

Comparative analysis of degradation of engine oils from hybrid and conventional vehicles

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ABSTRACT

Hybrid drive systems are becoming the dominant drive type in currently manufactured passenger cars. This article presents the preliminary tests of an analysis of the content of selected heavy metals in used engine oils collected from car service stations during oil changes. The combustion engine in hybrid systems operates under unusual conditions due to frequent switching on and off. The main aim of the study was observe the difference in the heavy metal content (Cd, Co, Cr, Cu, Fe, Mn, Ni, Pb, Sn, and Zn) in 0W16 oils used in hybrid vehicles and conventional gasoline vehicles. Twenty samples of used engine oils collected from passenger cars were analyzed. Heavy metal content was quantified using the ICP OES technique after mineralization of the oil samples. The metal content profiles for both engine types were similar. Comparing the average elemental content across engine types shows that hybrid-system oils contained 1474 mg/kg of heavy metals – about 9% less than oils from gasoline engines (1622 mg/kg). This may indicate smaller oil degradation, which – under these conditions – allows for longer service life and reduces vehicle operating costs. Reduced oil degradation also means fewer oil changes, lower energy consumption for its production, as well as reduced waste, energy, and resources required for waste oil disposal.

Keywords: heavy metals, lubricating oil analysis, waste lubricant oil, car with a hybrid system, petrol engine.

INTRODUCTION

Among the many different lubricants, the most common are engine oils used in cars with gasoline, compression-ignition, and hybrid engines. According to ACEA, hybrid vehicles in the EU remain the most popular category of new cars, accounting for 35.3% of new car sales in 2025 and enjoying unwavering popularity. Gasoline and hybrid cars currently account for over 71% of new cars in the EU [1]. Testing engine oils for a wide range of element content enables the analysis of wear processes. It allows for the assessment of wear dynamics in a given engine type, monitoring additive levels, and detecting undesirable contaminants. Testing the elements in lubricants allows for appropriate design and maintenance actions to be taken at the optimal time, which translates into increased reliability, reduced costs,

and long-term, trouble-free operation [2]. Engine oils consist primarily of base oil and 10–30% of various additives that improve lubrication properties, protect the engine from corrosion, keep the engine clean, stabilize viscosity over a wide temperature range, prevent oil foaming, and neutralize the acids formed during oxidation. Base oils include both mineral oils, obtained by distilling crude oil, and synthetic oils [3]. The combustion engine in hybrid systems operates under rather unusual conditions due to frequent switching between electric and combustion modes. This is particularly true in urban environments. Combustion engines in hybrids are often overheated. Intermittent engine operation, warming up, and cooling can affect the lubricating properties of the oil. Furthermore, variable temperature conditions increase the risk of water vapor condensation in

the lubrication system. During urban driving, the combustion engine is constantly turned off and on. During acceleration, there is a greater demand for power immediately after starting and a significant increase in engine speed. This means that the oil must immediately lubricate the engine, requiring a sufficiently low viscosity and fluidity. The standard viscosity for these engines is 0W-20, with some designs even requiring 0W-8 oil [4]. The chemical profile of used oil depends on the base oil type, the additives applied, the physicochemical transformations taking place during use, as well as potential impurities arising from its collection and storage. The total metal content in European used oils is approximately 0.7% (m/m) [5]. Used engine oils are particularly hazardous to the environment due to contamination with thermal decomposition products and heavy metals. Used engine oils are extremely difficult to biodegrade and have carcinogenic properties; therefore, assessing the heavy metal content in these products is also crucial for environmental protection [6,7]. A single drop of used engine oil released into the environment can contaminate up to 1.000 liters of surface water, causing irreparable damage to the ecosystem. Used engine oils are classified as hazardous waste with codes 13 01 10* (used mineral oils) and 13 01 10* (used synthetic oils). These waste codes are special numbers assigned to each type of waste based on the waste catalog applicable throughout the European Union. An asterisk (*) next to each code indicates hazardous waste. This allows for a clear identification of the type of waste, its environmental risk, and the procedures to be followed when storing and transferring it for disposal or recovery [8]. Combustion engine lubricant performs several important functions that significantly contribute to the reliability of the system, which is related to its proper operation during operation. Replacing engine oil too early or too late can lead to additional costs or adversely affect engine performance. There is a close relationship between engine reliability and effectiveness of lubrication. This is of great interest to both manufacturers and users. Especially for owners of fleets with multiple vehicles, it is crucial to know when to make the decision to change the oil. Vehicle manufacturers recommend precise technical inspection intervals. However, vehicle operating conditions can vary significantly between inspections, which can significantly impact the quality of engine oil. Under harsh operating conditions, the oil can

quickly degrade and lose its valuable properties. In this situation, adherence to predetermined, excessively extended inspection intervals leads to premature engine wear. This will have serious economic consequences. On the other hand, under mild operating conditions oil still retains its full protective properties, and such oil can be successfully used even after the inspection period has been exceeded. This will have a significant impact on both economic and environmental conditions – it will reduce waste. On the basis of these observations, examining the used engine oil can guide appropriate decisions and contribute to significant cost reductions [9–13].

ENVIRONMENTAL ASPECTS

Used engine oil is a common environmental pollutant because of its widespread use in transportation and industry. As it degrades during engine operation, it becomes contaminated with hazardous substances, such as heavy metals, polycyclic aromatic hydrocarbons (PAHs), and chemical additives. Improper disposal or accidental spills can severely affect soil, water, and air quality. This highlights the need to improve systemic strategies for managing the environmental impact of used engine oil, aimed at protecting the ecosystem. The less used engine oil that enters the environment, the lower the costs of mitigating its effects [14,15]. The hydrophobic nature of petroleum compounds derived from used engine oils, their low solubility in water and sorption of pollutants in the soil matrix cause a significant decrease in the mass transfer rate, because most of the carbon sources are inaccessible to cells, which significantly limits the biodegradation of this type of compounds, especially under anaerobic conditions [16–18]. Among the numerous contaminants that accumulate in oil during its use, heavy metals are particularly hazardous due to their toxicity, carcinogenicity, and environmental persistence. These contaminants result from the wear of engine bearings containing a number of alloyed metals (e.g., lead, copper, tin) and the use of protective coatings containing cadmium [19–21].

Used engine oil has drastic consequences for soil, water, and air quality. The introduction of used engine oil into soil disrupts its physical structure by diminishing porosity and permeability, negatively impacting water movement

and storage. Additionally, the formation of a hydrophobic coating on soil particles reduces the accessibility of key nutrients, including nitrogen and phosphorus, leading to decreased soil fertility and inhibited plant development. Used engine oil also affects soil pH, causing acidification or alkalization, interfering with the uptake of nutrients by plants and soil microorganisms, inhibiting their activity and diversity. This disrupts soil processes, such as organic matter decomposition and nutrient cycling, limits phosphorus and nitrogen fixation, causes a decline in soil biodiversity, and impacts the entire soil ecosystem. Serious threats include the uptake of heavy metals from used engine oil by plants, leading to their bioaccumulation and toxic effects on herbivores and higher trophic levels [22,23]. By discharging used motor oil into sewers, landfills, or directly into the ground, contaminated soil causes used motor oil to leach into water bodies (surface waters of rivers and lakes, and even into groundwater) during rainfall. This leads to contamination of nearby springs and drinking water intakes. Used motor oil in the aquatic environment has a harmful impact on water quality and the functioning of aquatic organisms. Oil layers on water surfaces impede oxygen exchange, lowering dissolved oxygen concentrations and creating hypoxic conditions detrimental to aquatic ecosystems. PAHs and heavy metals exhibit chronic toxicity, disrupting reproduction, growth, and survival in fish, invertebrates, and other aquatic species. Additionally, these pollutants can bioaccumulate and biomagnify, posing ecological risks and potential hazards to human health [24,25].

Used motor oil comprises numerous volatile organic compounds (VOCs) that may evaporate into the atmosphere, including benzene, toluene, ethylbenzene, and xylene, collectively termed BTEX [26]. These substances, frequently detected in used motor oil, play a role in the formation of ground-level ozone and particulate matter, thereby posing substantial threats to ambient air quality. This can lead to smog, which reduces visibility, impairs respiratory function, and exacerbates a variety of conditions, such as asthma. Long-term exposure to these toxic air pollutants can result in serious health risks, including cancer, liver and kidney damage, and disorders of the central nervous system. The volatile components released from used engine oil also contribute to the greenhouse effect. Combustion of used engine oil itself releases carbon dioxide, which,

as a major greenhouse gas, further contributes to climate change [27–29]. However, used automotive lubricating oils represent a prime example of waste that can – and should be recycled, and converted into useful, valuable products. They can be processed as well as refined, and subsequently used to produce fuels or serve as a base for new lubricating oils [30]. Annually, 4.3 million tons of engine oil are introduced to the European market. Of this amount, only 35–40% are collected. Regeneration occurs in 20–25% of the collected engine oil. Recycling used oil requires advanced technologies that recover clean base oil with parameters comparable to the virgin product [31]. High-efficiency filtration technologies can remove particulate matter from used engine oil, extending its service life and reducing the need for frequent oil changes.

Hydroprocessing is a refining method that employs hydrogen to strip contaminants from used engine oil. The result is high-quality base oils that meet or even surpass the specifications of virgin base oils. Recent technological advancements are being developed with the objective of minimizing contaminants and enhancing the sustainability of used engine oil management. Contemporary installations utilize vacuum distillation, filtration, and catalytic purification processes. Catalytic depolymerization is a process that involves the breakdown of complex hydrocarbon molecules present in used engine oil into simpler compounds. This facilitates the removal of contaminants and improves the quality of the recycled oil [23,32]. The average cost of an oil change for a passenger car, including materials, in the EU ranges from €100 to €200, depending on the car brand, oil type, workshop, and local rates. The average annual mileage of a car in Europe is 12,000 km, but in some countries it reaches up to 18,000 km. The average car lifespan in European countries is 18 years. There are no reports on the content of elements in oils used in hybrid engines. This article expanded this research by analyzing the content of selected metals in new and used lubricating oils from gasoline and hybrid cars with varying mileage and oil life. This will enable the creation of an average degradation profile for engine oils over their service life, thus increasing the scope of diagnostics. Early detection of excessive wear or irregularities can prevent costly breakdowns, reduce vehicle downtime, and decrease repair costs. It can also facilitate decision-making regarding the planned engine oil life

in hybrid vehicles and the management of used waste oils, which will impact overall costs.

POSSIBILITIES OF ENERGY RECOVERY FROM USED ENGINE OILS

Used engine oils should be purified and processed not only because of their toxicity and negative environmental impact. However, opportunities and solutions that would additionally allow for the recovery of energy from waste engine oil before processing are important. Fuel cells (FCs) seem to be an interesting solution that allows the use of used engine oil for direct electricity production. The actual efficiency of this type of fuel cell is very high, estimated at up to 80%. Furthermore, they are characterized by zero or low negative environmental impact and quiet operation [33–38].

An interesting analysis was conducted by [39], comparing the energy potential, emissions profile, and economic viability of used engine oil with conventional fuels such as crude oil, heavy fuel oil, and diesel fuel. The results indicate that using used engine oil can generate significant annual savings, exceeding €50 million for a country like Kuwait. Additionally, environmental benefits include a 19% reduction in CO₂ emissions and a 45% reduction in NO_x emissions compared to traditional fuels. Used engine oil can be a viable alternative for sustainable energy and responsible environmental management.

Another practical use for used engine oil is the production of alternative diesel fuel based on technological pyrolysis and cracking (breaking down or transforming long-chain hydrocarbon molecules into smaller molecules) and chemical processing. These solutions are used industrially in many countries, bringing tangible ecological and economic benefits. The fuel produced in this way can be used directly in existing diesel engines or with minor modifications. This allows for the replacement of a large portion of fossil fuels, becoming a significant energy source for these types of combustion engines in transportation [40].

MATERIALS AND METHODS

The plasma discharge was generated in argon gas of 99.999% purity supplied by Air Products (Warsaw, Poland). Argon was used as the nebulizing, plasma and torch cooling gas for ICP

OES measurements. Standard solutions were prepared from a 1000 mg L-1 stock solution ICP IV Multi-element standard solution from Merck (Darmstadt, Germany) was used for calibration curve preparation in 1M HNO₃ (69%, Trace pure, Merck, Germany). Doubly distilled was obtained through deionization (DEMIWA 5 ROSA, Watek, Czech Republic) and distillation in a quartz system (Heraeus Bi18, Hanau, Germany).

Sample preparation

The oil samples were transferred to the PTFE reaction vessels of 108 mL (internal volume) used for the decomposition procedure and weighed using microanalytical balance (Sartorius M2P, Göttingen, Germany). To quantify all elements using the ICP OES instrument, the samples were decomposed in a closed-vessel microwave system. Microwave-assisted sample digestion was employed for ICP OES determination.

Microwave digestion system

Microwave-assisted sample digestion system with focused energy (ERTEC, POLAND) was employed for the digestion procedure. According to the methodology presented elsewhere [41].

Analytical procedure

Approximately 400–500 mg of oil samples were placed in the reaction vessel and 8 mL of HNO₃ was added. The decomposition was carried out for 10 min at 150 W (at pressure of 25–40 bar). The obtained solution was transferred into a 25 mL volumetric quartz flask and made up to the mark with pure water. Blank samples were processed identically to correct for any possible contamination from the reagents.

Metals determination in oil real samples using the ICP OES method

An ICP OES spectrometer (Thermo Jarrel-Ash Iris HR, Franklin, USA) was used for the simultaneous quantification of tested elements in oils [42]. The apparatus is equipped with optical system working in the range of 175–900 nm. As a sample introduction system, the concentric nebulizer (Meinhard, Germany) was inserted to a standard cyclonic spray chamber (Glass Expansion, Australia). After completion of the aerosol

generation, the mist was transported in argon stream to inductively coupled plasma discharge. The parameter set for the measurements with the ICP OES instrument are listed in Table 1.

RESULTS

The study was conducted on used SAE 0W16 (full syn.) viscosity grade Toyota oils from 14 Toyota hybrid engines (HEV type), 9 conventional gasoline engines Toyota. The combustion engines had a displacement of 1.8 dm³ and an output of 140 hp. The results were also compared to new engine oil. The oils were changed after 10,000 or 15,000 km. A summary of the samples, along with the measurement precision, is provided in Table 2.

On the basis of Table 2, average contents for individual metals were calculated separately for hybrid systems and gasoline engines. The summary was supplemented with oil service life and the total mileage for a given vehicle. The summary is provided in Table 3.

In order to interpret the obtained test results, Figure 1 presents the profile of metal content in used oils from combustion engines in hybrid systems, whereas Figure 2 – in oils from classic gasoline engines. The content profiles of individual metals in used engine oils from hybrid and

conventional gasoline engines were similar. The highest concentrations were observed for zinc (376 mg/kg for the hybrid and 476 mg/kg for the gasoline engine).

The lowest contents were recorded for chromium and tin, which did not exceed 55 mg/kg for both drive types. A comparison of the average content of individual metals in used oils for hybrid systems is presented in Figure 3 and the percentage increase of individual metals in relation to new engine oil in Figure 4. The total content of metals in used oil was in the range: for hybrids 745–2375 mg/kg (average: 1474 mg/kg – 171% increase compared to new oil), for petrol engines 1055–2945 mg/kg (average: 1622 mg/kg – 199% increase compared to new oil). Therefore, the total metal content turned out to be 9% lower in the used oils of hybrid systems compared to the oils used in classic petrol engines.

Despite the overall lower content of metals in the used oils from hybrid systems, there were two exceedances of the content of such typical wear metals: copper by 18.3% and iron by as much as 42.8% compared to the oils from classic petrol engines (Figure 3)

When analyzing the percentage increase in metal content in used oils compared to new oil (Figure 4), the largest increases were observed for chromium (327%) and zinc (321%) in gasoline engines, while for hybrid engines, the largest

Table 1. Operating parameters for the ICP OES determination

Parameter	Value
Rf generator frequency/MHz	27.12 MHz
Power/W	1350
Plasma gas flow rate/L min ⁻¹	14
Auxiliary gas flow rate/L min ⁻¹	0.5
Carrier gas flow rate/L min ⁻¹	0.7
Torch	Quartz, axial
Replicates	3
Integration time/s	3.0
Nebulizer type	pneumatic
Solution introduction mode	Continuous
Solution flow rate/mL min ⁻¹	1.8
Spray chamber type	Cyclonic (50 mL)
Nebulizer gas flow rate/L min ⁻¹	0.7
Rinse time between the samples/s	360
Wavelength/nm (line type)	Cd 226.5, Co (228.6), Cr (206.1), Cu (224.7), Fe (259.9), Mn (257.6), Ni (221.6), Pb (220.3), Sn (242.9), Zn (202.5)

Note: determination of Cd, Co, Cr, Cu, Fe, Mn, Ni, Pb, Sn, and Zn was calculated from linear calibration curves. Blank solution was measured after every sample to eliminate memory effects.

Table 2. List of samples and determined content (expressed in mg/kg) of metals with measurement uncertainty (H-hybrid, G-gasoline)

Sample No.	Cd	Co	Cr	Cu	Fe	Mn	Ni	Pb	Sn	Zn
H-1	61.5 ± 5.1	68.7 ± 6.6	26.5 ± 2.7	852 ± 88	850 ± 87	74.4 ± 7.6	68.8 ± 7.3	85.0 ± 9.1	25.6 ± 2.7	261 ± 27
H-2	124 ± 12	138 ± 13	54.8 ± 5.5	194 ± 20	168 ± 19	144 ± 16	138 ± 15	161 ± 17	52.3 ± 5.5	538 ± 55
H-3	197 ± 20	212 ± 21	49.7 ± 5.0	225 ± 24	260 ± 29	230 ± 24	211 ± 22	191 ± 20	15.9 ± 1.7	492 ± 51
H-4	116 ± 12	127 ± 12	35.8 ± 3.6	139 ± 15	159 ± 18	133 ± 14	126 ± 13	140 ± 15	27.2 ± 6.9	377 ± 39
H-5	53.4 ± 5.5	60.0 ± 5.8	24.2 ± 2.5	64.4 ± 6.9	76.9 ± 7.9	61.0 ± 7.1	59.4 ± 6.8	72.6 ± 7.4	22.9 ± 2.4	251 ± 29
H-6	113 ± 11	134 ± 13	45.9 ± 4.6	140 ± 16	148 ± 17	129 ± 14	125 ± 13	154 ± 17	53.6 ± 5.6	454 ± 47
H-7	121 ± 13	135 ± 13	46.6 ± 4.6	146 ± 49	159 ± 18	139 ± 15	135 ± 15	165 ± 18	58.0 ± 5.9	465 ± 48
H-8	121 ± 13	133 ± 14	50.9 ± 5.4	143 ± 15	165 ± 17	139 ± 15	133 ± 14	153 ± 16	23.7 ± 2.5	527 ± 54
H-9	76.2 ± 7.6	85.9 ± 8.5	27.2 ± 2.8	94.8 ± 9.8	108 ± 12	89.0 ± 9.8	83.8 ± 8.7	91.8 ± 9.6	21.5 ± 2.3	280 ± 30
H-10	102 ± 10.0	119 ± 12	57.2 ± 5.7	164 ± 18	240 ± 27	118 ± 12	114 ± 15	147 ± 16	53.9 ± 5.5	421 ± 44
H-11	135 ± 12	145 ± 14	10.8 ± 1.1	155 ± 17	209 ± 25	158 ± 17	144 ± 15	133 ± 14	13.0 ± 1.5	295 ± 31
H-12	109 ± 11	120 ± 12	40.3 ± 4.2	130 ± 35	149 ± 18	124 ± 13	119 ± 13	151 ± 17	52.8 ± 5.4	410 ± 42
H-13	146 ± 14	156 ± 15	32.0 ± 3.3	167 ± 19	123 ± 16	170 ± 10	154 ± 16	124 ± 14	13.9 ± 1.5	326 ± 34
H-14	81.9 ± 8.2	96.9 ± 9.8	16.0 ± 1.8	102 ± 12	155 ± 18	172 ± 18	95.4 ± 9.8	78.6 ± 8.3	14.1 ± 1.5	164 ± 18
G-1	213 ± 22	236 ± 24	96.8 ± 9.8	268 ± 28	286 ± 31	246 ± 25	236 ± 25	285 ± 29	71.4 ± 7.3	1007 ± 110
G-2	115 ± 12	124 ± 12	27.3 ± 2.8	139 ± 14	151 ± 17	135 ± 14	123 ± 13	110 ± 12	14.9 ± 1.6	270 ± 30
G-3	79.9 ± 7.6	88.3 ± 8.5	31.9 ± 3.2	116 ± 13	108 ± 12	93.0 ± 9.7	87.1 ± 9.1	100 ± 11	23.7 ± 2.5	327 ± 34
G-4	119 ± 11	128 ± 12	37.2 ± 3.9	135 ± 16	74.5 ± 8.6	138 ± 14	126 ± 14	117 ± 13	20.7 ± 2.2	396 ± 41
G-5	130 ± 12	125 ± 12	39.1 ± 2.8	135 ± 15	80.3 ± 8.5	141 ± 14	129 ± 13	127 ± 14	23.4 ± 2.2	260 ± 25
G-6	109 ± 11	120 ± 13	40.6 ± 2.3	130 ± 12	149 ± 15	124 ± 12	118 ± 12	151 ± 15	33.7 ± 3.4	310 ± 35
G-7	123 ± 10	135 ± 10	47.5 ± 3.3	138 ± 17	89.7 ± 9.1	139 ± 14	120 ± 12	135 ± 13	24.1 ± 2.5	405 ± 41
G-8	135 ± 12	133 ± 13	38.9 ± 2.4	146 ± 15	109 ± 11	148 ± 15	144 ± 14	124 ± 12	22.3 ± 2.2	295 ± 32
G-9	215 ± 21	240 ± 23	104 ± 10	269 ± 30	290 ± 28	240 ± 25	245 ± 25	288 ± 29	75 ± 6.5	1012 ± 92
New	50.2 ± 5.1	55.1 ± 5.6	11.5 ± 1.2	64.2 ± 6.6	72.2 ± 8.1	59.0 ± 6.4	54.4 ± 5.9	50.4 ± 5.4	14.5 ± 1.6	113 ± 11

increases were observed for chromium (209%), copper (203%), iron (195%), and zinc (233%). This can be used to determine the condition of engine oil by determining the concentrations of several selected metals. The content levels of certain metals, such as iron, chromium, copper, and zinc, can be an indicator of lubricant degradation and allow for the assessment of the remaining oil life. Figures 5 and 6 show the relationship between the total metal content and the distance traveled by the vehicle. Generally, increased metal content in oils (up to 3000 mg/kg) is observed in the initial period of vehicle operation up to 10,000 km, which includes the engine break-in period. It then stabilizes at 1000 mg/kg with an oil change interval of 15,000 km. This indicates the recommended need to change the engine oil for a new vehicle after the first few thousand kilometers driven during the engine break-in period due to the rapid increase in metal contamination of the engine oil. This

is particularly important when oil manufacturers introduce so-called “Long-Life” has a significantly extended service life, with oil changes occurring only after 30,000 km or two years. The quality of engine oils has improved significantly over the last 30 years. Engine oil lubricates internal combustion engines, reducing friction and wear, removing combustion residues, neutralizing acids, improving piston ring sealing, and dissipating heat from moving parts.

Although complex modern oil formulations are enriched with a range of anti-wear additives, detergents, inhibitors, dispersants, and the additives that increase the viscosity index at higher temperatures, the oil change interval of 30,000 km or every two years seems like a marketing ploy and is greatly exaggerated.

The above observations also correspond to the dependence of the total metal content on the oil service life shown in Figures 7 and 8. After exceeding one year of engine oil service

Table 3. Summary of metal content in engine oil of hybrids (H) and petrol vehicles (G) taking into account the oil service life

Sample No.	Metals total amount [mg/kg]	Oil life [month]	Distance traveled by the vehicle [km]	Total metal content in 1 kg of oil for a distance of 1 km [mg/kg km]
H-1	2375	12	9079	0.262
H-2	1712	12	9927	0.173
H-3	2084	12	18499	0.113
H-4	1380	9	29086	0.047
H-5	745	18	44782	0.017
H-6	1497	3	30045	0.050
H-7	1570	11	91900	0.017
H-8	1589	12	145214	0.011
H-9	959	9	30014	0.032
H-10	1536	8	15419	0.100
H-11	1398	6	46136	0.030
H-12	1405	5	75903	0.019
H-13	1412	13	25570	0.049
H-14	976	4	169444	0.006
G-1	2945	15	16985	0.173
G-2	1209	9	35570	0.034
G-3	1055	13	14590	0.072
G-4	1292	5	110200	0.012
G-5	1189	9	65433	0.018
G-6	1284	8	86540	0.015
G-7	1355	7	100205	0.014
G-8	1294	10	55024	0.024
G-9	2978	11	10547	0.282
New oil	544	0	0	-

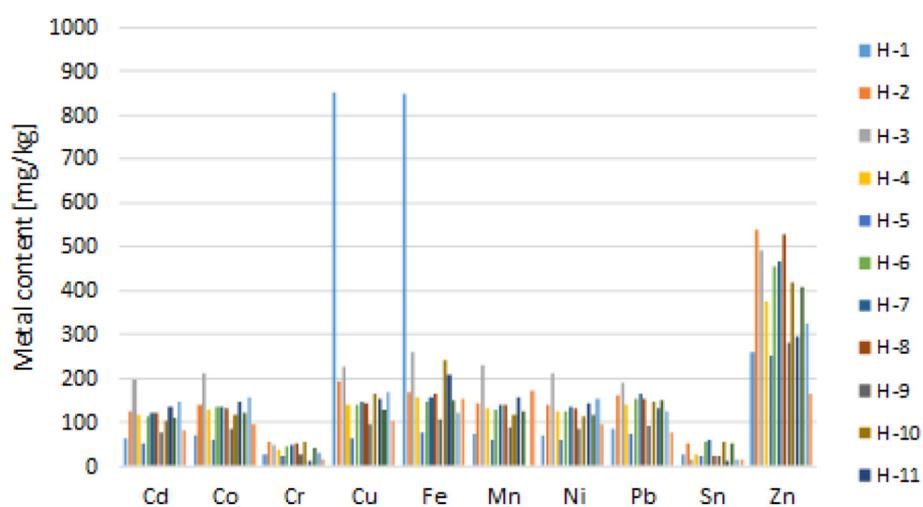


Figure 1. Profile of metal content in hybrid engine oils for individual samples

in hybrid vehicles, a rapid increase in the total metal content is observed from 1500 mg/kg to even 2400 mg/kg (an increase of 60%), and for a classic petrol engine from 1200 mg/kg to even 3000 mg/kg (an increase of 240%). On the

basis of Table 3, Figure 9 illustrates the total metal content for 1 kg of used oil per 1 km of mileage for hybrid and classic gasoline vehicles. The largest amounts of metals penetrate the oil in the initial period of vehicle operation

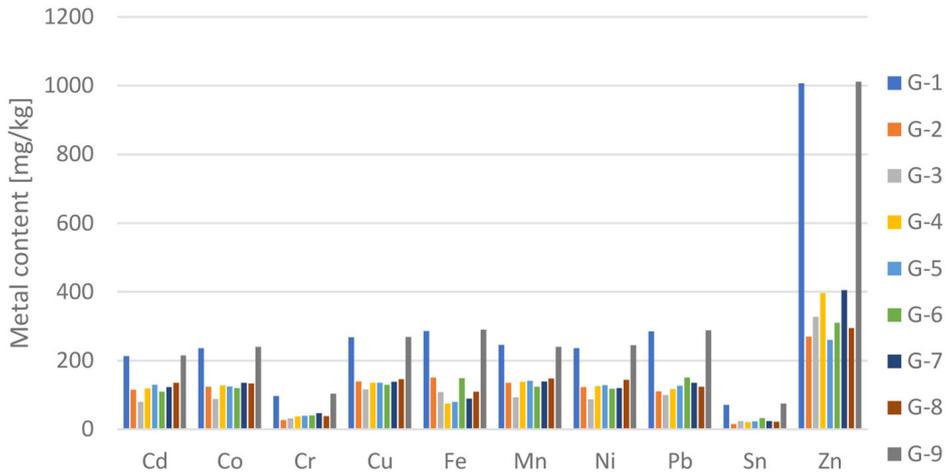


Figure 2. Profile of metal content in classic gasoline engine oils for individual samples

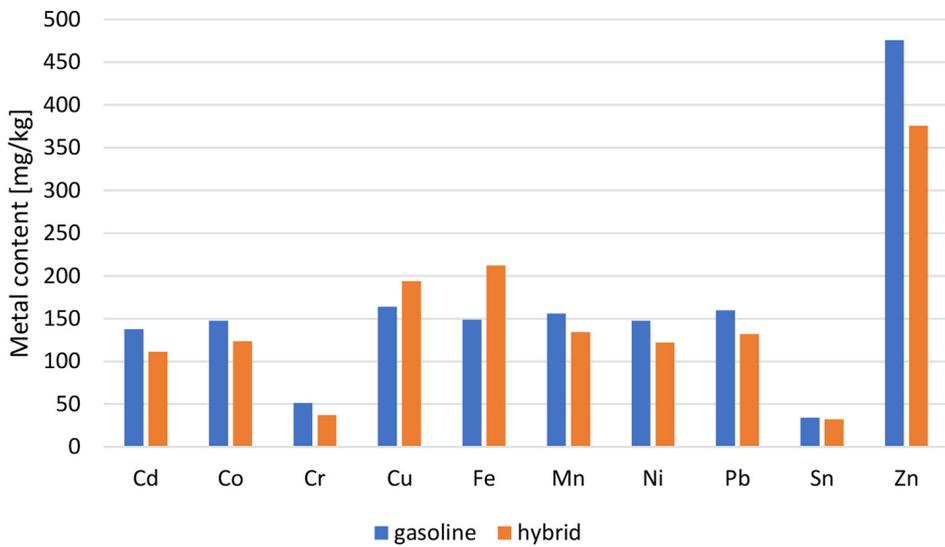


Figure 3. Average metal contents in the oils for hybrid and petrol engines

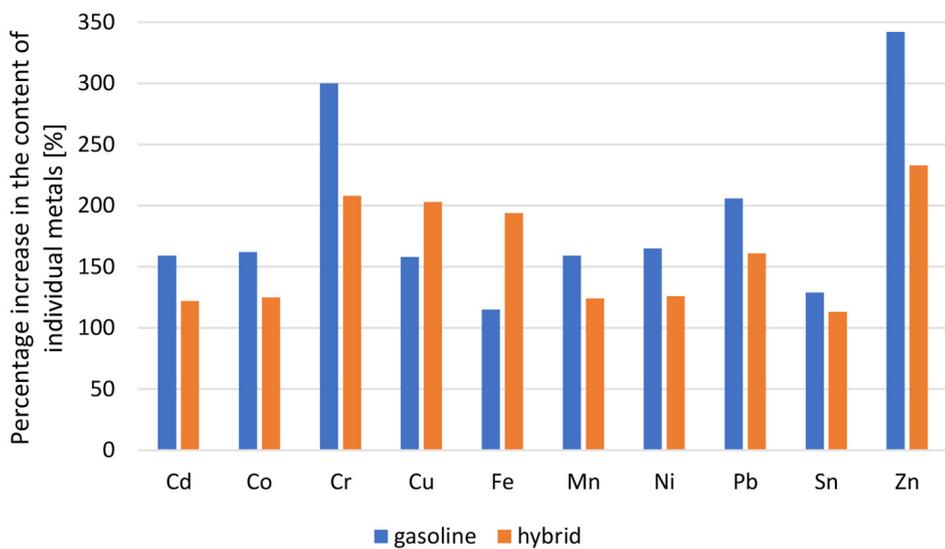


Figure 4. Percentage increase in metals in the oils for hybrid and classic petrol engines compared to new oil

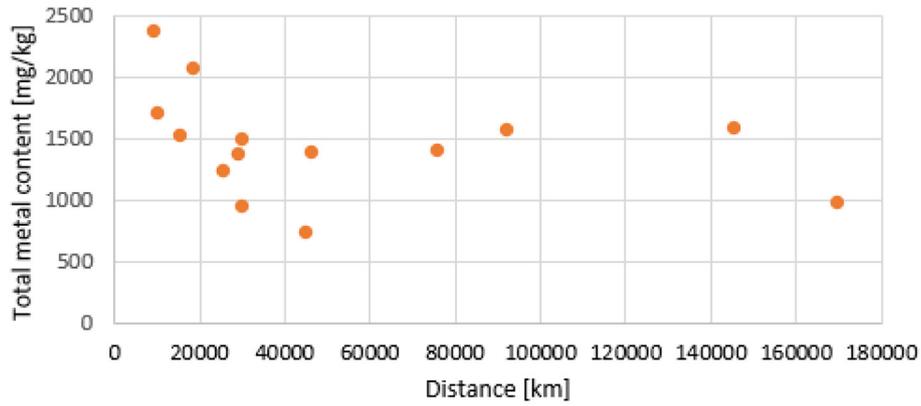


Figure 5. Total metal content in oil based on the distance traveled by the hybrid vehicle

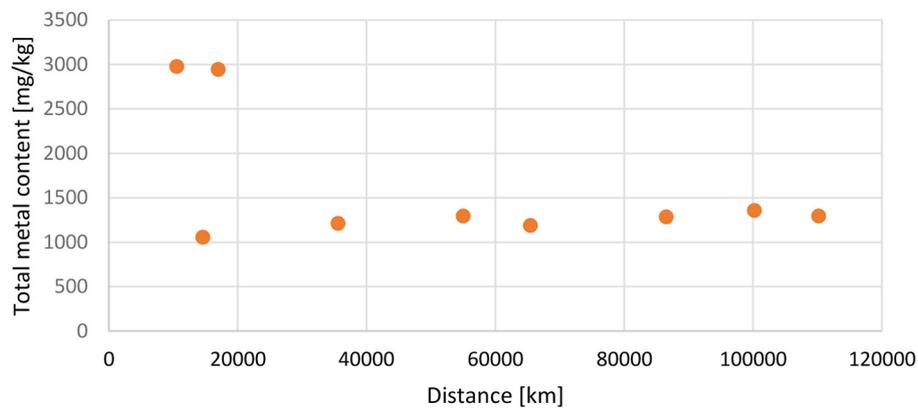


Figure 6. Total metal content in oil based on the distance traveled by a classic petrol vehicle

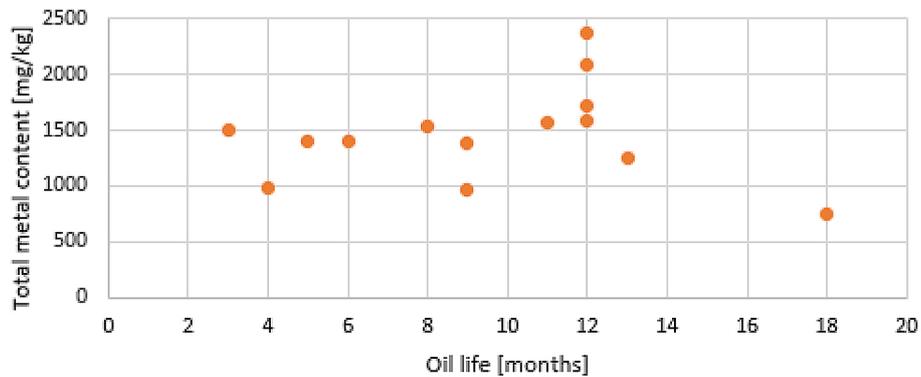


Figure 7. Total metal content in the oil since the oil was used in the hybrid vehicle

– up to 0.15 mg/kg of oil per km. After exceeding a distance of 20,000 km, the increase in metal content is much smaller and amounts to 0.025 mg/kg of oil per km. The average metal content for 1 kg of used oil per 1 km of mileage for hybrid vehicles was 0.066 mg/kg of oil per km, and for classic gasoline vehicles 0.073 mg/kg of oil per km, meaning oil degradation in hybrid vehicles was 8% lower.

DISCUSSION

For new oil, the content of most of the metals tested was found to be 50 mg per kilogram of oil. The total content of the 10 metals tested was 0.5 g/kg. The highest zinc content was observed at 113 mg/kg, resulting from protective engine oil additives. The high zinc content in fresh oils stems from its anti-wear and antioxidant properties.

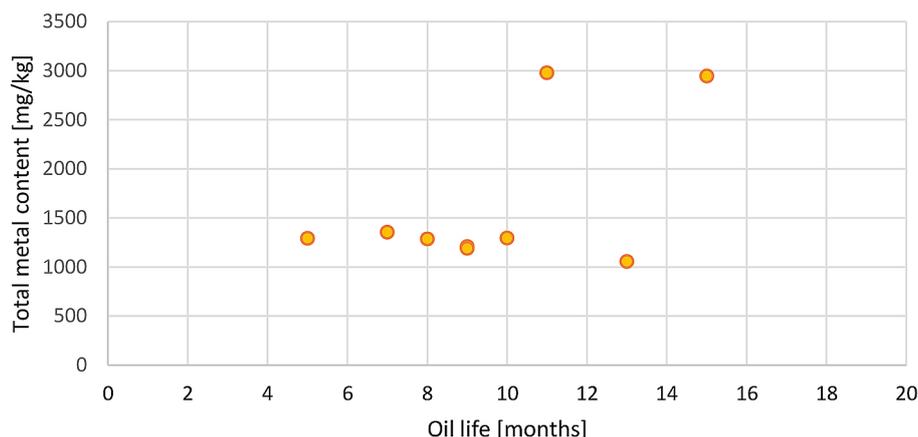


Figure 8. Total metal content in the oil since the oil was used in the classic petrol engine

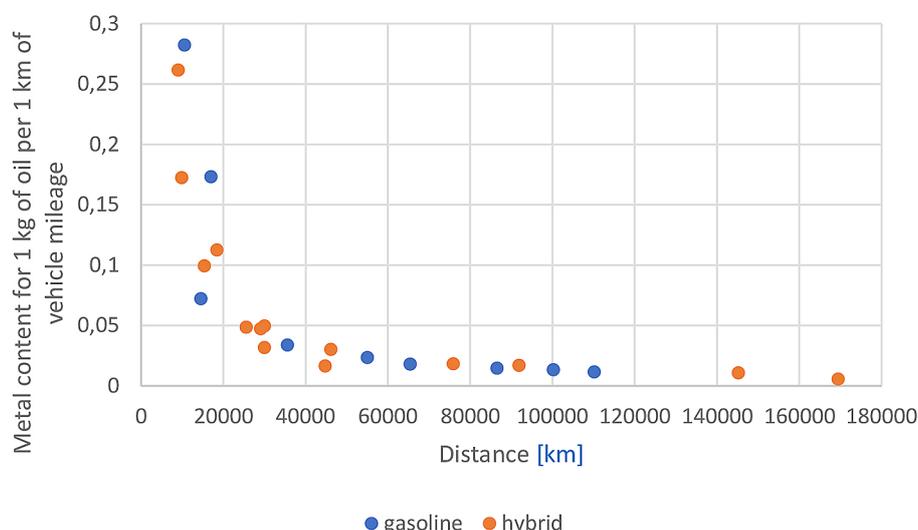


Figure 9. Metal content for 1 kg of oil per 1 km of mileage for a hybrid and classic petrol vehicle

Zinc dialkyl di-thiocarbamates (ZDDTc) are used as antioxidants and anti-wear additives in oils, particularly in lubricants, but the most common compound is zinc dialkyl dithiophosphate (ZDDP) [43–46].

The content profiles of individual metals in used oils from both hybrid systems and gasoline engines were similar. Although the fluctuations in the content as RSD (relative standard deviation) reached up to 400% for copper and iron in the hybrid system engine oil. For a classic gasoline engine, RSD also often exceeded 200%, which indicates very different methods and conditions in which a given motor vehicle was operated. The highest contents were observed for zinc (370 mg/kg for the hybrid and 500 mg/kg for the gasoline engine). The lowest contents were observed for chromium and tin, which did not exceed 50 mg/kg for both drive types.

The total metal content in used oil was in the range of 745–2375 mg/kg for hybrids (average: 1462 mg/kg – a 169% increase compared to new oil), and 1055–2978 mg/kg for gasoline engines (average: 1625 mg/kg – a 199% increase compared to new oil). Therefore, the total metal content was 9% lower in the used oils from hybrid drives compared to the oils used in classic gasoline engines.

CONSLUSIONS

When analyzing the percentage profile of the increase in metal content in used oils in relation to new oil, the greatest increase is observed for petrol engines for chromium (327%) and zinc (321%), while for engines operating in a hybrid system the greatest increase was observed for

chromium (209%), copper (203%), iron (195%) and zinc (233%).

Despite the overall lower metal content in the used oils from hybrid systems, two exceedances of typical wear metals were observed: copper by 18.3% and iron by as much as 42.8%, compared to the oils from conventional gasoline engines. Generally, increased metal content in oils (up to 3000 mg/kg) is observed during the initial period of vehicle operation, up to 10000 km, including the engine break-in period. Subsequently, it stabilizes at 1000 mg/kg with an oil change interval of 15,000 km.

To determine the degree of oil degradation, it is not necessary to measure all elements. It is likely that knowledge of the concentrations of a few selected metals can provide information regarding the condition of the oil. The levels of certain metals, such as iron, chromium, copper, and zinc suggest, can be an indicator of lubricant degradation and allow for an assessment of the remaining oil life. However, such findings would require further, more extensive research. Although hybrid vehicle drivetrains operate under variable temperature conditions due to the increased frequency of starts and stops, they are more durable and more economical due to their fuel consumption. Average fuel consumption in a standard gasoline vehicle ranges from 7 to 8 l/100 km, while in a hybrid vehicle, it is 5.5 to 6.5 l/100 km. The real benefit for a hybrid in Europe is typically 15–25% lower fuel consumption. Furthermore, the average lifespan of a hybrid vehicle is estimated at 338,000 km. The average mileage for vehicles with conventional gasoline engines is estimated at 223,000 km. The higher mileage potential of a hybrid vehicle is likely due to the lower load on the combustion engine, which is supported by the electric motor.

Such trends were observed based on these preliminary research results, which found a 9% lower total metal content in oil from the hybrid system (reduced oil degradation) compared to oil from a conventional gasoline engine. However, more conclusive findings will require further extensive research, which opens the door to discussion.

If further testing confirmed reduced oil degradation, also means less frequent oil changes and lower energy consumption for its production on a global scale. The average technological production of 1 liter of engine oil under European conditions requires as much as 10 kWh of energy. Rerefining 1 liter of used engine oil back to

base oil requires 2.5 kWh of energy. Furthermore, reduced waste means less energy and resources needed for processing and disposal of used oils.

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