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Investigation of Damage Caused by Chlorine-Contaminated Fuel in Standard Vehicle Components †

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Abstract: Several car manufacturers have encountered corrosion in certain mechanical components caused by chlorine in fuel. The current regulations governing the quality of fuel allowed for trade are briefly described. Next, this paper analyzes the possible origin of chlorine in damaged components. In particular, the phenomenon of corrosion found in EGR valves and EGR coolers is analyzed. The analyses conducted to determine the nature of the corrosion and its origin are illustrated. Finally, the effects of the phenomenon on engine operation are analyzed, depending on the type of damaged component.

Keywords: chlorine; automotive components; EGR; fuel contamination; turbocharger

1. Introduction

For several years now, many customers have discovered that the fuel in their tank is compromised by the presence of chlorine, a substance banned by regulations as harmful to the environment and causing serious damage to the mechanical systems of the vehicle. It is, in fact, an extremely harmful substance due to its ability to corrode metals, with its aggressiveness accentuated by combustion. Using contaminated fuel leads to damage to various components of the vehicle, resulting in warning lights turning on and even the vehicle being stopped.

The effects of contamination do not occur immediately after refueling but after several kilometers, depending on the concentration of chlorine present in each refueling and the number of contaminated refueling events. This is why chlorine is not always found in the tank when the vehicle is taken to the workshop, and why the customer cannot exactly identify the gas station. As of today, the phenomenon is known to automobile manufacturers, who have trained the repair network to recognize the presence of chlorine corrosion on components with simple visual examinations. Since chlorine should not be present in the fuel, the repair is not covered by warranty, and especially if the car is new or has low mileage, customers may not readily accept the diagnosis, instead blaming it on design and/or manufacturing defects.

Imagine that you have filled the fuel tank of your car with chlorine-containing fuel. The injection or carburetion system transports this fuel to the cylinders, where it burns during combustion, reaching elevated temperatures (over 2000 °C), before exhausting it through the exhaust system.

The problem, however, is not immediately noticeable to the customer because the engine does not show malfunctions right away after introducing the contaminated fuel into the vehicle, in contrast to what may occur if the fuel is impure or mixed with water. The

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first signs of damage may even occur several months after the critical refueling; the time frame depends on the concentration of chlorine in the fuel, the number of refueling events using adulterated fuel, the type of engine, its condition, and the use of the vehicle. The fact that customers generally do not always refuel from the same gas station also makes it difficult to trace the culprit.

Furthermore, depending on the type of car, the materials used, and the temperatures and concentrations reached in the various sections of the exhaust path, different components will fail; for example, the weakest point of vehicles of mostly all brands turns out to be the exhaust gas recirculation (EGR) system, while for other brands it is the exhaust tailpipes. We can apply the same reasoning to each vehicle, highlighting why the EGR system is statistically more susceptible to corrosion than, for instance, the intake components that receive recirculated cooled gases.

This topic is not dealt with in the literature, except for a relatively recent study by Wozniak et al. [1], in which the effects of running an engine with chlorine-containing fuel at a well-determined concentration are simulated on the test bench. Furthermore, the study only focuses on the effects of emission control components such as the EGR system and not on other components. Thus, there is no treatment for the problem that both analyses the effects that contaminated fuel can cause on various components and is based on the results of real cases.

The aim of this work is to present the most plausible hypotheses motivating the presence of chlorine in fuels and to evaluate the impact of the said chemical species on the engine components. This paper will then examine the potential causes of chlorine in fuel, detailing the harm it inflicts on the most impacted components across various vehicle brands and models. The main focus will be dedicated to the EGR system, followed by the turbocharger. This paper does not deal with isolated or less frequent damage to other components, such as high-pressure fuel pumps, injectors, and glow plugs, or damage to secondary components that do not affect vehicle operation, such as exhaust terminals.

2. Fuels Adulterated with Chlorine

This section analyzes how chlorine could end up in the tanks of self-drivers. It follows the raw product to the filling station to understand at what stage the contamination could occur.

2.1. Presence of Chlorine in Crude Oil

Crude oil contains many contaminants that pose a real challenge to refiners. Some of these elements are naturally present in crude oil, while others tend to accumulate in processes upstream of refining. The first step of removing these substances is desalting or desalination. After extracting the oil from the subsurface, desalting involves removing salty reservoir water, which can either disperse or emulsify the oil. If the salts (which are primarily sodium chloride, calcium and magnesium chloride, sulfides, sulfates, carbonates, bicarbonates, and metal oxides) are not removed, they can cause various inconveniences. This is particularly true for calcium and magnesium chlorides, which under certain conditions, can hydrolyze and release hydrochloric acid, leading to corrosive phenomena.

Regardless of its nature, any type of contaminant present in the crude oil that is not removed by de-salting will inevitably require chemical removal. Therefore, chlorine is of particular importance. This chemical species can exist either as inorganic chlorine (calcium chloride, sodium chloride, and magnesium chloride) or as organic chlorine. The desalination process typically removes inorganic chlorine, leaving organic chlorine in the crude oil.

It is important to consider that chlorine can react with amine treatments to form ammonium chloride, which, by settling in systems, would impair heat transfer and lead to crevice corrosion.

2.2. Presence of Chlorine in the Refined Fuel

The fuel tanks of a gas station can contain substances that are more or less hazardous to engine health. Occasionally, the issue arises from the proliferation of organisms (algae and mold) resulting from the combination of biofuel, water, and petroleum products. In 2017, an oil company in Salento admitted that many customers ended up with a broken-down vehicle after filling up with the wrong additives. In 2018, the hypotheses surrounding the now-established presence of chlorine in diesel fuel gave rise to the first reports of gasoline adulteration. Years later, the phenomenon does not seem to be stabilizing, and indeed, an increasing number of users are experiencing damage to their vehicles, regardless of brand, model, and fuel type.

The authorities' increasing frequency of seizures of illicit petroleum products only partially curtails the scourge of adulterated fuels.

Therefore, the question is as follows: How does chlorine mixed with gasoline or diesel fuel reach gas stations? To date, it has not been possible to determine at what stage of distribution the fraudulent mixing takes place. The Italian association UNEM (Unione Energie per la Mobilità), which has long been aware of this question, based on its audits, has ruled out complications related to production cycles. UNEM is a free association stemming from Unione Petrolifera that represents the main companies in the territory involved in the refining, storage, and distribution of petroleum products. Thus, the implemented controls appear to shirk responsibility upstream. However, once gasoline and diesel enter refineries, their traceability becomes more challenging. Consequently, the association advocates for more attention to the distribution chain, particularly in the areas most impacted by the phenomenon, through intensified controls by the competent authorities.

2.2.1. Possible Causes of Contamination in Diesel Fuel

For diesel fuel, in addition to the trivial fraudulent action, it can be speculated that chlorine is being used as a cheap biocide to keep in check the proliferation of bacterial flora in the tanks, which arises due to the addition of biodiesel, as allowed by norms. Thus, carelessness in the cleaning of gas station fuel tanks and car tanks cannot be ruled out a priori; for example, the use of chlorine-containing solvents (which are cheaper than those provided for normal cleaning) could end up contaminating the product distributed by gas stations.

Another possible motivation is related to the illicit trade in agricultural fuel, also known as denatured fuel. This type of fuel is intended for specific professional categories, and its purchase by ordinary citizens is strictly prohibited; indeed, those who violate the ban commit a crime punishable under the current penal code. Chemically, and in terms of technical characteristics, there is no difference between agricultural diesel fuel and ordinary vehicle diesel fuel, except for some possible additives added by specific distribution companies to improve the performance of heavy agricultural vehicles. Indeed, denatured gasoil complies with the European standard UNI EN 590 legal requirements and customs regulations; however, from a fiscal point of view, it benefits from a reduced excise duty compared to traditional diesel fuel, and for this reason, before marketing, it is treated with a dye that gives it a characteristic green color [2].

Given the substantial economic benefits, various criminal organizations are interested in the illegal trade of agricultural fuel, but removing the artificial coloring is a prerequisite. Generally, the dye is relatively easy to remove by using a bleaching agent [3], which can react with colored organic compounds and transform them into colorless compounds. Oxidizing agents, which are chemicals that can remove electrons from other molecules, comprise most bleaching compounds, with chlorine serving as the active agent. Chlorine is a potent oxidant.

2.2.2. Possible Causes of Contamination in Gasoline

Pure chlorine is expensive and only soluble in water, so it is unlikely to dissolve voluntarily in gasoline. Since it cannot mix directly with hydrocarbons, it would end up at the bottom of the tank, activating special sensors that would block product dispensing. We must reject this hypothesis a priori for gasoline, as it fails to address the issue of algae presence. The only plausible explanation for gasoline contamination is that the fuel is mixed with waste liquids from industrial processing (which frequently contain chlorine). Instead of following the legal procedures for disposing of such wastes, criminals take control of them, diluting them into petroleum products and potentially reselling them through companies with fictitious nominees. Illicitly used waste substances burn only at high temperatures (chlorine itself is an oxidizer, like oxygen), leaving highly corrosive residues. Waste solvents of this type include, for example, tetrachloroethylene, trichloroethylene, and trichloroethylene, which, when burned, release corrosive products such as hydrochloric acid.

Some of the affected vehicle's tanks contain up to 1200 mg of chlorine per kg of analyzed substance; a significant amount that could not have resulted from a transfer error between a depot and a tanker truck, for example.

3. Effects of Chlorine on the EGR System

3.1. EGR System

In the latest generation of powertrains, the need to lower concentrations of NO_x has forced the use of high-efficiency EGR systems to treat exhaust gases before they make their final steps to the outside environment [4]. EGR systems work by recirculating a portion of the exhaust gases back into the cylinders. The exhaust gases reintroduced into the chamber join the fresh charge fed in by acting as an inert gas, which absorbs the heat generated during exothermic reaction and dilutes the concentration of oxygen in the combustion zone. This lowers the combustion temperature and consequently significantly reduces NO_x emissions.

There are different EGR systems, each with their respective advantages and disadvantages. In general, in both Otto and diesel engines, EGR is applied at partial loads so as not to sacrifice the power developed at full load, and the achievable effect differs depending on the type of fuel supply. In a conventional diesel engine, at partial loads, combustion gases (consisting of CO_2, H_2O, and O_2) replace some of the excess air; in conventional spark ignition engines, at partial loads, combustion gases (consisting of CO_2 and H_2O) are added to the fresh charge, resulting in dilution of the charge [5]. Dilution has two effects: it reduces the amount of oxygen present and lowers the maximum temperature achievable in the chamber. Diesel engines can only benefit from a reduction of maximum temperature, but this is usually enough to contain NO_x, possibly even in cooperation with other systems. In any case, the use of EGR can lower the NO_x emission by up to 60 percent, considering that the system can achieve up to 40 percent of the total gas recirculation rate. If the recirculation rate were to exceed this value, a further reduction in the emission of NO_x would be achieved, but due to the shortage of oxygen, the emission of unburned hydrocarbons (*HC*) and particulate matter (*PM*) would increase significantly.

Referring to the cylinder, a distinction is made between internal EGR and external EGR; in diesel engines, the latter type prevails, while in Otto cycle engines with variable valve timing, the former may be opted for [6].

Internal recirculation can occur through either the intake valve or the exhaust valve. The intake valve brings back into the cylinder the mass of combustion gases that are moved to the intake manifold during the crossover (when both valves are open), and the exhaust valve brings back into the cylinder the combustion gases from the previous cycle. It may be possible to directly prevent gas exit at the cycle end. Regardless of the specific case, variable valve timing can control the recirculated mass.

The external EGR system is now described, from a general view, as the one affected by chlorine corrosion [7].

For this type of system, the location of exhaust gas extraction and recirculation typically makes the most significant difference. The most popular system on the market is high-pressure EGR (HP-EGR), shown in Figure 1a. In this system, the exhaust gases are taken out partially before they expand in the turbine and are then recirculated after going through a heat exchanger (EGR cooler) that is separate from the intercooler. The second most common system is low-pressure EGR (LP-EGR), Figure 1b, which extracts exhaust gases downstream from the turbine's expansion and reintroduces them into the airflow before compression. From a performance point of view, the LP-EGR has greater potential than the HP-EGR; in LP-EGR, all exhaust gases pass through the turbine, thus enabling better turbocharger performance [8].

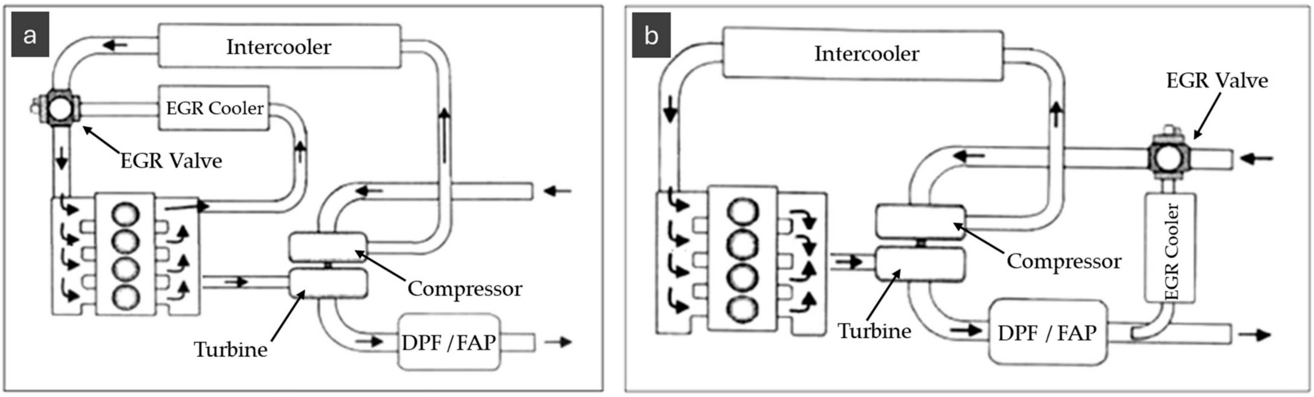

Figure 1. Schematic diagram of the most popular system on the market for EGR: high-pressure (**a**) and low-pressure (**b**) EGR.

LP-EGR is also known as long route EGR because the exhaust gas path is longer than in HP-EGR. This aspect promotes the mixing of recirculated exhaust gas with fresh air from the intake, resulting in a more homogeneous mixture that improves NO_x reduction. Additionally, exhaust gases are extracted after the particulate filter (DPF or FAP); in this way, they reach the cylinders in a cleaner condition, thereby preserving engine durability. However, the high-pressure system is more widespread than the low-pressure system mainly because:

1. A few particles may stay in the exhaust stream even after the LP-EGR system's exhaust gases go through the after-treatment parts. These particles could still cause erosion on the compressor impeller as it spins very quickly.
2. The heat exchanger generally has rather narrow cooling ducts, which can be problematic if particulate matter accumulates for a prolonged period. Indeed, high-pressure drops may arise, resulting in reduced engine performance and increased fuel consumption.

3. Many heat exchangers are made of aluminum because of their high thermal conductivity and low weight. It is well known that aluminum corrosion resistance is highly dependent on the *pH* of its operating environment [9]. This becomes critical when the gases to be processed are mixtures of exhaust gas and fresh air [10].

Many engines currently have both a high-pressure and low-pressure EGR system, and both are refrigerated and equipped with the appropriate cooler to comply with the more restrictive anti-pollution regulations [11].

3.1.1. EGR Cooler

By cooling the gases, there is a decrease in peak temperature and combustion rate, leading to a 70% reduction in NO_x emissions [12]. The EGR cooler is made of stainless steel or aluminum alloys. The materials chosen must provide excellent resistance to high temperatures and pressures (more than 700 °C and 3 bar) as well as chemical attack by condensed exhaust gases [13]. The EGR cooler, in general, is not to be considered a wear component; however, extreme temperature fluctuations and missing or aggressive coolant additives can cause leakage (internal or external). This may initially go undetected due to higher exhaust gas backpressure than coolant pressure (when the engine is running). To a more indirect extent, the accumulation of particulate matter and debris in the EGR system can also be a cause of failure. In the presence of cracks in the EGR cooler, exhaust gas pressure can drop sharply, leading to a major drop in engine performance due to a lack of boost pressure [14].

EGR coolers are mostly of the shell and tube type; in them, the flue gases circulate inside the tubes while the coolant fluid flows inside the shell by lapping the tubes from the outside. Experimental results reveal that increasing the number of tubes with larger shell sizes is required (resulting in a diminution of the heat transfer coefficient), but the heat transfer surface area will increase and the pressure drop will decrease. However, an increase in the number of tubes leads to an increase in weight and manufacturing costs [15], as the cooler is often directly connected to the EGR valve. However, some coolers also feature an exhaust gas bypass solenoid valve, which prevents the cooling of the recirculated gases, thereby preventing engine choking during start-up phases or when bringing the engine and catalyst up to temperature quickly.

The EGR system provides fertile ground for chlorine-contaminated flue gases, with pressures, humidity, and temperatures that facilitate the formation of hydrochloric acid, making the corrosive action particularly aggressive. As a result, abundant deposits (rust, dust, and yellow-green crystals, a symptom of the presence of hydrochloric acid) form in the channels traversed by recirculated gases, and their presence, when combined with particulate matter, often leads to the accumulation of residues in the EGR valve.

As a result of these accumulations, the vehicle will begin to exhibit fueling irregularities and shut down unexpectedly. When the corrosion reaches the last stage, the metal walls of the EGR cooler will fail; this will result in a loss of coolant, and the proportion of fluid in the expansion tank will drop. If the customer does not notice, the vehicle may eventually start emitting white smoke from the exhaust, a clear indication of damage, when it is too late. The white smoke is in fact due to the combustion of coolant from the EGR cooler, which mixes with the flow of exhaust gas recirculated to the cylinder. Any mixing of the chlorine with the engine oil then reduces the lubricating capabilities, leading to overheating, seizures, and failure.

We analyzed numerous EGR coolers from various brands and models, made of different materials. Chlorine corrosion is already present in the mating flanges of all of them; indeed, Figure 2 shows the typical white/yellowish residues of hydrochloric acid around the corroded areas.

Figure 2. Examples of EGR coolers that are affected by chlorine corrosion; the three cases shown relate to increasingly severe degrees of corrosion.

Samples of particulate matter from the gas passage sections were analyzed in order to confirm the presence of chlorine. An initial scanning electron Microscope (SEM) analysis was performed, as depicted in Figure 3, revealing the presence of white-colored particulate residues. Subsequent analysis by energy dispersive X-ray spectroscopy (EDS) on some of these residues revealed significant chlorine concentrations by weight up to more than 30 percent, depending on the type of sample examined.

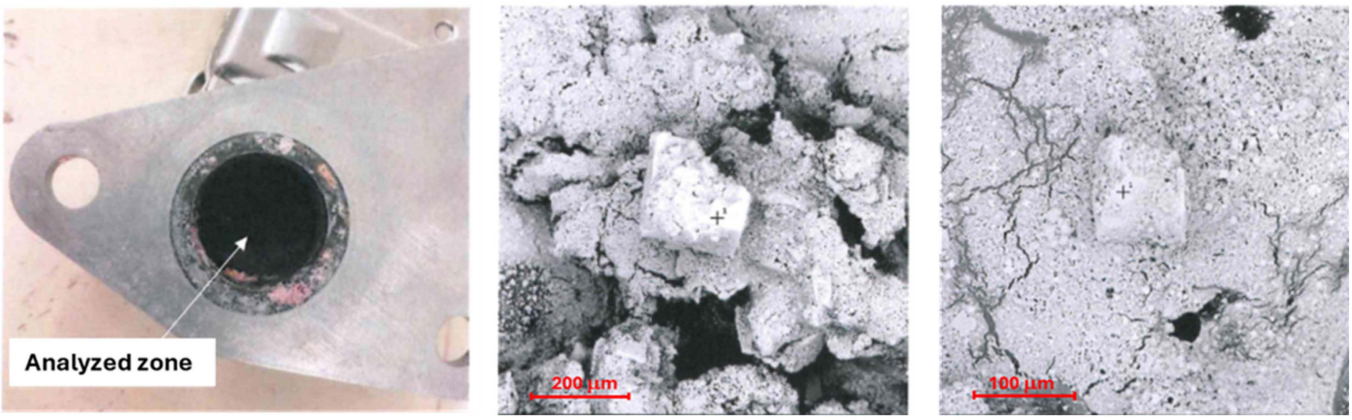

Figure 3. SEM analysis at different magnifications of a soot sample taken from an EGR cooler.

The same analyses were repeated on the white/yellowish residues adhered to the exhaust gas passage surfaces and the same results were obtained, confirming the non-negligible presence of chlorine. These analyses are enough to confirm the presence of chlorine in the fuel. Indeed, only the coolant and exhaust gases pass through the EGR cooler; therefore, the presence of chlorine can only come from the exhaust gases, and consequently, from the fuel.

The conducted analyses consistently revealed the presence of chlorine, irrespective of the material used for the cooler and the type of fuel used (diesel or petrol). Despite their special design to withstand corrosion from substances in the exhaust gases of compliant fuels, such as sulfuric acid or nitric acid [16], these components were powerless against hydrochloric acid's highly corrosive attack. Regulations forced the absence of chlorine in fuels for market sale, owing to these highly harmful characteristics. At the outlet of the cooler, gases are sent to the EGR valve.

In the following section, we describe the effects on this component.

3.1.2. EGR Valve

In engine operation, EGR valves are a delicate component. Indeed, because exhaust gases contain solids, such as carbonaceous particles, the passages through which they must pass are subject to obstruction, which can reach levels that disrupt the flow. In addition, many engines are designed to conduct exhaust gases to the intake of multiple cylinders. A clogged cylinder could direct all the recirculated gas flow to a single cylinder, leading to irregular ignition and a common misdiagnosis. The buildup of carbon residue inside the EGR valve can cause it to be stuck in the open position, resulting in irregular idling or a drop in engine power. Failures of the sensors that monitor gas flow, or the ducts and wiring that control the system, are also very common. In addition, carbon in the exhaust gas can also coat the throttle body. In this case, uneven idling and engine sputtering are possible. Cleaning the valve often solves this issue [6].

As observed in the cooler, using chlorine-tainted fuel leads to the accumulation of corrosion deposits in the tubes used for recirculated gases. These deposits, along with particulate matter, can often cause the EGR valve to stick [1].

Many components from vehicles of different brands and models, combined with the previously illustrated coolers, were also analyzed to examine the valves. Visually, the presence of chlorine has already caused an abnormality. Indeed, even in this component, there are copious traces of oxidation in the areas integrated by the passage of gases, such as at the interface with the cooler. Figure 4 shows some damaged components; the red arrows highlight the part where corrosion is present.

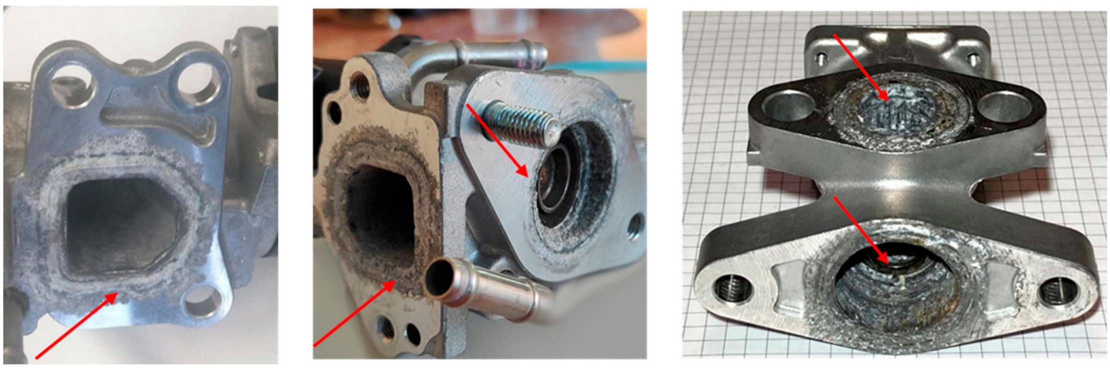

Figure 4. EGR valves affected by chlorine-loaded corrosion. Red arrows highlight valve connection areas with unmistakable signs of corrosion.

Some valves were dissected to examine the entire fluid passage surface, which revealed a whitish, grainy deposit firmly attached to the metal. Figure 5 shows a stuck valve due to chlorine corrosion. The analysis of the shutter stop area and the plunger working area revealed how the corrosion impacted the valve's blockage, as evidenced.

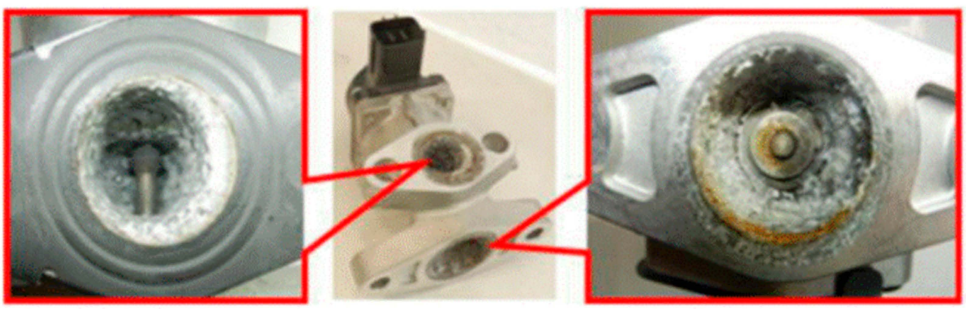

Figure 5. EGR valve damaged by corrosion. The highlighted details on the right and left show how the action of corrosion leads to the blocking of valve operation.

The results obtained by EDS show the presence of elements that are normally contained in fuel combustion residues, such as sulfur, but also the presence of pollutants that should not be present, such as chlorine, calcium, and fluorine.

Figure 6 illustrates the analysis of a valve as an example. More specifically, the portion outlined in yellow in Figure 6a was extracted from the section of the valve, and the detail indicated with 1 in Figure 6b was analyzed by SEM, detecting the presence of pitting and intergranular corrosion, as is visible in Figure 6c.

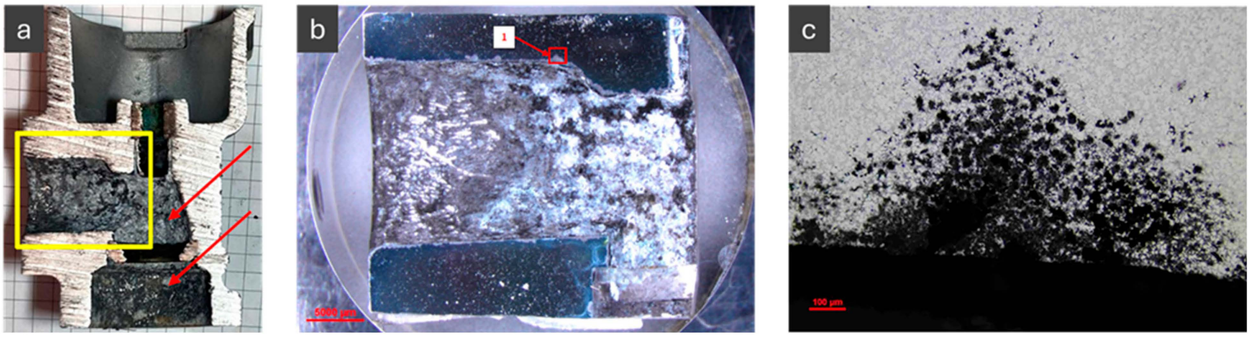

Figure 6. (**a**) sectioned of a damaged EGR valve; (**b**) stereomicrograph of the specimen; (**c**) 100× SEM detail.

3.2. Turbocharger

Exhaust gas turbocharging is an attempt to recover some of the energy loss due to the residual pressure of the exhaust gases [17]. The turbocharger then recovers a portion of the exhaust gas energy and uses it to turbocharge the engine. By increasing the mass of air sent into the combustion chambers, the torque and power output of the powerplant are significantly improved without re-displacement.

The turbocharger consists mainly of two vane impellers, the turbine (centripetal radial type) and the compressor (centrifugal radial type). A shaft connects them mechanically, and floating plain bearings housed on special housings machined in the crankcase support them. The turbine impeller is usually made by high-precision casting in an alloy of austenitic steel and nickel, while the compressor impeller is obtained by light alloy die casting. The turbine is inserted in a crankcase communicating with the exhaust ducts, while the compressor is housed in a crankcase communicating with the intake ducts.

In contrast to the EGR system, where the condensed gases are responsible for the corrosive phenomena, in the turbocharger, the focus must be more on a different fluid, namely the lubricant. Indeed, once the cylinder nebulizes the chlorine-containing fuel, a small amount of this fluid seeps through the piston rings. This fluid then partially absorbs the lubricating fluid, which acts on the connecting rods, cylinders, and pistons in these conditions. The lubricating oil undergoes filtering, and its well-known function is to halt the lubricant's premature degradation from solid impurities, such as metal particles removed by friction, particulate matter, and silica or lime dust. The problem is that regular filters cannot hold onto liquids or impurities that are dissolved in the oil. They also cannot change the way the oil changes chemically and physically during machine operation, such as when it comes into contact with chlorine and then absorbs it.

Lack of power and reduced powertrain performance are the first signs of damage to the turbocharging system due to the introduction of chlorine-adulterated fuel into the vehicle. Chlorine in the oil causes oxidation and scoring of the bearings and washers that support the turbo shaft. Indeed, the shaft of the vane element has a certain amount of clearance to allow the lubricant to create the sustaining meatus; it happens that due to the corrosion caused by chlorine, the width of the clearance increases, causing the sustaining system to lose efficiency. The turbine/compressor vane assembly then begins to streak against the crankcase, and in addition to damage, significant overheating develops due to steel/steel contact at high speed [18]. Thermal conduction causes the oil in contact with the overheated parts to deteriorate, drastically reducing its viscosity, and leading to disastrous consequences for the components it impacts [19]. The phenomenon is self-exacerbated, and the contact of the impellers with their crankcases becomes more and more severe until scoring with consequent torsion failure of the shaft. Figure 7 shows the elements that suffer from this type of failure.

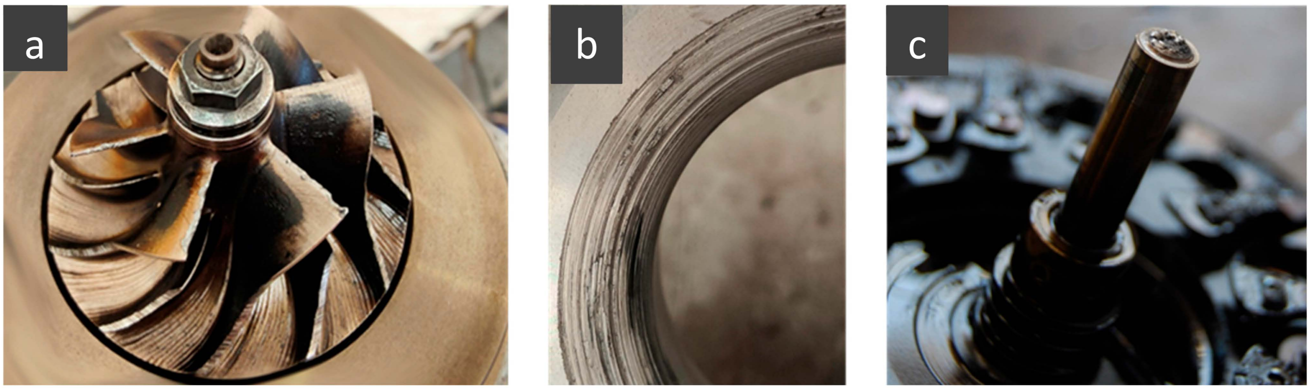

Figure 7. Details of a damaged turbocharger assembly. The pictures show the effects of damage to the bush: (**a**) interference effects on the compressor blades; (**b**) signs of blade contact with the case; (**c**) shaft broken due to torsion.

However, damage to the turbocharger is not solely caused by the lubricant; polluted exhaust gases also play a role. As an example, the analysis results from a failed turbocharger of a gasoline vehicle are represented below, specifically focusing on the turbine near the impeller. Analysis of the solid residue by SEM reveals the presence of irregular and various particles, as shown in Figure 8; EDS analysis on one of these particles reveals that this residue consists of carbon, oxides, and other elements, among which, chlorine appears in the amount of about 2.7%.

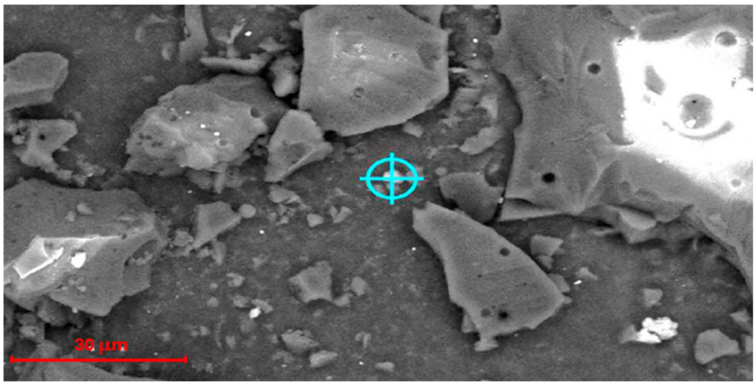

Figure 8. SEM image of the residues analyzed with EDS.

These analyses make it possible to establish how the presence of chlorine in the fuel affects even the turbocharger assembly, which can be damaged to the point of rupture. Given the temperature and pressure conditions that the exhaust gases reach in this component, the corrosion on the elements in contact with the exhaust gases is not as evident as for the EGR system; however, contamination of the lubricating oil with chlorine leads to the effects shown above. Due to the absence of noticeable corrosion traces, contaminated fuel and turbocharger failure seem to be unrelated. This would explain why the case history of turbocharger failure associated with chlorine is relatively low to date.

4. Conclusions

In the present work, after analyzing the causes that can lead to the presence of chlorine in the fuel, the damage that the use of fuels adulterated with chlorine can occur on some components of vehicles was analyzed. The phenomenon appeared to impact nearly all brands and models, powered by both diesel and petrol. This study focused specifically on two components. The first is the EGR system, which appears to be always affected by chlorine corrosion due to the pressure and temperature conditions that exhaust gases reach when passing through this system. The second is the turbocharger, which is not always directly affected by the corrosion phenomenon, but it can fail due to the effects of contamination of the engine oil with chlorine. These conditions lead to the formation of hydrochloric acid, which attacks the surfaces of the components that are crossed by the exhaust gases until they enter the cylinders. In the combustion chamber, chlorine also reaches the lubricating oil, which, when introduced into the lubrication circuit, can cause further damage. This paper specifically analyzes the damage that chlorine-containing oil can do to the shaft friction bearings of the turbocharger assembly. In the case of the EGR system, the failure of this component is not always associated with chlorine due to the absence of obvious traces of corrosion present. Therefore, it may happen that on vehicles that have been repaired due to the use of adulterated fuel, the oil is not replaced or, even if it is replaced, the degenerative process of the bushings of the turbocharger impeller shaft has begun.

Unfortunately, the damage that chlorine causes to vehicle components and the engine can vary significantly, depending on the concentration of hydrochloric acid affecting these components and the duration of exposure. Indeed, it may be the case that using a single full tank of contaminated fuel may not cause obvious damage, depending also on the concentration of chlorine in the fuel input. However, prolonged use irreparably causes various components to fail. Restoring the vehicle, by replacing, for example, the EGR cooler and the EGR valve and cleaning the fuel tank and fuel system, brings the vehicle back to efficiency but may not necessarily solve the problem. Indeed, using additional adulterated fuel not only corrodes newly installed components, but corrosion continues on the previously partially involved ones too, leading to their eventual failure. Therefore, as time goes by and with prolonged use of chlorine in the fuel, the damage is more and more extensive to the point of involving the piston rings, with consequent major ruptures of the engine crank gear.

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