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LOGISTICS OF ELECTRIC DRIVE MOTOR VEHICLES RECYCLING

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RESEARCH ARTICLE

ABSTRACT: Increase in number of transport vehicles, especially motor vehicles, has negative impact on environment. It refers to air pollution problem due to usage (combustion) of fossil fuels in motor vehicles. Agriculture activities, factories, industry and many other activities additionally contributes to air pollution. Greenhouse gas emission is main cause of global warming and air pollution, and mainly occurs due to industry and transport.

In many countries, the adoption of legislation gives priority to the use of electric vehicles due to lower emissions compared to conventionally powered vehicles (diesel or gasoline engines). In this way, goals have been set in the European Union and regulations have been passed which, among other things, require a certain percentage of motor vehicle recycling at the end of their service life. The Directive 2000/53/EC of the European Parliament and of the Council regulates waste management in the vehicle sector.

Due to the increased number of electric vehicles, which participate in the transport of goods and people, the paper partially analyzes the problem related to the adaptation of existing recycling centers (for classic vehicles), for the needs of recycling electric vehicles and their specific parts and equipment (such as magnets and electric motors).

KEY WORDS: Electric drive, motor vehicles, recycling

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LOGISTIKA RECIKLAŽE MOTORNIH VOZILA NA ELEKTRIČNI POGON

REZIME: Povećanje broja transportnih sredstava, prvenstveno motornih vozila, ima negativan uticaj na čovekovu okolinu. To se odnosi na problem zagađenja vazduha zbog upotrebe (sagorevanja) goriva fosilnog porekla u motornim vozilima. Zagađenju vazduha dodatno doprinose aktivnosti na poljoprivredi, fabrike i industrija i mnoge druge aktivnosti. Emisija gasova staklene bašte je glavni uzročnik globalnog zagrevanja i zagađenja vazduha i nastaje uglavnom zbog industrijske ativnosti i transporta.

U mnogim državama se donošenjem zakonskih propisa daje prioritet upotrebi vozila na električni pogon zbog manje emisije u odnosu na vozila sa klasičnim pogonom (dizel ili benzinskim motorima). Tim putem su u Evropskoj uniji postavljeni ciljevi i donešeni su propisi kojima se između ostalog zahteva određeni procenat reciklaže motornih vozila na kraju njihovog servisnog veka. Direktivom Evropskog parlamenta i Saveta (engl. Directive of the European Parliament and of the Council 2000/53/EC) uređuje se upravljanje otpadom u sektoru vozila.

Zbog sve većeg broja vozila na električni pogon, koja učestvuju u transportu robe i ljudstva, u okviru rada je delom analiziran problem koji se odnosi na adaptaciju postojećih reciklažnih centara (za klasična vozila), za potrebe reciklaže vozila na električni pogon i njihovih specifičnih delova i opreme (kao što su magneti i električni motori).

KLJUČNE REČI: Električni pogon, motorna vozila, reciklaža

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1. INTRODUCTION - ENVIRONMENTAL PROTECTION AND RECYCLING OF MOTOR VEHICLES - CONDITION AND LEGAL REGULATIONS

One of the basic goals is protection of the environment. The importance of this goal can be illustrated by data related to the production of motor vehicles.

It is estimated that approximately 107 million vehicles will be produced worldwide by the end of 2020. A total of about 79 million cars are expected to be sold worldwide. By comparison, over 26 million motor vehicles were sold worldwide in 2017, with U.S. the largest market for commercial vehicles (trucks and buses) [1, 2].

The transport sector is responsible for one quarter of the total greenhouse gas emissions in the European Union (EU). The largest emission is generated by the energy sector, followed by transport, industry, households, agriculture, etc., Figure 1 [3].

Road traffic emits a fifth of the total carbon dioxide (CO2) emissions in the EU that is more than two thirds of the total greenhouse gas emissions emitted by vehicles during various modes of transport [1, 2].

The rest of this paper is organized as follows. In Section 2, independent and dependent suspension systems are introduced. Preliminary considerations, including design constraints and load conditions, and design development are proposed in section 3. Numerical analysis of the proposed system is presented in Section 4. Finally, in Section 5, conclusions are presented.

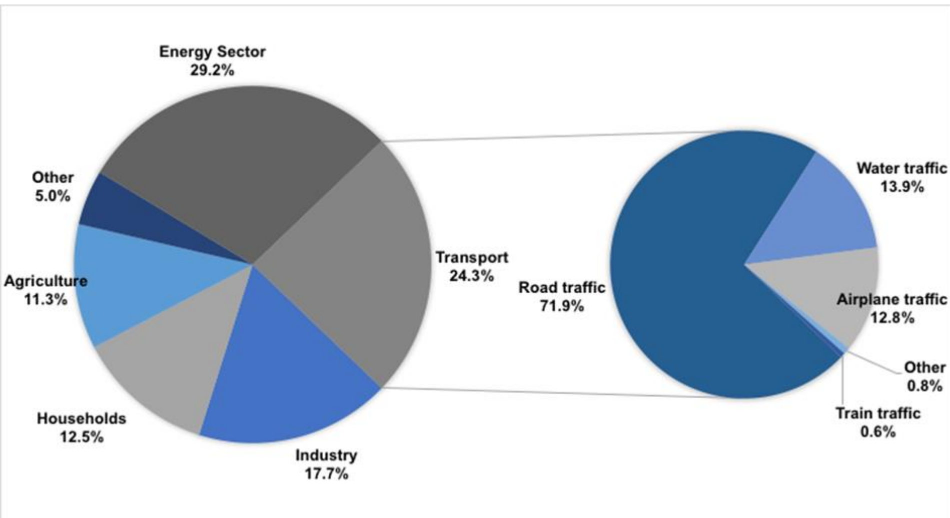

Figure 1: *(EU28) Greenhouse gas emissions by sectors and presentation of the share of road traffic*

Due to the increasing load on the environment with the increase in the number of motor vehicles in use, the emission of noise and toxic exhaust gases has increased, which must be limited and reduced. Also, a large amount of materials, different types of metals and fluids are used within the vehicle, which have to be produced from renewable raw materials and which must be recycled [4-6].

In this way, the 20/20/20 strategy was implemented in the European Union, which was established in 2007 and included the following three goals: increase of energy efficiency by 20%, reduction of carbon dioxide emissions by 20% and 20% share of renewable energy sources, for period until 2020. In general, the goal is to reduce carbon dioxide emissions by 40% by 2030, if we look at the value of emissions from 1990 that is to reduce emissions by 80-95% by 2050 [1, 2].

Due to all the above, electric drive is a serious alternative to classic motor vehicle drive systems. As an example, the number of cars with exclusively electric drive between 2017 and 2018 increased by 43% in the EU. More than one million electric (plug-in) passenger and light cargo (truck vans) vehicles were registered by the beginning of June 2018 in Europe. Mass registration of such vehicles has been recorded only in China [3, 7].

In general, parallel in the world, in addition to the classic ones, the number of written-off electric vehicles, which are at the end of the service life (ELV) and which must also be recycled, is increasing. Therefore, it is important to introduce certain regulations in this area. It is also important to reduce the illegal sale of written-off vehicles, instead of recycling them, and to strengthen inspections in this area inside and outside the EU.

Appropriate regulations must regulate the procedures from writing off the vehicle to disassembling the vehicle into its component parts, their classification, recycling and re-installation in a new vehicle. This facilitates the whole process, because it should be borne in mind that the vehicle consists of different materials, starting from precious metals, different fluids and they all require special procedures. The complete problem is more complex due to the fact that manufacturers place new models on the market with some additional new materials. This especially applies to electric vehicles, gas vehicles, etc.

Annually in the EU, the disposal of vehicles at the end of the service life creates between 8 and 9 million tons of waste that must be properly managed. From that aspect, the Directive 2000/53/EC of the European Parliament and the European Council of the EU regulates the measures and logistics of dealing with ELV in order to protect the human environment and save the engaged energy. The Directive also restricts the re-use of certain parts that have been dismantled from decommissioned vehicles [8].

The Directive regulates the procedure for handing over a vehicle that has no market value (or is negative) by the last owner, to authorized recycling facilities, for which an appropriate Certificate is issued. At the same time, an appropriate financial incentive is prescribed by the vehicle manufacturer.

According to the requirements of the Directive (2000/53 / EC), the vehicle as a whole must contain a certain percentage of reusable parts and fluids and recyclable materials [8, 9].

2. BASIC CONSIDERATIONS ON THE PROCESS OF RECYCLING MOTOR VEHICLE

During the dismantling process (consisting of the collection, removal of unauthorized impurities and crushing) of ELVs in Europe, two main aspects must be taken into account:

- First, there is evidence to suggest that ELVs are being treated illegally in some cases; and

• Second, even in authorized recycling facilities, the classification of specific waste is not done properly and is not fully in line with the relevant requirements of the existing ELV Directive. Certain types of fluid in vehicle systems, such as brake fluids, windshield washer fluid, oil filters or shock absorbers, are not always disposed of in an environmentally friendly manner.

Also, it is necessary to properly separate the parts from hazardous substances such as mercury (Hg), which can be an integral part of the light group or switch, etc., and prevent their spillage into the environment.

Lead-acid batteries and acid are also dismantled from vehicles in a special way and treated in a special way because, in addition to their toxic properties, they can also damage shredders at recycling plants. The same applies to fuel tanks and airbags due to the presence of toxic and flammable gases.

Shredders are used for tearing to pieces and/or for shredding and crushing vehicles and parts. In general, after crushing, metal residues remain without the presence of hazardous substances. However, in practice, it has been shown the opposite and that impurities often appear.

An international standard (ISO 22628: 2002) defines a procedure for calculating the percentage of recyclability and reuse of installed materials within a new vehicle, calculated per unit mass of the vehicle [10].

The percentage of recyclability (R_{cyc}), or (recyclability indicator) of a motor vehicle, represents the percentage of mass (percentage by mass share), and can be calculated using the following equation (1):

$$R_{cyc} = \frac{m_P + m_D + m_M + m_{Tr}}{m_V} \cdot 100 \geq 85\% \quad (1)$$

Percentage or indicator of reuse of embedded materials (R_{cov}), is calculated using the following equation (2):

$$R_{cov} = \frac{m_P + m_D + m_M + m_{Tr} + m_{Te}}{m_V} \cdot 100 \geq 95\% \quad (2)$$

where:

- m_p - Mass of materials released during the vehicle recycling preparation process; (all liquids, batteries, oil filter, tires, catalysts, etc.);
- m_D - Mass of materials released during the vehicle disassembly process (large, easily replaceable parts made of polymeric materials and elastomers, such as bumpers, instrument panels, etc.);
- m_M - Mass of materials released during the process of crushing and separating metals;
- m_{Tr} - Mass of non-metallic materials, which are separated during the crushing process; and
- m_{Te} - Mass of non-metallic materials (polymeric materials and elastomers which are difficult to disassemble and which are lighter than 100-200 g, respectively), as well as other flammable materials (Leather, wood, card reader, etc.).

The time of disassembling the vehicle depends on the construction, the way of connecting individual parts of the construction, the technical instructions for disassembling, etc.

3. DEVELOPMENT OF RECYCLING CENTERS FOR MOTOR VEHICLE RECYCLING ON THE DOMESTIC MARKET

3. 1 Market projection of purchase of vehicles for recycling and sale of recycled materials

The market for the purchase of waste vehicles and for the sale of recycled materials primarily represents the territory of Serbia, and on the foreign market these are the former Republics of SFRY. It should be borne in mind that due to the announced abolition of imports and withdrawal from the use of obsolete vehicles. Therefore, an additional increase in the volume of activities in the field of recycling is forecast, that is planned dismantling and dismantling of obsolete vehicles.

Also, it should be taken into account the fact that the number of manufacturers of electric vehicles, as well as hybrid vehicles, is increasing.

At the same time, the turnover is increasing, that is the demand for recycled materials and the so-called repaired spare parts, in which, in our region, Slovenia leads, following the example of European and world countries.

3.2 Organization and optimization of the electric vehicles recycling process

Having in mind the increase in the number of electric vehicles, it is necessary to think about their recycling in a timely manner. Since electric vehicles contain additional parts and equipment that are not available on classic vehicles (electromagnets, batteries, etc.), it is necessary to invest part of the profit in the formation of a new separate plant for dismantling and recycling electric vehicles. In that way, the company would remain competitive on the market. The concept of one such plant is shown in Figure 2 [11].

The goal is to further adapt the existing plant within the company for recycling motor vehicles with classic engines by networking the part for disassembly of electric vehicles. Within the additional network, the issue of recycling electric batteries has been developed a lot [11]. Emphasis is placed here on disassembling electric motors, separating magnets, their depolarization and reuse.

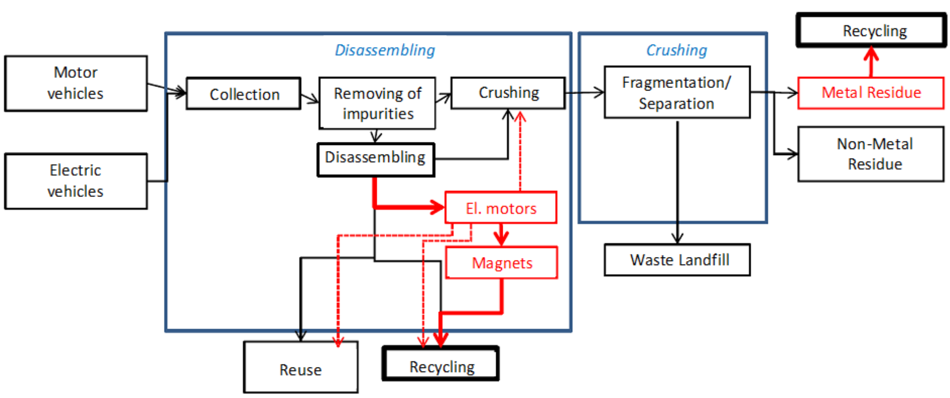

Figure 2: *Pilot plant for recycling electric vehicles with preparation for separation and reuse of permanent magnets*

The complete plant consists of a receiving department, a sector for disassembling vehicles and part for disassembling electric vehicles and separating electric motors and magnets. After crushing, metal and non-metal parts are separated and materials that cannot be used further are deposited.

Considering that it is the obligation of the designer to select recyclable materials on the designer's table, it can be expected that the share of plastics and plastic materials will have a declining trend in the coming years.

As there is a growing problem today in the recycling of plastic materials, especially polyvinyl chloride (PVC), a number of manufacturers are replacing this type of material with various alloys, especially aluminum alloys. The use of aluminum in motor vehicles (especially passenger vehicles) has been constantly increasing in recent years. Thus, in 1998, the average amount of aluminum was 85 kg per vehicle, while in 2008 it was about 160 kg per vehicle [12-14]. For now, the greatest application of aluminum is in the manufacture of engines, transmissions and bodies, especially in vehicles of higher class.

Aluminum has been proven to be completely recyclable, with the recycled material fully retaining all its characteristics, which is another advantage of this metal. Due to these favorable characteristics, aluminum is increasingly used in the automotive industry. In the USA, for example, the trend of increasing the use of aluminum lasts over 50 years and it is predicted that by 2028, about 256 kg of this metal will be installed in passenger and light trucks, Figure 3 [15-17]

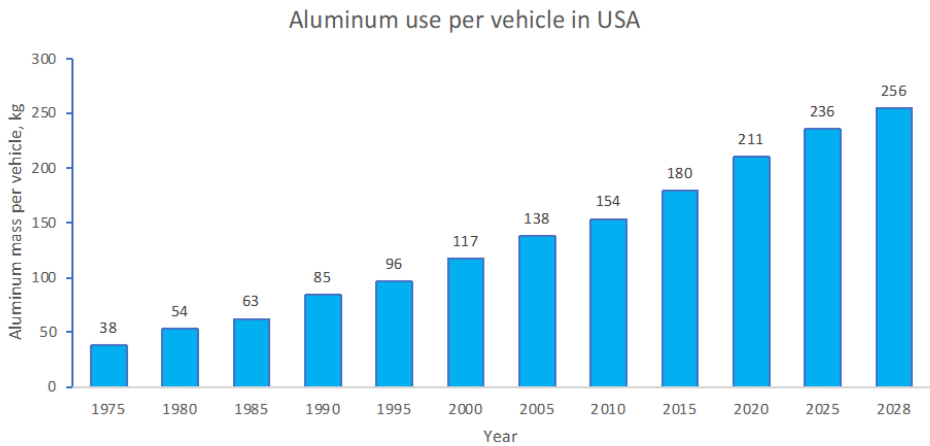

Figure 3: *Trend of Al use in passenger and light truck vehicles in the USA*

Also, it is predicted that by 2030, about 10 million tons of aluminum will be installed in electric and hybrid vehicles, which is 10 times more than the current situation. As an example, the e-Golf is equipped with about 129 kg of aluminum, the Nissan Leaf 171 kg, while the luxury model Tesla S has about 661 kg of this metal [15-17].

3.3 Motor vehicle recycling process after use

It is important to note that regardless of whether the recycling process is performed with prior disassembling of the vehicle, or the vehicles are delivered directly for crushing, the removal of hazardous materials and materials from vehicles that may endanger the environment must be performed before any procedure (Depollution process). This is defined in Annex 1 of Directive 2000/53/EC, Article 6. Directive 2000/53/EC stipulates that all materials and fluids that can pollute the environment must first be removed from waste vehicles and only then can they be sent to waste or crushing. Annex 1 of Directive 2000/53/EC specifies what such a procedure must include [8]:

- Removal of batteries, tanks for conventional fuels (petrol and diesel) or tanks for alternative fuels (liquefied petroleum gas, hydrogen, methane);
- Removal and neutralization of potentially explosive components (for example airbags, gas shock absorbers);
- Removal, separation, collection and storage of fuels, motor oils, gear oils, differential oils, hydraulic oils, coolants, brake oils, fluids from the vehicle air conditioning system, as well as all other fluids and fluids that may be found in waste vehicle; and
- Removal of components containing mercury and other toxic materials.

After this procedure, waste vehicles are transported to special plants that are intended for grinding and crushing, the so-called shredders. The vehicle is transported and compacted in a shredder where it is broken and torn into pieces the size of a few centimeters, which enables easier recycling of materials that are part of the vehicle and recovery of up to approximately 80% of the material. After grinding and crushing the vehicle, the materials are separated and divided, usually into metals and non-metals [18].

The maximum thickness of materials processed in the Shredder plant is 2 mm for sheet metal, 5 mm for steel and 10 mm for circular parts. In Figure 4, a schematic representation of the Shredder metal waste recycling plant is given [18, 19].

Prior to processing in the Shredder, the materials must be free of explosive, flammable, toxic and chemically aggressive liquids, gases and dust.

Before crushing the vehicle in the Shredder plant, the following are removed: windows, battery, electronics and electrical installation, tires, plastic parts (bumpers), fuel tank, air conditioning, waste oils in the gearbox, shock absorbers, brake system, engine, power steering device, etc.

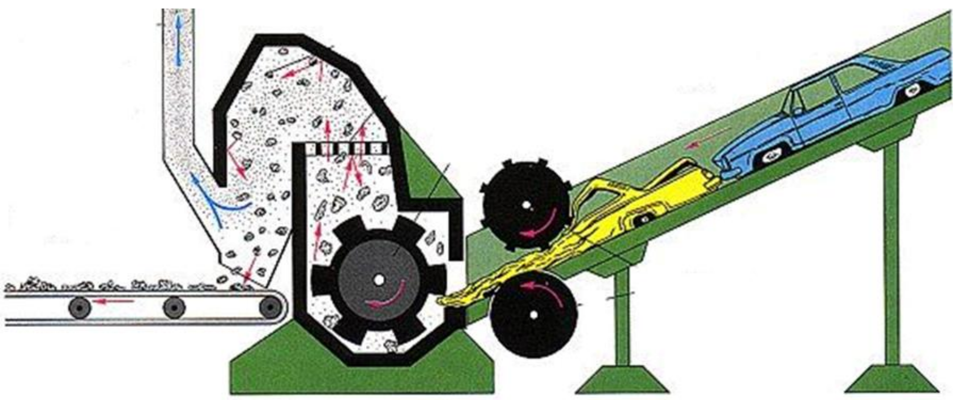

Figure 4: *Shredder Plant for recycling vehicles and scrap metal*

The basic products of recycling old passenger cars in the Shredder plant are, Figure 5 [18-20]:

- Magnetic waste fractions (iron and steel) about 70%;
- Mixed fractions of non-magnetic metals (aluminum, copper, etc.) maximum 6.4%;

- Light fractions from Shredder plants (PVC, elastomers, polyurethane, glass, ceramics, paints, etc.) about 23%; and
- Iron with copper content of 0.2% to 0.3% that can be used for production of less useful steel (about 0.6%).

Figure 5: *Products of recycling old vehicles in Shredder plant*

4. CONCLUSIONS

The transport sector is responsible for one quarter of the total greenhouse gas emissions in the European Union. The largest emission is generated by the energy sector, followed by transport, industry, households, agriculture and others.

The Directive of the European Parliament and of the Council Directive 2000/53/EC regulates waste management in the vehicle sector. Appropriate regulations thus regulate the procedures from writing off the vehicle to disassembling the vehicle into its component parts, their classification, recycling and re-installation in a new vehicle.

The International Standard (ISO 22628:2002) defines a procedure for calculating the percentage of recyclability and reuse of installed materials within a new vehicle, calculated per unit of mass of the vehicle. The method is harmonized by the motor vehicle manufacturers and is applicable to each new manufactured vehicle.

Through its activities, the new recycling center for recycling electric vehicles should contribute to the development of the domestic material market through ecological disassembling and dismantling of obsolete vehicles, which parts are further recycled and reused. Since electric vehicles contain additional parts and equipment that are not available on classic vehicles (electromagnets, batteries, etc.), it is necessary to invest part of the profit in the formation of a new separate plant for disassembling and recycling electric vehicles.

As today there is a growing problem in the recycling of plastic materials, especially polyvinyl chloride (PVC), a number of manufacturers are replacing this type of material with various alloys, especially aluminum alloys. The use of aluminum in motor vehicles (especially passenger vehicles) has been constantly increasing in recent years. Aluminum has been proven to be completely recyclable, with the recycled material fully retaining all its characteristics, which is another advantage of this metal.

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