system (near the engine), is the tasks of which are to: reduce nitrogen oxides; oxidize hydrocarbons; oxidize carbon monoxide; oxidize trace amounts of hydrogen. When using the term “catalyst,” it is important to remember that it refers only to the carrier (ceramic or metal with an intermediate layer) and the active phase applied to its surface. The catalytic layer is most often a combination consisting of platinum, palladium, rhodium, and less often ruthenium and iridium (in the form of particles of high fineness, of the order of 1–10 nm (Bojanowska 2005; Kolodziej et al. 2007) and oxides of base metals (Zr, Ba) and rare earth metals (Ce), which act as catalytic stabilizers, preventing the “wear” of the catalyst (Ryczkowski 2003; Moldovan et al. 2003). Regardless of the type of active layer used in the catalyst (e.g., Pd-Rh, Pt-Rh, Pt-Pd, Pt or Pt-Pd-Rh), the percentage of platinides in the total weight of the catalyst is usually on the order of tenths of a percent. Depending on the data source, the platinum content of the catalyst is estimated to be between 1 and 3 g (Platinum, Air Quality Guidelines 2000). Pt/Rh type catalytic converters, which are fitted to cars manufactured in Europe, are characterized by a mass ratio of these metals in the catalyst of 5:1, which translates into a platinum content of 0.9–2.5 g, and rhodium content of 0.2–0.3 g (Twigg 2007). For some time, there has been a trend to replace platinum by palladium, as this metal is cheaper and more resistant to poisoning (Krähenbühl et al. 2006; Lough et al. 2005; Limbeck et al. 2007).

Based on the mode of operation, automotive catalytic converters can be divided into two basic groups: oxidizing, multifunctional (most often trifunctional, TWC). The first type of catalytic converters mentioned is used in diesel vehicles, using compression-ignition engines (cars and trucks, buses, tractors, industrial machinery). It allows oxidation of only carbon monoxide and hydrocarbons. Due to the specific nature of the operation of these engines (operation on a lean mixture), it is impossible to reduce nitrogen oxides at the same time. For this reason, additional catalysts (e.g., using urea as a reaction catalyst) are often used in diesel vehicles. The second type of catalytic converters (i.e. multifunctional catalytic converters) has found application in vehicles equipped with a spark-ignition engine, mainly in passenger cars. These catalysts allow the simultaneous conversion of all three toxic components of exhaust gas, with about 90% of the nitrogen oxides and carbon monoxide formed during combustion (which are converted to nitrogen and carbon dioxide) and 80% of the hydrocarbons present in exhaust gas, which are then oxidized to carbon dioxide and water (Balcerzak and Kaczmarczyk 2001) (Figure 1).

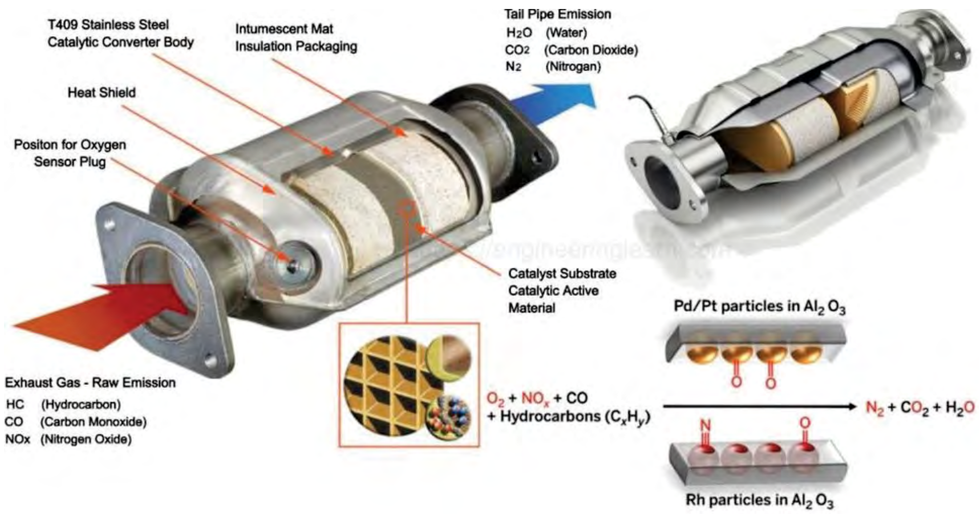

Fig. 1. Schematic of the construction of a catalyst
Source: Engineering Learn 2022

Rys. 1. Schemat budowy katalizatora

For the production of an automotive catalytic converter, it is necessary to take a number of steps, including the collection of raw materials and the organization of various forms of processing. Three phases can be distinguished in the process of creating a catalyst carrier: ceramic carrier preparation, precious metal preparation and stainless steel preparation. The next phase of the life cycle of a catalyst after the catalyst is installed in the vehicle is the use phase. Modern and well-used devices of this kind installed in cars in series should work for at least 80–90 thousand kilometers, or for an average of 5 years (Fornalczyk 2016). In practice, however, automotive catalytic converters are used much longer, although their efficiency drops sharply. However, their lifespan is limited, and when the car is decommissioned and dismantled, they should be properly managed. Any car catalytic converter can be recycled by processing the stainless steel housing, the use of a precious-metal recovery process and reusing the ceramic material. To outline how beneficial this process is, it is necessary to analyze the amount of energy required to produce platinum and rhodium compared to metal recovery. This data is presented in Table 1.

Table 1. Processing energy vs. recycling energy for platinum and rhodium

Tabela 1. Energia przetwarzania vs. energia recyklingu dla platyny i rodu

Metal	Energy Type	Energy Value (MJ/kg)
Platinum	Energy required for primary production	$1.14 \cdot 10^5$
	Energy needed for recycling	$1.08 \cdot 10^3$–$1.2 \cdot 10^3$
	Energy savings	$13 \cdot 10^5$–$1.13 \cdot 10^5$
Rhodium	Energy required for primary production	$1.22 \cdot 10^5$–$1.35 \cdot 10^5$
	Energy needed for recycling	$2.44 \cdot 10^3$–$2.7 \cdot 10^3$
	Energy savings	$1.20 \cdot 10^5$–$1.32 \cdot 10^5$

Source: Belcastro 2012.

Table 1 shows the classification of platinum and rhodium processing in relation to their recycling. For both platinum and rhodium, less energy is used in recycling than in obtaining these raw materials from primary sources. As for the extraction of raw materials from primary sources to rhodium requires more energy. The same applies in the case of recovering rhodium from recycling processes.

Despite the large amount of energy required for the precious-metal recycling process, the recycling of precious metals remains a priority due to their rarity and the high cost of extraction. The extraction of precious metals from automotive catalytic converters can be performed by various technologies (Moschovi et al. 2018). The choice of method depends on the type of automotive catalytic converter. In the world today, there are mainly two methods used to process automotive catalytic converters by pyrometallurgical or hydrometallurgical means. Mixed methods are also used, consisting of multiple intermediate pyro- and hydrometallurgical operations, with the goal of separating pure metal. The process of recycling automotive catalytic converters involves most of the entities that make up the end-of-life vehicle-recycling network. In broad terms, recycling network entities include all entities that participate directly or indirectly in the vehicle end-of-life process. In a narrow view, recycling network entities include only entities directly involved in SWE processing (disposal and disposal), these are vehicle collection points, dismantling stations, industrial mills and material recovery companies (material recycling plants).

Platinum Group Metals, mainly platinum, palladium and rhodium, stimulate carbon monoxide, hydrocarbons and nitrogen oxides contained in exhaust gases to react, resulting in the reduction of harmful emissions (Directive 2000/53/EC). PGMs convert CHx and CO to CO_2 and H_2O. Rhodium in the catalyst reduces the NOx to N_2. On average, the PGM content in automotive catalyst cartridges ranges from 0.2 to 0.3 percent, depending on the age of the vehicle and the type of fuel burned (Sun et al. 2022). Catalyst recycling processes are geared towards the recovery of precious metals for reuse (Trinh et al. 2020). The recycling of automotive catalytic converters enables the recovery of up to 95% of platinum metals contained therein, and also, in comparison with traditional mining, saves considerable amounts of energy (the processing of 1 ton of used catalytic converters prevents the extraction of 150 tons of ore or, alternatively, 400 tons of waste rock) (Moschovi et al. 2018).

Since the use of automotive catalysts began, the demand for platinum group metals has dominated the market for platinum and rhodium (Molnár and Papp 2017). In 1989, the USA consumed around 32,094 kg of platinum group metals with 6,594 kg recovered. In 1997, the annual demand for PGMs in this sector reached the level of 120,000 kg (52,000 kg for platinum, 65,000 kg of palladium and 1,000 kg of rhodium) (Resano et al. 2015). Nowadays, we can talk about the demand for PGMs in this sector about 422,700 kg (90,600 kg for platinum, 301,000 kg for palladium and 31,000 kg for rhodium) (data for 2019). Spent catalysts from cars have about 1 kg of PGMs per 1,000 kg of catalyst (Moschovi et al. 2021). Although in the first twenty years of using catalysts in cars, it consumed more than 568,000 kg of PGMs (just in the USA) and legislations there (as well as in many other countries) requires the removal of catalysts before crushing the scrap vehicles, only 56,800 kg of PGMs have been recovered (Knobloch et al. 2018). In 2019, an amount of 149,800 kg of PGMs was recovered (Tercero et al. 2020).

Different sizes of automotive catalysts contain different amounts of platinum group metals used for catalytic materials. Usually the ranges are: 3–7 g of Pt, 1.5–5.0 g of Pd and 0.8–1.5 g of Rh (Tercero et al. 2020). However, this consumption corresponds to amounts of 50% of globally produced platinum, 80% of globally produced palladium and 80% globally produced rhodium (Paiva et al. 2022). This causes automotive catalytic converters to be a very important secondary source of PGMs. With the development of the car industry, catalysts for automobiles cover the largest market share of platinum group metals with the consumption of Pt, Pd and Rh over 45, 67 and 85% of their global demand in 2016, respectively (Generowicz et al. 2021). The world reserves of PGMs are very rare and scarce (only about 69,000 Mg) and 99% of them are in South Africa, Canada, Russia, America and Zimbabwe (de Oliveira Demarco et al. 2020). The concentration of PGMs in these sources is very low, usually in the range of between 2 and 10 ppm (g/t) and are usually obtained as coproducts (Saternus et al. 2020). In South Africa, for example, there have been many challenges facing the mining industry (Nicol et al. 2021). Current exploitation has decreased worldwide. In the Bushveld Complex, it has been noted that the ore grade has decreased from 2.8 g/t to 0.7–1.4 g/t. With the increase of car industry needs, in the long-term, these resources will not meet tchem (Nicol et al. 2021). This is especially true because of their rapid depletion of high-grade and low-grade ores and that remaining ores have low concentration, which makes the mining process unprofitable from both economic and environmental perspectives (Wilburn and Bleiwas 2005). Furthermore, other countries suffer from lack of PGMs and have to overcome a serious supply risk. Recently, the number of discarded cars has increased and subsequently more than 80,000 Mg of spent auto-catalysts are available in the world for recycling, and in addition, these secondary sources have a higher concentration of PGMs that can be extracted than natural ores (Yakoumis et al. 2018). The change between The Euro 1 and Euro 4 standards show that the average PGM loading in a 1.4–2 l gasoline vehicle rise from the level of 2.04 to 3.99 g/car. It illustrates the importance of the recycling of catalytic converters and its impact on PGM market. These aspects make the primary producers economically disruptive. Together with catalysts' limited lifetime, this means that spent catalysts have become the most significant source of secondary PGMs, but to estimate the efficiency and profitability of the extraction procedure of metal from catalytic converters substrates, it is crucial to know their concentration in the original sample (Yakoumis et al. 2018).

2. Innovative catalyst recycling projects

Rising precious-metal-mining prices and changes in recycling regulations in European Union countries are resulting in a requirement to recover platinum from used automotive catalytic converters (Tercero et al. 2020). In Poland, the processing of used catalytic converters on a production scale is virtually non-existent as only a few companies are engaged in processing platinum as a secondary raw material (Nicol et al. 2021). The process of recovering platinum (Pt, Pd and Rh) from catalysts from recycled auto parts in the domestic market is mainly performed abroad (Generowicz 2021). There are successfully implemented projects with the primary goal of implementing the principles of a circular economy, taking care of environmental aspects and creating innovative facilities for processing catalysts. One example of innovative projects implementing the above-mentioned assumptions is the PHEIDIAS project (EIT KIC RAW MATERIALS) (PHEIDIAS project b) and the project with the acronym container (NCBiR) (Unimetal Recycling Company 2022).

PHEIDIAS aims to bring an innovative hydrometallurgical process into the market for the recovery of platinum group metals (PGMs) from spent vehicle catalytic converters (SVCCs). This technology offers an increased material recovery rate and significantly lower operational costs, as the recovery rates of PGMs from SVCCs, namely platinum (Pt), palladium (Pd), and rhodium (Rd), have already reached ~98, ~98 and ~60% respectively. This novel process requires significantly less energy loads than the pyro-metallurgical processes mostly employed in the ESEE region. Furthermore, waste management performance is improved, as this innovatory technology uses solvents in lower concentrations.

The project will focus on the markets of Greece, Poland, Hungary, Bulgaria, Slovakia, Slovenia, Romania, Cyprus, and Serbia, where project partners have already developed a network of SVCC suppliers through their previous collaboration in other initiatives. To that end, partners will upscale and pilot-test the proposed technology on large-scale operation conditions, bringing it from Technology Readiness Level (TRL) 5 to TRL 8 during the project, commercializing it within one year following project completion (TRL 9), in 2023 (PHEIDIAS project a).

In Poland, there are many companies dealing with recovery of valuable raw materials from waste. One of the company focusing its activity on the area of recycling from vehicles is Unimetal Recycling. This company, using the potential of very high automotive recycling recovery rate (ca 85% of the vehicle's total weight is recycled), deals with the purchase and processing of used catalytic converters since most precious metals are recovered in the catalyst recycling process. The most commonly used catalysts have a ceramic structure coating which is the substrate for PGM elements (very fine particles). Platinum and palladium are used to oxidize carbon monoxide and hydrocarbons, and rhodium is used to reduce nitrogen oxides. Depending on the requirements of car manufacturers, various combinations and concentrations of metals from the PGM group are used in catalysts (from 0.1 to 0.5%).

Unimetal Recycling specializes in the recovery of platinum, palladium, and rhodium from automotive catalysts. Over the course of their almost twenty years of experience, the company has created procedures and qualified staff and introduced and improved processes in order to obtain the largest amounts of precious metals for reuse as well as having established a network of almost 100 partner offices in Poland and several dozen abroad (Europe, Africa and Asia).

The company operates in accordance with the principles of sustainable development, combining innovative technological solutions with environmental protection and social responsibility. Fair, ethical and transparent rules of cooperation with many domestic entities and new business models enable dynamic development. Unimetal introduces new investments not only in technology, but also in human capital, which is the most valuable resource. The raw material produced in the technological processes conducted in the company is a commodity characterized by a high degree of fragmentation and purification; therefore, it is possible to conduct cooperation on the basis of permanent contracts only with recognized partners who are the best in the world. The main raw material goes to a Japanese smelter, one of five similar factories in the world, with which the company has a supply contract. Since there is a constant shortage of the raw material produced by the company in the world, its marketability is very easy and fast.

The shortage of critical raw materials on the one hand and very high automotive recycling recovery rate and possibility of recovering most precious metals from catalytic converters on the other hand generate the interest of companies in the recovery of valuable raw materials from automotive catalysts.

The adaptation of the circular economy policy and instruments encourage Polish companies to implement strategies and technologies that enable obtaining the largest amounts of precious metals for reuse. Unimetal is constantly improving its operations, focusing on high quality and increasing its competitive position. From the beginning of its existence, it has been conducting process analysis, which enables the improvement of productivity and the increase of profits.

Unimetal Recycling is carrying out a project with the acronym container entitled "Development of an innovative fully automated and mobile catalyst recycling technology". Thanks to the launch of the mobile containers developed as part of the project, the company will be able to provide its services in multiple locations simultaneously. Moreover, thanks to such a solution, Unimetal will not only expand the area of its operation but also the target group. It is planned that the mobile container will change its location once a month so that a large group of customers can benefit. Smaller vehicle disassembly stations will be able to sell catalytic converters directly to Unimetal, thus avoiding middlemen, which will result in greater economic efficiency. Furthermore, the company's services will also be available to entities for which, until now, transporting catalysts was unprofitable due to the long distances separating them from Unimetal's headquarters. The implementation of the project, thanks to automation, will enable easier the processing of material and will reduce logistics costs and will allow the reduction of random factors, risks and emissions. The device assumed for development, which has a semi-automatic trimming system and an automatic dust absorption system in an open-air container housing, is an unprecedented solution. Moreover, by automating the recycling process, it is planned to reduce the human factor in the process to a minimum. The research process of the ongoing project leads to the development of a universal and weatherproof solution, with the assumption of it being operated by one person. The module provides the ability for the operator to work without additional training and provides the ability to perform the entire range of recycling work without external tools, according to the concept of a single automated mobile device, thus shortening the path from the customer to the end of the recycling process. A model of the entire catalyst processing line is shown below (Figure 2).

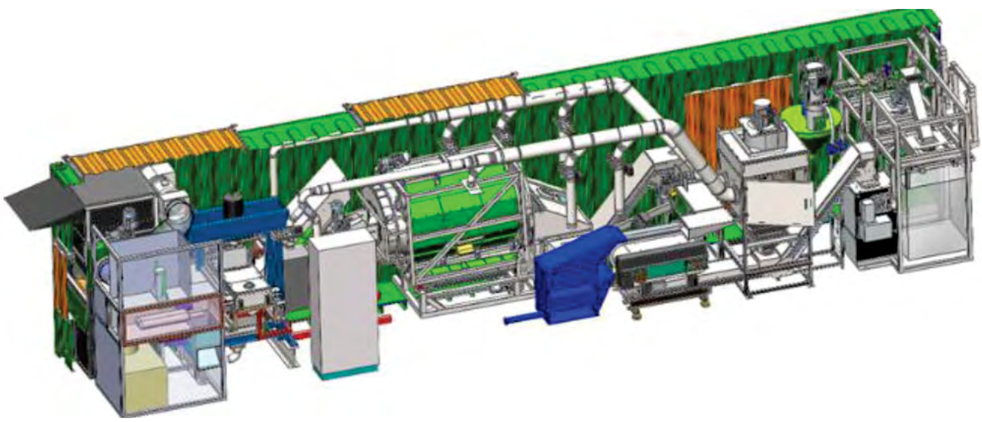

Fig. 2. Model of catalyst processing line
Source: Unimetal Recycling 2022

Rys. 2. Model linii technologicznej do przetwarzania katalizatorów

The process line consists of individual modules:

1. Module for receiving and batching raw material for recycling
   The material to be recycled is delivered in very different forms, most often, catalytic converters arrive with piping components so they must be properly prepared for the recycling process before it begins. For this purpose, a system was designed to remove unnecessary exhaust components, which was built inside the container. The process is conducted through the use of hydraulically driven shears. The cutting process is dangerous, so the module for receiving and portioning the raw material had to be properly protected.
2. Pre-drying and purification process module, along with pre-weighing and feeding system
   The catalyst is pre-cut to size and placed in the batch container of the column feeder – at this point, the size of the catalyst is verified by laser sensors. During the transport of the catalyst by the bucket conveyor, drying and cleaning of the surface of the catalyst from loose rust or from any lingering impurities is conducted. The preparation of the feedstock and the removal of any loose contaminants positively affects the quality of the final product. Moisture is removed through an electric dehumidifier. Contaminants are absorbed by a lamella filter replaceable from the front of the container. Keeping the material in a constant moisture range improves the efficiency of the grinding process and the separation of the ceramic monolith from the housing. The cleaned and dried catalyst goes to the scale, there – in order to document the customer's material and control the operation of the device – a photo of the weighed element is taken, and the element itself is successively transported to the feeder heap.
3. Module of the compact catalyst grinding system to obtain the appropriate fraction
   The next stage of catalyst processing is the grinding of the feedstock and the initial separation of the ceramic monolith from the steel casing. This stage is performed by a guillotine module and a shaking drum. The pre-weighed component goes to the guillotine feeder, with which the catalyst is transported to a specific position under the guillotine, where it is then cut. Thanks to the repeated cutting, it is possible to reduce the surface area of the catalyst housing, and thus the size of rigid elements, i.e. sheets and castings, is reduced at the beginning of the process, which has a positive effect on the realization of the milestone. The catalyst in the feeder is moved by using two sliding plates driven by servo motors.

During the implementation of the project, a number of tests were conducted to verify the effectiveness of the various proposed design solutions, as well as to eliminate the risks that could arise during the subsequent use of the dust collection system – extraction.

The developed solution will make it possible to increase the company's productivity and area of operation without a significant expansion of the company's infrastructure. The container-sized unit contains all the necessary machinery and equipment for catalyst recycling. The newly developed technology within the project is designed to facilitate material processing and reduce logistics costs. Automation will reduce recovery costs by reducing human labor and the time required to dismember catalysts and completely homogenize the material. The automated process makes it possible to apply an innovative approach to the problem of recovering dust deposited on filters in each of the catalyst processing stages. In addition, the new solution will take into account environmental aspects directly related to a circular economy. By placing the equipment in a closed environment, emissions and noise levels generated by the equipment will be reduced. The developed products will contribute to a significant improvement in competitiveness, strengthening the company's market position in Poland and worldwide.

The use of this type of solution is not found in the catalytic-converter recycling market and is also unheard of in the entire recycling industry, which is based practically only on storage points and centralized high-capacity lines. While there are simple portable facilities for recycling in general, they cover one to two stages of the process without control of the working atmosphere or proper and comprehensive process supervision. It is also possible to minimize the negative impact on the environment to a small extent due to the operations and manual activities performed. The installation focuses on reducing the proportion of human labor in hazardous processes and reducing the environmental impact by reducing transportation and decreasing dust emissions. It also maximizes the chances of obtaining raw material from the market by facilitating access for individual customers and giving direct feedback on its quality. The obtained raw material, which includes valuable precious metals (i.e. platinum, palladium and rhodium) is the basic feedstock for the metallurgical process of catalytic element recovery. The operation of the planned solution is completely different from currently used industrial processes. One of the main tasks is to perform recycling processes as close as possible to the storage site and ensure easy access and customer confidence in a transparent technology.

The result of the project will be one comprehensive device that performs the entire process on small batches (tailored to local customers) in a closed environment and without human intervention. This offsets the tedious process of storing and normalizing raw material (catalysts), and reduces the number of intermediate containers, and dust losses. Nowadays, the use of containerized construction is becoming an increasingly popular way of utilizing both space resources and an innovative approach to placing various pieces of equipment in containers, and thus using this type of construction for a variety of needs. However, to date, no one in the Polish or global markets has yet used containerized bodies to perform processing that enables the recycling of platinum group precious elements from used car catalytic converters. The mobile, modular construction of individual automatic workstations implemented by Unimetal Recycling, assembled in a container body, will create conditions for the more effective implementation of the recycling process of used catalytic converters over a much larger area of the country (at a further stage, beyond the borders). The novelty and innovativeness of the solution in the market lies in the automation of each stage of processing starting with the grinding of the catalyst, the separation of individual streams of the resulting differentiated materials and ending with the assumed functionality of dust recovery from each module. In processing organized on a fairly large scale, the traditional approach requires sufficient space, the construction of extensive processing halls and the provision of adequate infrastructure and personnel.

In the processing of catalysts, the most important task is to recover the ceramic monolith containing sputtered catalytic precious metals. Their precise amount can be estimated with very fine grinding and their proper homogenization, so that the samples taken for spectrometric studies are as adequate (representative) as possible for the entire portion of the material. Such material dispersion conditions will be created in the device to make it directly suitable for spectrometric analysis. This is also a novelty compared to the currently implemented method of material evaluation, in which only a small portion from the entire pool of material is ground to the appropriate granulation for analysis. An additional aspect of such significant milling is the reduction in the size of the space needed to collect the raw material produced. An important aspect of the plant's innovation is the establishment of a mobile laboratory. The method of sampling the material (whether pneumatic or mechanical) and determining the location in the hopper with the homogeneous mass developed through experience is expected to create a reliable method of analysis.

Conclusions

Since the Polish market lacks modern and innovative catalytic-converter recycling facilities, the presented modern green solutions provide a certain point of reference for potential entities that would establish a viable PGM-recovery network. According to EU regulations and directives, there is a requirement for Poland to meet the appropriate levels of recycling and the recovery of waste from end-of-life vehicles (85% for recycling, 95% for reuse and recovery per vehicle weight). In addition, EU regulations require the manufacturers of cars and their parts to use recycled or recovered materials or raw materials for production. In view of these requirements, players in the automotive and waste management market should in the near future strive to create innovative technological solutions. However, activities in the area of catalyst recycling and the recovery of platinum from used automotive catalytic converters will primarily require the development of appropriate strategies and the implementation of industrial research in cooperation with science.

Some of the arguments in favor of recovering platinum-arsenes from automotive catalytic converters include their limited resources, their rarity, the costly and energy-intensive extraction process, and the significant amount of waste generated in the process. The recovery of spent catalysts also has other advantages; it reduces the amount of landfilled waste and the level of atmospheric emissions is lower during the processes of obtaining metals from waste materials than in the technology of obtaining them from virgin raw materials. For the implementer, the recovery technology is a product/service, and like any other enterprise activity, it is expected to provide the enterprise with financial benefits and a competitive advantage.

If companies implement a new technology for recycling catalytic converters and recovering platinum from automotive catalytic converters in Poland, this will allow them to fill a niche in the market, which will also significantly affect the image of the entrepreneur.

The implementing entity will be eager to adopt platinum recovery technologies from car catalytic converters knowing that there are no entities in the Polish market dealing with this. An entrepreneur considering launching a new technology also considers what market risk is involved and what opportunities there are to minimize the risk.

Due to the need to achieve appropriate levels of recovery, it is important to support entrepreneurs undertaking the implementation of innovative technologies and modern solutions.

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INNOVATIVE TECHNOLOGIES FOR THE RECOVERY OF PLATINUM GROUP METALS FROM CATALYSTS – A CASE STUDY OF SELECTED PROJECTS

Keywords

recovery of PGMs, recycling, catalysts, innovative technologies, circular economy

Abstract

The growing increase in the use of cars and transportation in general is causing an increase the emission of pollutants into the atmosphere. The current European Union regulations impose the minimization of pollution through the use of automotive catalytic converters on all member countries, which stops toxic compounds from being emitted into the atmosphere thanks to their contents of platinum group metals (PGMs). However, the growing demand for cars and the simultaneous demand for catalytic converters is contributing to the depletion of the primary sources of PGMs. This is why there is now increasing interest in recycling PGMs from catalytic converters through constantly developing technologies. There are newer and more sustainable solutions for the recovery of PGMs from catalytic converters, making the process part of a circular economy (CE) model. The purpose of this article is to present two innovative methods of PGM recovery in the framework of ongoing research and development projects.

INNOWACYJNE TECHNOLOGIE ODZYSKU METALI GRUPY PLATYNOWCÓW Z KATALIZATORÓW – STUDIUM PRZYPADKU WYBRANYCH PROJEKTÓW

Słowa kluczowe

odzysk PGMs, recykling, katalizatory, innowacyjne technologie, gospodarka o obiegu zamkniętym

Streszczenie

Rosnący wzrost wykorzystania samochodów i generalnie środków transportu przyczynia się do emisji zanieczyszczeń do atmosfery. Obecne przepisy UE narzucają na wszystkie kraje członkowskie minimalizacje zanieczyszczeń poprzez stosowanie katalizatorów samochodowych, które dzięki zawartości metali z grupy platynowców (PGM) zatrzymują toksyczne związki przed emisji do atmosfery. Jednak rosnący popyt na samochody i jednoczesny popyt na katalizatory przyczynia się do zubożania pierwotnych źródeł pozyskiwania PGM. Dlatego też obecnie coraz więcej mówi się o recyklingu PGM z katalizatorów poprzez ciągle rozwijające się technologie. Powstają coraz nowsze, bardziej zrównoważone rozwiązania odzysku PGM z katalizatorów, dzięki czemu proces ten wpisuje się w model gospodarki o obiegu zamkniętym (CE). Celem artykułu jest przedstawienie dwóch innowacyjnych metod odzysku PGM w ramach prowadzonych obecnie projektów badawczo-rozwojowych.