

Environmentally friendly disposal of used automotive oil filters: legislative aspects and technology

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Abstract. Due to external environmental concerns, new European Union (EU) legislation is currently increasing the requirements for the disposal of vehicles and their used components. Used automotive oil filters (UAOF) are both a threat to the environment and contain valuable components for reuse. Waste minimization, their environmentally safe disposal, neutralization, utilization and conservation of natural resources is an urgent global problem. It is the legislative rationale for solving this problem and the search for an environmentally friendly UAOF recycling technology that is the purpose of this study. The legislative aspects were studied by reviewing the current regulatory and legislative documents of Ukraine and the EU countries, as well as scientific literature. The reviewed scientific literature was collected from three main databases: Scopus, Web of Science, ResearchGate, where the corresponding keywords. It was found that the current legislation in the field of waste management is not perfect and has many gaps and contradiction. The search for environmentally friendly technology was carried out in different temperature conditions and using different amounts of detergents, which made it possible to determine the most effective detergent sodium percarbonate ($\text{Na}_2\text{CO}_3 \cdot 1.5 \text{H}_2\text{O}_2$) – a chemical compound that is a safe and convenient carrier of hydrogen peroxide. As a result of the conducted theoretical and experimental researches the complex utilization technology of UAOF and the detailed algorithm is presented. The scheme process plant for washing the contaminated filter paper and the washing technology, which allows retrieving resource valuable components, has been developed. It is experimentally proved that pre-treatment of the filter paper with a washing solution allows reducing the number of pollutants, namely the content of waste oil is reduced by 55%, and the number of pollutants in the flue gases by 89% of sulphur (IV) oxide, 15% of nitrogen (IV) oxide, 66% of carbon (II) oxide, 86% of carbon (soot).

Keywords: used automotive oil filters, detergent, utilization, recycling, toxic gases.

1. Introduction

Today there are about 800 million cars in operation in the world, and according to experts, by 2035 their number will increase to 3 billion units. According to international standards, the allowable service life of cars is 10 years, after which they must be sent for recycling. In addition to air pollution, global motorization has added another problem

to humanity: cars that have expired. Much of the mass of each of them are recycled, but up to 7 million tons of unused wastes, among which a significant amount are car components, are found worldwide annually (Andersson et al., 2017; Vambol et al., 2016; Ortego et al., 2018; Vambol, 2016; Millet et al., 2012). This problem needs to be addressed immediately, since the continued accumulation of hazardous waste such as car parts made of polymers and composite

materials, as well as UAOF, contributes to the environment degradation (Guerrero et al., 2013; Sokolov et al., 2018; Karak et al., 2012; Ziarati et al., 2020; Zia et al., 2017). The International Organization for Standardization (ISO) has developed requirements for the assessment and management of environmental safety of products for its full „life cycle”, which includes the stages of extraction of raw materials, manufacturing, energy production, use and disposal. World practice shows that the owner pays for the disposal of the car (when buying it) (ZRSA, 2006; Simic & Dimitrijevic, 2012; Zhou et al., 2016).

All vehicle waste is hazardous to the environment and, at the same time, has a resource potential (Vambol et al., 2018b). Old car bodies, used batteries, UAOF, and other components must be collected and recycled. Dangerous elements are paper, waste oil, and mechanical impurities. One of the most important points in ensuring the safety of ecosystems in the context of natural processes is to prevent their contamination by, particularly hazardous substances. As a result of the operation of cars, there is a large amount of the fulfilled materials where filters for oil clearing are a waste which is polluted with oil and products of wear of the engine (UAOF). Therefore, it is necessary to establish a system of collection and recycling of vehicle waste (high-tech garbage), which in turn will provide a significant reduction in pollution of urban areas with petroleum products, heavy metals and will provide raw materials for further use in industry (Hanoshenko & Holik, 2018b).

The scientific approach to the issues of automotive waste management involves the use of traditional and innovative technologies. Minimization of waste generation, their environmentally safe disposal, neutralization, utilization, and saving of natural resources is an urgent global problem. The choice of an environmentally safe way of handling such waste should be based on the possibility of reusing the components that are part of them, in order to reduce the man-made load on the environment.

Therefore, the development of a comprehensive environmentally friendly technology for the disposal of UAOF, which will reduce the man-made impact on the environment, is an urgent scientific and applied task in the field of environmental safety (Vambol et al., 2018a).

When choosing a priority method of automotive waste management should take into account the possibility of reuse of components that are part of such waste, as well as minimize their amount. The experience of the Baltic countries, Poland, the United States, Japan, and others are covered in studies by foreign experts (Rainkhard, 2007; Zbychynskyi et al., 2014; Vyller, 2005). Improved car recycling technology after the end of its service life can serve as an important strategy for the use of exhaustible resources. This is due to the increased

demand for scarce metals (Ohno et al., 2015). Used tires and their accumulation are a global environmental problem (Ryzhkov et al., 2017; Vambol et. al., 2018b; Markina & Kryva, 2018). Such wastes are not biodegradable, and about 1.5 billion units are generated annually (Mohajerani et al., 2020).

With regard to the disposal of directly used automotive oil filters (UAOF), it is necessary to note the methods and systems for the disposal of used oil and fuel filters. In (Schmidt, 1998) it is proposed to grind and then burn UAOF, in (Bogacka et al., 2016) – after cutting immersed in a solvent. The method described in (Babenko & Vlasov, 2000) includes clamping by means of a clamping device of the oil filter housing, cutting the housing into a casing and a base, separating from each other, as well as separating from it the internal elements of the oil filter. The considered methods and techniques are based on the grinding, partial separation of some elements, and combustion, which requires inclusion in the disposal process of an expensive and complex system of gas emissions treatment, which makes the relevant research not appropriate.

An option to overcome these difficulties may be to recycle the oil filter, in which all its parts can be separated, processed, and reused. This approach is used in (Wen-Cheng, 2008), but there is a difficulty with a large number of types, models, sizes of automotive oil filters.

A small number of companies are engaged in the processing of automotive oil filters in different countries. Most of them combine the utilization of filters with the regeneration of waste oils and energy from incineration and recycling of other hazardous waste (Gaidajis et al., 2011). The problem of processing oil filters is the complexity of their morphological composition and therefore for effective disposal, it is necessary to divide the filter into separate fractions.

Among the methods of UAOF utilization we can distinguish the main ones: squeezing the oil from the filter, burning the filter, grinding the filter with separation into fractions, a gradual separation of the filter into components with their subsequent utilization (NC, 2009; OFC, 2020; OFR, 2020; LLI, 2013; Cleanaway, 2019).

The review of the current state of solving the problems of the impact of the waste of the motor transport complex demonstrates the high level of study of various aspects as separate scientific directions. There is reason to believe that the existing technologies for the disposal of a particularly dangerous component of UAOF – contaminated filter paper – are insufficiently defined. This component simultaneously poses a threat to the environment and contains valuable components that can be separated for reuse. This allows us to argue about the feasibility of conducting research in this direction.

2. Materials and Methods

The legislative aspects were studied by reviewing the current regulatory and legislative documents of Ukraine and the EU countries, as well as scientific literature. The reviewed scientific literature was collected from three main databases: Scopus, Web of Science, ResearchGate, where the corresponding keywords related to the disposal of used vehicles and emissions of toxic and greenhouse gases were used for the search, therefore the keywords „used vehicles” and „legislation” was combined with: utilization, regulations, greenhouse gases, Ukraine, EU countries. Scientific articles written in any language from 2015 to the present were considered. In addition, additional publications were taken into account, which were identified by links in the discovered publications. The most important available reports and unpublished documents were also consulted with fellow practitioners, stakeholder representatives and experts.

In most cases, thermal disposal systems in special furnaces and installations are used to dispose of contaminated UAOF paper. The process of thermal disposal is accompanied by the formation of a large number of pollutants, especially soot, solid undifferentiated particles, volatile organic compounds, and others. Therefore, it is advisable to use a pre-separation of waste oil from filter paper, which will reduce the man-made load on the atmosphere by reducing the number of pollutants formed during combustion.

Studies have been conducted in different temperature conditions and using different amounts of detergents, which made it possible to determine the most effective detergent sodium percarbonate ($\text{Na}_2\text{CO}_3 \cdot 1.5 \text{H}_2\text{O}_2$) – a chemical compound that is a safe and convenient carrier of hydrogen peroxide.

The technology of incineration of waste filter paper must meet environmental requirements. The criterion of compliance is the provision of concentrations of harmful substances in the surface layer of the atmosphere on the territory of the object and outside the sanitary protection zone below the maximum one-time MPC (maximum permissible concentration) of these substances. The incineration of the filter paper was carried out in accordance with environmental requirements, and the results were confirmed by means of devices that determine the concentrations of pollutants in the flue gases. Determination of soot concentrations was performed using the gravimetric method using an aspirator with a filter cartridge. A gas analyzer was used to determine the temperature and composition of flue gases Testo 350 S with a range of temperature measurements from -40°C (313.15K) to $+1200^\circ\text{C}$ (1473.15K). Emission sampling was performed using a dust intake tube. The concentrations of sulphur (IV) oxide, nitrogen (IV) oxide, carbon (II)

oxide, carbon (soot) were determined in the work; the corresponding average concentrations of these substances in flue gases were experimentally established.

3. Results and Discussion

3.1. Legislation

The main legislative and regulatory acts that operate in the field of handling vehicles that have reached their end of life are:

- Constitution of Ukraine (CU, 1996);
- Law of Ukraine „On Waste” dated 5.03.1998 No. 187/98-BP with amendments and additions (ZU „Pro vidkhody”, 1998);
- Law of Ukraine „On Automobile Transport” dated 05.04.2001 No. 2344-III (ZU „Pro avtomobilniy transport”, 2001);
- Law of Ukraine „About scrap metal” dated 05.05.1995 No. 619-XIV with amendments and additions dated 16.09.2012 (ZU „Pro metalobrukht”, 1995);
- Resolution of the Cabinet of Ministers of Ukraine „Some issues of collection, disposal, neutralization and disposal of waste oils (oils)” dated July 27, 2011 No. 1075 (Postanova No. 1075, 2011);
- Order of the Ministry of Ecology and Natural Resources of Ukraine 04.11.2011 No. 431 „On approval of the licensing conditions for the implementation of economic activities for the collection, preparation of certain types of waste as secondary raw materials” (Order No. 431, 2011);
- Resolution of the Cabinet of Ministers of Ukraine „On uniform requirements for the design and technical condition of wheeled vehicles in operation” dated December 22, 2010 No. 1166 (Postanova No. 1166, 2010);
- Resolution of the Cabinet of Ministers of Ukraine „On approval of the list of certain types of waste as secondary raw materials, the collection and procurement of which are subject to licensing” dated February 28, 2001 No. 183 (Postanova No. 183, 2001);
- Resolution of the Cabinet of Ministers of Ukraine „On the introduction of a system for the collection, preparation and disposal of waste as secondary raw materials” dated July 26, 2001 No. 915 (Postanova No. 915, 2001).

According to Article 16 of the Constitution of Ukraine, ensuring environmental safety and maintaining environmental balance on the territory of Ukraine is the responsibility of the state. In accordance with Article 41, everyone has the right to own, use and dispose of his

property, the results of his intellectual, creative activity. The use of property cannot harm the rights, freedoms and dignity of citizens, the interests of society; worsen the ecological situation and the natural qualities of the land (CU, 1996).

The Law of Ukraine „On Waste” defines the legal, organizational and economic foundations of activities related to the prevention or reduction of waste generation, collection, transportation, storage, sorting, processing, disposal and disposal, neutralization and burial, as well as with the negative impact of waste on the environment and human health on the territory of Ukraine. This law regulates relations related to the formation, collection and procurement, sorting, transportation, storage, processing (processing), disposal, disposal, neutralization and burial of waste generated in Ukraine, transported through its territory, removed from it, as well as with transportation, processing and disposal of waste imported into Ukraine as secondary raw materials.

According to Article 5 of the Law of Ukraine „On Waste”, entitled „Basic principles and directions of state policy in the field of waste management”, the priority principles of state policy in the field of waste management include the protection of the environment and human health from the negative impact of waste, ensuring economical use material and raw materials and energy resources and waste in order to ensure sustainable development. Consequently, according to Ukrainian legislation, complete collection and timely neutralization and disposal of waste must be ensured, as well as environmental safety rules must be observed when handling them and facilitated to the maximum possible waste disposal through direct reuse or alternative use of valuable waste. Also, this law defines the specifics of regulating relations with respect to the handling of uncaptured gaseous substances that are emitted directly into the air, substances discharged with wastewater into water bodies, as well as secondary material or energy resources and other waste.

In Ukraine, most vehicles that have lost their operational value are handed over for scrap, certain parts of the vehicle are removed and processed as secondary raw materials or disassembled into spare parts and sold, and the rest of unnecessary parts and materials, oils, as a rule, are taken to landfills (Vambol et al., 2019). This situation is associated with the economic disadvantage of processing a whole vehicle, the lack of special processing technologies, an appropriate control system for the processing process and reporting on processing rates and residues from the processing of vehicles with a spent resource.

In accordance with Ukrainian legislation, mixing or burial of waste is prohibited, for the disposal of which there is an appropriate technology in Ukraine. It is prohibited to unauthorized dumping and disposal of waste, including household waste, in underground horizons, on the territory

of cities and other settlements, on the territories of a nature reserve fund, on lands of nature conservation, health-improving, recreational and historical and cultural purposes, within water protection zones and zones sanitary protection of water bodies, in other places, can pose a danger to the environment and human health. EU regulations also limit the amount of waste sent to landfills to the required minimum. To support the EU’s transition to a circular economy, the Landfills Directive (IWFD, 2018):

- Introduces restrictions on the disposal of all recyclable waste or other materials or energy recovery from 2030;
- Limits the share of household waste disposal in landfills to 10% by 2035;
- Introduces rules for calculating the achievement of targets for municipal waste and requires EU countries to implement an effective quality control and traceability system for the disposal of municipal waste;
- Requires the European Commission, together with the European Environment Agency, to draw up early warning reports 3 years before each deadline in order to identify deficiencies in achieving targets and recommend actions to be taken;
- Allows EU countries to use economic instruments and other measures to encourage the use of the waste hierarchy.

At the same time, the current legislation in the field of waste management is not perfect and has many gaps and contradictions.

Ukraine has been a member of the European Union’s Eastern Partnership program since 2009, and in recent years has begun to actively implement common European approaches, including in the field of waste management. One of the areas of successful implementation of European approaches in this sphere is the comprehensive revision of legislation in order to take into account the provisions of EU directives and the practice of organizing an integrated waste management process. First of all, it is necessary to bring the framework law on waste in line with EU legislation, as well as to harmonize the provisions of the Law of Ukraine „On scrap metal” and the Law of Ukraine „On waste”.

In a common waste management strategy, the European Commission has sought to combine environmental and industrial interests with the aim of reaching a consensus on how to deal with significant waste such as used vehicles. Following a second reading by the European Parliament, Directive 2000/53/EC was slated for adoption during 2000, with the automotive industry still opposing its main provisions (Directive 2000/53/EC, 2000). Directive 2000/53/EC on end-of-life vehicles was published on October 21, 2000. It is motivated by concern for the environment and requires that 85% of each vehicle scrapped by weight be scrapped by 2006 and 95% by 2015 (Kazmierczak et al.,

2004). The motive is therefore to encourage manufacturers to redesign their products to avoid the use of hazardous materials and to make recovery and reuse as easy as possible (Ashby, 2016; ELV, 2000). As required by national legislation, the following parts and materials with or without low market value must be dismantled or separated: fuel, antifreeze, oils, oil filters, brake fluids, starter batteries, tire rim balancing weights, air conditioning – equipment, airbags and belt tensioners, mercury switches, radioactive materials, catalysts, tires (Kazmierczak et al., 2004).

Some of the provisions of Directive 2000/53/EC include:

- EU countries establish the necessary system and appropriate structures for the collection of disused vehicles and used parts, and also ensure that manufacturers (manufacturers or direct importers) cover all or most of the associated costs;
- EU countries ensure that only authorized (certified) organizations are involved in the disposal of ELVs;
- The EU countries are striving for the coefficient of reuse and recycling of components and materials contained in one ELV, as of January 1, 2006, to be 85% of its mass, including the production of thermal energy due to the combustion of a part of car shredding residues (USA), or 80% of its mass without burning. For cars manufactured before January 1, 1980, this ratio must be at least 75% with combustion and 70% without it. And as of January 1, 2015, this coefficient should be 95% including combustion and 85% without combustion;
- EU countries ensure that car manufacturers used standard coding of parts and materials on cars for the convenience of their recognition and subsequent disposal and provided information about such materials and the procedure for their dismantling to interested organizations no later than 6 months after the appearance of these cars on the market;
- In order to reduce environmental pollution, the EU countries, since July 1, 2003, do not allow the sale of cars, in the manufacture of which lead, mercury, cadmium and hexavalent chromium are used, and encourage manufacturers to make cars from recycled materials.

Recyclability of component parts, recyclability and/or recovery of materials form an essential part of the EU's waste management strategy. Therefore, vehicle manufacturers and their suppliers should be asked/obligated to include these aspects at the earliest stages of the development of new vehicles in order to facilitate the handling of vehicles as they reach the end of their useful life (Directive 2005/64/EC, 2005).

In order to bring Ukrainian legislation in line with EU legislation in the field of waste management, it is necessary to remove the existing definitions of „waste” and

„hazardous waste”, „disposal” and replace them with the approach of Directive 2008/98/EC, establish waste categories (Annex I to Directive 2008/98/EC), a list of waste disposal operations (Annex IIA to Directive 2008/98/EC), a list of waste disposal operations (Annex IIB to Directive 2008/98/EC), introduce a five-step hierarchy of priorities in dealing with waste management issues, introduce public registers of all waste management businesses (carriers, recycling and disposal operators, their dealers and waste management intermediaries) in order to take into account Directive 2008/98/EC (Directive 2008/98/EC, 2008).

Directive 2000/53/EC covers the basic concepts:

- „treatment” means any activity after the end-of life vehicle has been handed over to a facility for depollution, dismantling, shearing, shredding, recovery or preparation for disposal of the shredder wastes, and any other operation carried out for the recovery and/or disposal of the end-of life vehicle and its components;
- „reuse” means any operation by which components of end-of life vehicles are used for the same purpose for which they were conceived;
- „recycling” means the reprocessing in a production process of the waste materials for the original purpose or for other purposes but excluding energy recovery. Energy recovery means the use of combustible waste as a means to generate energy through direct incineration with or without other waste but with recovery of the heat.

The definition of the term “recycling” differs between member states and in certain regions of the EU. Due to the lack of a single definition of “recycling” and “energy recovery”, the performance of the Member States cannot be compared with each other. In this regard, the EU automotive industry is making recommendations on the harmonization of definitions of concepts.

Article 6 of Directive 2000/53/EC sets out the minimum requirements for the recycling of endurance vehicles, including the Member States taking the necessary measures to ensure that endurance vehicles are stored (even temporarily) and handled according to the general requirements set out in Article 4 of Directive 75/442/EEC (Council Directive 75/442/EEC, 1975), and in accordance with the minimum technical requirements set out in Annex I of Directive 2000/53/EC, without violating national health and environmental legislation.

Thus, according to Article 4 of Directive 75/442/EEC, member states must take the necessary measures to ensure that waste disposal and disposal takes place without any threat to human health and without the use of processes and methods that may harm the environment, and in particular:

- No risk to water, air, soil, plants and animals;

- Do not create inconvenience due to noise and smells;
- Without prejudice to the countryside and places of special interest.

Member States should take the necessary measures to impose bans on abandonment of vehicles, landfills and uncontrolled disposal.

In all Member States, measures have been taken to ensure the reuse/recycling and reuse/recycling of vehicles, as provided for by Directive 2000/53/EC, are achieved at the expense of business entities. Most Member States have fully implemented the provisions of Directive 2000/53/EC into their national legislation and encourage institutions or enterprises that carry out processing operations to introduce certified environmental management systems in their production. Under the terms of Directive 2000/53/EC, the manufacturer has and remains an obligation to ensure that the final destruction of the vehicle takes place in the most environmentally friendly way.

Cars have been officially classified as hazardous waste since the early 1990s and are already among the most recyclable consumer products. However, their enormous size and volume, as well as their relatively short lifespan compared to other complex machines (e.g. machine tools, airplanes, ships), have created a steady stream of significant waste. For example, according to NBR 10004 (Brazilian regulation), the oil filter is considered a Class I (hazardous) waste (Kulitch et al., 2017), as well as in Ukraine and some other countries (ZU „Pro vidkhodny”, 1998).

At the same time, toxic gases are a significant problem, which create a greenhouse effect and contribute to climate change. The release of such gases into the atmospheric air is carried out both by old cars due to the use of used filters and obsolete spare parts, and by the hazardous waste recycling. Thus, it should be emphasized that when recycling hazardous waste from end-of-life vehicles, the relevant legislation on reducing emissions of toxic gases, including greenhouse gases, must be observed.

So, greenhouse gases include water vapour, carbon dioxide (CO₂), methane (CH₄), ozone, nitrous oxide (N₂O), sulphur hexafluoride (SF₆) and other gaseous constituents of the atmosphere that absorb and emit infrared radiation (ZU „Pro zasady monitorynhu, zvitnosti ta veryfikatsiyi vykydiv parnykovykh haziv”, 2021; Kiehl & Trenberth, 1997). Anthropogenic halogenated hydrocarbons and nitrogen oxides can potentially contribute to the greenhouse effect; however, due to low concentrations in the atmosphere, the assessment of their contribution is problematic.

According to the most widely accepted scientific estimates, the ozone contribution is about 25% of the CO₂ contribution (https://web.archive.org/web/20121030071354/http://www.ipcc.ch/pdf/assessment-report/ar4/syr/ar4_syr_ru.pdf). Most tropospheric ozone is formed when nitrogen

oxides (NO_x), carbon monoxide (CO) and volatile organic compounds chemically react in the presence of oxygen, water vapour, and sunlight (resulting in the formation of photochemical smog. Transport, industrial emissions, and some chemical solvents are the main sources of these substances in the atmosphere. Methane, whose atmospheric concentration has increased significantly over the last century, also contributes to the formation of ozone. Tropospheric ozone has a lifetime of about 22 days; the main mechanisms for its removal are soil binding, decomposition by ultraviolet rays and reactions with OH and NO₂ radicals (Stevenson et al., 2006).

Article 3 of the Draft Law of Ukraine On Greenhouse Gases dated 09.12.2009 No. 5425 (consideration date: 09.12.2009 (<https://ips.ligazakon.net/document/JF46P00A?an=3>), which unfortunately was removed from consideration 07.07.2010 (http://search.ligazakon.ua/l_doc2.nsf/link1/JF46P00I.html) presents the basic principles of reducing emissions or increasing absorption of greenhouse gases, namely, some of them are:

- Minimizing the adverse social, environmental and economic impacts of greenhouse gas emissions;
- Creation of stimulating conditions for entrepreneurial activity in the field of introducing new environmentally efficient technologies and achievements aimed at reducing emissions and increasing absorption of greenhouse gases;
- Scientific validity, consistency and comprehensiveness of the approach to reducing emissions and increasing absorption of greenhouse gases;
- The use of market relations and competition as one of the main tools to stimulate environmental performance;
- Stimulating the development of the energy complex, industry, transport, agriculture, forestry and communal services, resource-saving production, housing construction and related services, improving the environmental situation in Ukraine and improving the quality of life of the population;
- Ensuring the economic attractiveness of investments aimed at improving the environmental efficiency of plant operators to reduce greenhouse gas emissions and/or increase their absorption.

On June 11, 1992, Ukraine signed the United Nations Framework Convention on Climate Change (UNFCCC), according to which developed country parties and other parties included in Annex 1 assume the following specific obligations:

- each of these Parties pursues a national policy and applies appropriate measures to mitigate the effects of climate change by limiting its anthropogenic emissions of greenhouse gases and protecting and

improving the quality of its sinks and reservoirs of greenhouse gases. Such policies and measures will demonstrate the leadership of developed countries in changing long-term trends in anthropogenic emissions for the purposes of the Convention, recognizing that the return by the end of this decade to previous levels of anthropogenic emissions of carbon dioxide and other greenhouse gases not controlled by the Montreal Protocol will contribute to such a change, and, taking into account the differences in the starting points and approaches of these Parties in their economic structures and resource bases, the need to maintain high and sustainable rates of economic growth, available technologies and other specific circumstances, and the need for an equitable and appropriate contribution of each of these Parties to global efforts to achieve this goal.

These Countries may implement such policies and measures in conjunction with other Countries and may help other Countries to contribute to the achievement of the objective of the Convention and, in particular, the objectives of this subparagraph (UNFCCC, 1992). According to Appendix 1 of this Convention, Ukraine is one of the countries in which the process of transition to a market economy is taking place.

Article 2 of the Kyoto Protocol states:

1. Each of the Countries included in Annex I (UNFCCC), in fulfilling their quantified emission limitation and reduction commitments in order to promote sustainable development:

- Carries out the protection and improvement of the quality of sinks and reservoirs of greenhouse gases not regulated by the Montreal Protocol, taking into account its obligations under the relevant international environmental agreements (Kyoto Protocol, 1997). Therefore, to enhance the effect of reducing CO and CO₂, modern absorbers based on composite films (Mozaffari et al., 2020; Mozaffari et al., 2021) should be used
- Research, development, promotion of widespread use and implementation of new and renewable types of energy, carbon dioxide absorption technologies and innovative environmentally friendly technologies;
- Measures to limit and / or reduce emissions of greenhouse gases not regulated by the Montreal Protocol in transport;

At the same time, in accordance with the Vienna Convention for the Protection of the Ozone Layer (VCPOL) (https://ips.ligazakon.net/document/view/mu85302?an=15124&ed=1985_03_22), the parties undertake to organize research and scientific assess and cooperate directly or through competent international bodies in

their conduct on physical and chemical processes that can affect the ozone layer, as well as alternative substances and technologies. Therefore, when developing a technology for the disposal of hazardous waste of used vehicles, it is necessary to ensure the reduction of toxic emissions into the environment.

3.2. Technology

Detergents were selected for the experimental study of the processes of liquid purification of contaminated UAOF filter paper from residual oil. These are baking soda and washing powder, soda ash and hydrogen peroxide (35%) and sodium percarbonate (Na₂CO₃·1.5 H₂O₂). Washing the VAMF filter paper with a flotation means consists in the process of rapid decomposition of hydrogen peroxide when adding it to a solution heated to 70°C. There is a release of active oxygen, which is a highly efficient flotation agent that removes all oil contamination from the filter element to the surface of the solution in the form of an “oil cap”. At the same time, there is a clear separation of phases: the purified fulfilled filter element – the fulfilled detergent – oil product (Holik & Ganoshenko, 2017).

The planning of the experiment is performed and independent factors are determined, that is, variables that correspond to the ways of environmental influence on the process. After implementing a complete factorial experiment 2⁴ with an extended plan matrix, the following regression equation was obtained:

$$y = 33.56 + 2.81 \cdot x_1 + 5.67 \cdot x_2 + 5.23 \cdot x_3 + 12.06 \cdot x_4 - 0.62 \cdot x_1 \cdot x_4 - 0.71 \cdot x_2 \cdot x_3 - 0.61 \cdot x_1 \cdot x_2 \cdot x_3 - 1.019 \cdot x_1 \cdot x_3 \cdot x_4 - 0.606 \cdot x_1 \cdot x_2 \cdot x_3 \cdot x_4 \quad (1)$$

After studying the obtained function on the extreme by differential calculus, it was found that the surface of the function is a hyperbolic paraboloid, so it has no extremum points but has a stationary point that is saddle (Hanoshenko & Rassokha, 2019). It is found using the necessary condition of the extremum of the function of two variables using a mathematical package Maple 13. A saddle point with the following coordinates and efficiency value is obtained: $t = 87.89^\circ\text{C}$; $\tau = 32.67$ min; $E = 60.21\%$.

The response surface, in this case, has the form Figure 1.

As a result of the carried out mathematical calculations and researches of the received function the optimum ratio of parameters for the achievement of the maximum efficiency of the process of washing of filter paper of UAOF is established:

$$C = 150 \text{ g}; \Delta m = 6.51 \text{ g}; t = 87.89^\circ\text{C}; \tau = 32.67 \text{ min.}; \\ E = 60.21\%.$$

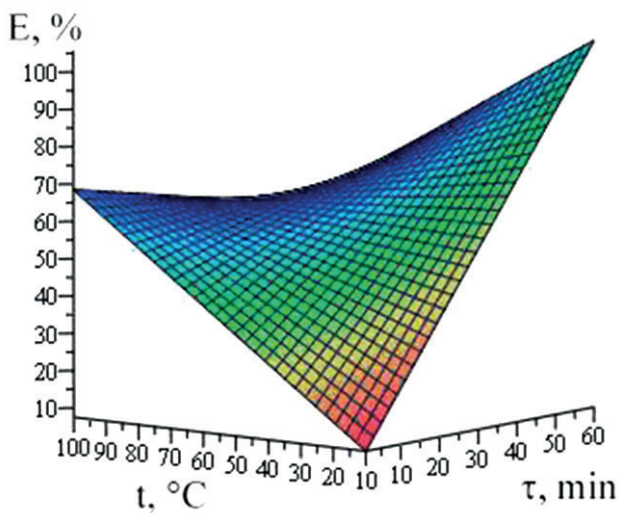


Figure 1. Response surface

To reduce the load on the environment and reduce the number of pollutants released into the environment, the scheme of installation of washing oiled filter paper of used automotive oil filters is proposed (Fig. 2).

The installation belongs to the automotive industry, namely to a method of extracting residual oil from oiled filter paper UAOF and can be used to remove oil residue from the paper. By washing the filter paper with a washing solution and reducing the number of contaminants, it can be used as fuel (Holik et al., 2018). The waste washing solution is in the circulating water supply system, so the need for freshwater is minimal and only if necessary. At technological service or at

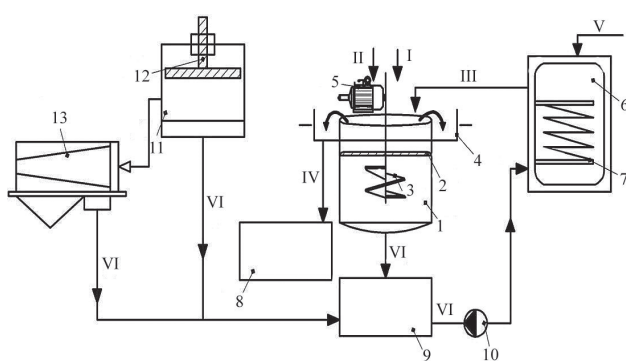


Figure 2. The scheme of installation of washing of the oiled filter paper of the fulfilled automobile oil filters: I – stage of loading oily filters; II – stage of filling with detergent (sodium percarbonate); III – stage of mixing the filter paper in a washing solution; IV – stage of removal of residual waste oil in the form of an „oil cap”; V – stage of additional fresh water supply (if necessary); VI – stage of filter paper washing and its removal from water for disposal; 1, 9, 11 – container; 2 – lattice; 3 – screw; 4 – pocket; 5 – electric motor; 6 – tank; 7 – heater; 8 – container for collecting waste oil; 10 – pump; 12 – press, with which the washed filters are wrung out; 13 – centrifuge

an emergency situation water passes the system of clearing, and then merges in the general sewer network (Hanoshenko & Holik, 2018a).

The scheme of washing of the oiled filter paper of the fulfilled automobile oil filters will allow solving the following tasks: extraction of resource-valuable components, reduction of loading on the environment. Incineration will reduce the number of pollutants entering the atmosphere and their negative impact on soils, surface, and groundwater.

The use of pre-washing and then burning of the filter paper with subsequent purification of flue gases by various devices allows obtaining a high degree of purification. The results of the experiments are presented in the Table 1.

It has been established that the use of a four-stage emission treatment scheme is not mandatory. It is possible to exclude bag and carbon filters. Waste washing solution formed during washing can be reused in the circulating water supply system after the removal of sludge and residual waste oils. This method allows you to minimize the flow of waste into the environment.

As a result of the conducted theoretical and experimental researches the complex technology of utilization of the fulfilled automobile oil filters which includes the following main stages is developed:

- Pre-collection of UAOF by the container way with a drain of the fulfilled oil, UAOF are subject to obligatory collecting and utilization;
- Cutting of UAOF with the drain of the fulfilled oil, there is a destruction of the case on the special equipment with the maximum separation of the fulfilled automobile oil;
- Separation of UAOF into constituent elements according to their properties and purpose with the subsequent washing of details and collecting of the fulfilled oil at all stages of complex technology;
- Sorting components by their further use, namely: steel 70% – for reuse (for type filters “KOLLAN”) or utilization; used oil 17% – for regeneration; plastic (polyethylene) 5% – for utilization; filter paper 8% – for washing followed by combustion as an alternative fuel;
- Removing contaminated filter paper and squeezing it from the oil;
- Washing the contaminated filter paper with a washing solution (sodium percarbonate) with the separation of waste oil;
- Burning purified filter paper in the furnace as an alternative fuel and obtaining thermal energy for space heating;
- Purification of gas emissions, when burning washed filter paper, which allows obtaining a high degree of purification, and the concentration of test substances within the MPC.

Table 1. The experiments results on the purification of flue gases

Cleaning machine	The method of processing UAOF	Changes in pollutant concentrations depending on the degree of purification			
		MPC m.p.o., mg/m ³			
		SO ₂ – 0.5	NO ₂ – 0.2	CO – 5.0	Carbon (soot) – 0.15
Initial concentrations of pollutants	contaminated filters	248.90	116.10	3338.65	2453.50
	washed with washing powder + NaHCO ₃	241.00	133.50	3295.85	1103.50
	Na ₂ CO ₃ + H ₂ O ₂	98.35	179.45	2401.20	496.00
	Na ₂ CO ₃ :1.5 H ₂ O ₂	25.25	103.70	1135.05	351.50
Cyclone SDK-CN-33	contaminated filters	224.01	104.49	2670.92	441.63
	washed with washing powder+ NaHCO ₃	216.90	90.80	2636.62	198.63
	Na ₂ CO ₃ + H ₂ O ₂	88.52	161.51	1920.96	82.28
	Na ₂ CO ₃ :1.5 H ₂ O ₂	22.73	93.33	908.40	63.27
Venturi scrubber	contaminated filters	44.80	20.89	267.09	24.28
	washed with washing powder + NaHCO ₃	43.38	18.16	263.67	10.92
	Na ₂ CO ₃ + H ₂ O ₂	17.70	32.30	192.10	4.91
	Na ₂ CO ₃ :1.5 H ₂ O ₂	4.55	18.67	90.80	3.48
Bag filter	contaminated filters	6.72	19.85	253.73	0.24
	washed with washing powder + NaHCO ₃	6.51	17.25	250.48	0.11
	Na ₂ CO ₃ + H ₂ O ₂	2.66	30.68	182.49	0.049
	Na ₂ CO ₃ :1.5 H ₂ O ₂	0.68	17.73	86.26	0.03
Carbon filter	contaminated filters	1.34	3.57	50.74	0.14
	washed with washing powder + NaHCO ₃	1.30	3.11	50.10	0.06
	Na ₂ CO ₃ + H ₂ O ₂	0.53	5.52	36.50	0.029
	Na ₂ CO ₃ :1.5 H ₂ O ₂	0.14	3.19	17.25	0.02

The detailed algorithm of the utilization of the fulfilled automobile oil filters is given in Figure 3.

In the process of utilization in this way, used automobile oil filters are converted into parts, one of which is used for recycling, and regeneration (metal parts, plastic parts, oils). Contaminated filter paper is washed and incinerated, followed by heat generation.

An alternative way of handling the washed UAOF filter paper can be its additional washing with carbon tetrachloride (tetrachloromethane, CCl₄). Tetrachloromethane is used as a solvent that acts on fats, resins, oils, varnishes, rubber, and other materials.

To do this, the UAOF filter paper washed with sodium percarbonate is additionally washed with carbon tetrachloride, squeezed on a press, and dried. The resulting solution is sent for distillation by heating. At t = 80°C there is a separation of oil from carbon tetrachloride. Then the oil is sent for regeneration, and carbon tetrachloride is reused.

The obtained after washing and dried paper is suitable for further use as a fibrous secondary raw material for the production of packaging and packaging cardboard, as well as roofing, insulation, and other building materials. In the case of sequential washing of the filter paper with

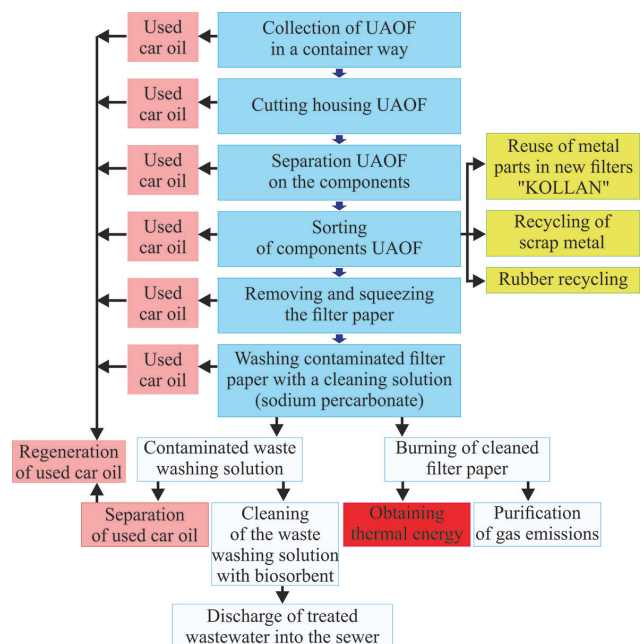


Figure 3. Algorithm for utilization of used car oil filters

sodium percarbonate and carbon tetrachloride, we obtain a completely waste-free technology for the disposal of UAOF.

4. Conclusions

It should be emphasized that one of the areas of successful implementation of European approaches in the field of automotive components recycling is the comprehensive revision of legislation in order to take into account the provisions of EU directives and the practice of organizing an integrated waste management process. First of all, it is necessary to bring the framework law on waste in line with EU legislation, as well as to harmonize the provisions of the Law of Ukraine "On scrap metal" and the Law of Ukraine "On waste".

In order to reduce harmful substances in flue gases during UAOF thermal utilization, it is necessary to pre-flush the filter material from oil residues. It is determined that the most promising washing reagent for washing UAOF filter paper is sodium percarbonate $\text{Na}_2\text{CO}_3 \cdot 1.5 \text{H}_2\text{O}_2$.

In order to obtain the maximum efficiency of filter paper cleaning, was determined the stationary (saddle) point was obtained, which determined the optimal ratio of technological process parameters: $C = 150 \text{ g}$; $\Delta m = 6.51 \text{ g}$; $t = 87.89^\circ\text{C}$; $\tau = 32.67 \text{ min}$; $E = 60.21\%$.

The technology of incineration of the washed filter paper of UAOF is developed. It is experimentally proved that pre-treatment of the filter paper with a washing solution allows reducing the number of pollutants in the flue gases. Thus, the content of waste oil is reduced by 55%, and the number of pollutants in the flue gases: sulphur (IV) oxide – 89%, nitrogen (IV) oxide – 15%, carbon (II) oxide – 66%, carbon (soot) – 86%.

As a result of the conducted theoretical and experimental researches, the complex ecologically safe technology is developed and the detailed algorithm of the utilization of UAOF is made, which eliminates the entry of hazardous waste into the environment and reduces the man-made load on the environment.

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