Impact of contaminants on engine oil: a review

S Rațiu, A Josan, V Alexa, V G Cioată and I Kiss

University Politehnica Timișoara, Faculty of Engineering Hunedoara, Department of Engineering and Management, 5 Revoluției Street, 331128 Hunedoara, Romania

E-mail: sorin.ratiu@fih.upt.ro

Abstract. Contaminants in engine oil alter its structure in different ways, depending on their nature, leading to the degradation of the lubricant and, if it is not replaced in time, even to loss of engine performance and its failure. Consequently, both for environmental reasons and from an economic point of view, it is important to be aware of the danger that these substances may present. This paper offers an investigation of the engine oil contaminants in general, emphasizing the most dangerous ones. It also includes the causes that contribute to their appearance, the types of contaminants, the way they act, the processes that result from contamination and the impact they have on engine components.

1. Introduction

The internal combustion engine is an assembly that includes both fixed and moving parts. In the operation of the engine, different types of friction may appear (dry, semi-dry, liquid and semi-liquid). To minimize the effects of friction (overheating and wear of parts), various lubricating oils are used that provide a protective film that reduces contact between the moving components of the engine [1]. Besides the lubrication role, the engine oil also performs a series of other functions, such as cooling certain parts of the engine, sealing possible clearances that could appear (especially in pistons and cylinders), offering protection against corrosion and cleaning the residue that otherwise would clog the engine. During these operations, the lubricant absorbs various contaminants and is subjected to physico-chemical and thermal processes that degrade its structure, ultimately leading to oil breakdown and the formation of used engine oil, which if not changed in time is harmful to the components and impedes the proper operation of the engine.

Contaminants that lead to engine oil degradation are of a wide variety. From particles of sand and dust absorbed through the intake air to water, fuel or drops of coolant, including metal fragments and oxidation products, all these substances destroy the structure of the lubricant, affecting the additives that improved its properties and modifying their chemical composition. Thus, the oil not only can no longer fulfill its function of protection of engine components, but also acts as a factor of enhancing engine wear and endangers the entire operation of the vehicle. Consequently, constant monitoring of the quality of the lubricant becomes necessary, as well as a periodic change of the used oil.

The purpose of this article is to provide as broad a view as possible of the contaminants that lead to engine oil damage. It is a strong link between an engine oil that is in good working order and performance and engine life. Thus, it is necessary to know the processes and substances that could destroy the quality of the lubricant, their causes as well as the risks they pose.
2. Types of contaminants

It has been established that engine oil contamination is a factor that causes oil deterioration and, consequently, engine wear. Some of the frequent sources of contaminants include dirt, sand and dust in the air, soot, unburned fuel in oil, water from condensation from the combustion process, wear and tear of metal particles that the oil filter cannot capture, by-products of corrosion and degraded additives. Table 1 presents a summary of the most common contaminants that can be found in used engine oil, as well as the issues they present for the engine life.

| Contaminant type | Sources | Impact |
|------------------|---------|--------|
| Soot            | Combustion blow-by | Abrasion, engine oil breakdown |
| Dust and sand   | Intake air | Abrasion and fatigue |
| Fuel            | Blow-by-rich mixture | Engine oil breakdown |
| Exhaust gases   | Combustion blow-by | Engine oil breakdown |
| Water           | Combustion blow-by | Corrosion and engine oil breakdown |
| Particles of metals | Engine wear | Abrasion, fatigue, engine oil breakdown |
| Metal oxides    | Corrosion/Engine wear | Abrasion, fatigue, corrosion |
| Oil oxidation   | Thermal degradation/contact with atmospheric air | Oil thickening |
| Acids           | Engine oil breakdown/Combustion blow-by | Corrosion |
| Glycol          | Coolant leakage | Engine oil breakdown |

Figure 1. Contaminant phases in used engine oil [3]
Abrasives, fuel, water and coolant are considered the most dangerous contaminants in the used engine oil. The causes that lead to their apparition, as well as the risks they pose and the means of identifying them are presented in Figure 2.

3. Mechanisms of contamination

There are four major routes by which the contaminants infiltrate the engine oil [5]:

1. Built-in contaminants: even if engine oil manufacturers follow all necessary procedures to prevent the ingress of contaminants, through rigorous quality control, there is a possibility that certain particles, such as abrasive materials, polishing compounds, casting materials or fibers remain after the manufacture and control processes.

2. External ingress: this category includes especially the solid particles from the intake air. They have melting points considerably above the temperatures reached in the diesel combustion process, thus remaining hard abrasive solids [5]. Impurities can also be carried into the engine oil through the blow-by process. Blow-by occurs when there is a leakage of air-fuel mixture or of combustion gases between a piston and the cylinder wall into the crankcase of the engine [6]. The gases are forced through the piston ring clearances by the strong pressure shock wave created during combustion, and then they are wiped by the rings into the oil sump on the next down stroke of the piston. A similar process happens to the exhaust gases, which may contain unburned fuel, water, nitrous oxide, soot, and other partially burned hydrocarbons, impurifying even further the engine oil. Also, water and coolant (containing glycol and other anti-freeze substances) are admitted into the oil cavity under pressure through defective head gaskets, or through cracks in the block [5].

3. Internal generation: it consists of oil breakdown, followed by the process of engine component wear. There are five forms of wear that occur in IC engine components: abrasion, fatigue, adhesion, corrosion, and erosion [7]. If wear debris and materials from lubricant breakdown accumulate in the oil, the result is more wear, generating more contaminants. The process of particles wearing surfaces and generating new particles that in turn cause more wear is known as the chain-reaction-of-wear [5]. Oil breakdown includes, besides the diminution of its properties, an increase of detrimental substances, such as acids, additive precipitates, sludges and various gels that affect engine components and clog flow passages.

Contaminants introduced to the lubrication system during maintenance: these can come from disassembly/assembly activities, as well as from make-up oil addition [8].
Figure 3. The mechanisms of engine oil contamination [9-12]

4. Impact of oil contamination on engine components
In addition to the damage to the engine oil itself, contamination leads to wear on the engine components. Manifested in 5 forms (Figure 4), this process leads to engine damage and the appearance of risks in terms of operation at optimal parameters of the entire car.

The effects of lubricant contamination on engine components can take the following forms:
1) Abrasion: this type of wear (Figure 5) occurs when a hard material rubs against a soft or hard material in direct contact. It may also happen that hard particles are present at the interface as contamination or as “third body”. The third body is defined as the wear debris or oxidized particles that are trapped at the interface [13]. Abrasion is then a material removal process in which the affected surfaces lose mass at some controlled or uncontrolled rate [14].
2) Adhesion: this is that part of the wear leading to material being moved around rather than removed (Figure 6). Large adhesive forces between materials lead to plastic deformation and material removal in the form of highly deformed flakes. Very large adhesive forces can also lead to what is known as cold welding at localized contact points. The cold-welded part can also tear-off the material locally [7].

3) Corrosion: wear may be accelerated by corrosion (oxidation) of the rubbing surfaces. Increased temperature and removal of the protecting oxide films from the surface during the friction promote the oxidation process. Friction provides continuous removal of the oxide film followed by continuous formation of new oxide film [14]. Corrosive species found in lubricating oils include naturally occurring sulphur compounds, acidic combustion products (oxy-acids of nitrogen and sulphur), acidic oil oxidation products, water, and carbon dioxide. The result of corrosion is shown in Figure 7.
4) Erosion: this process takes place when a small solid or liquid particle impacts a solid surface, deforming it. If such impacts are repeated over and over again with continuous impact of particles, there will be removal of the material locally, resulting in erosive wear (Figure 8) [7].

![Figure 8. Erosive wear [18]](image)

5) Fatigue: it is caused by a cycling loading during friction. Fatigue occurs if the applied load is higher than the fatigue strength of the material. Fatigue cracks start at the material surface and spread to the subsurface regions. The cracks may connect to each other resulting in separation and delamination of the material pieces (Figure 9).

![Figure 9. Fatigue wear [19]](image)

5. Conclusions
Contamination of engine oil during its use as a lubricant is inevitable. There are multiple ways for engine oil to get altered, such as built-in contamination, external and internal ingress and contamination during the maintenance activities. The most common impurities are: sand and dust, soot, fuel, water, exhaust gases, coolant, acids, and metallic particles. Of these, the ones that most critically affect the proper functioning of engine oil are abrasives, water, fuel and coolant. The most severe consequence of oil contamination is engine component wear, which manifests itself in five forms: abrasion, fatigue, adhesion, corrosion, and oil breakdown. The wear debris and materials from lubricant breakdown accumulate in the oil, resulting more wear, which in turn generates more contaminants. The process of particles wearing surfaces and generating new particles that in turn cause more wear is known as the chain-reaction-of-wear.
There is no possibility of completely avoiding engine oil contamination, but if certain steps are followed, such as choosing the right oil, changing the used oil in time, keeping filling tools and items clean and investing in technology to identify the type of contamination could minimize the risks that a severely contaminated engine oil poses for the entire engine system and for the automobile itself.

References
[1] Rațiu S, Alexa V, Josan A, Cioata V G and Kiss I 2020 Study of temperature dependent viscosity of different types of engine used oils, J. Phys.: Conf. Ser. 1426 012001
[2] Penchaliah R, Harvey T J, Wood R, Nelson K and Powrie H 2011 The effects of diesel contaminants on tribological performance on sliding steel on steel contacts, Proceedings of the Institution of Mechanical Engineers, Part J: Journal of Engineering Tribology 225 779-797
[3] Ali M K, Ezzat F H, El-Gawwad K and Salem M M M 2017 Effect of Lubricant Contaminants on Tribological Characteristics During Boundary Lubrication Reciprocating Sliding, Appl. Phys. Corneli Uni. arXiv 1710 04448
[4] *** https://oil-testing.com/identifying-engine-oil-contamination/
[5] Addison J A and Needelman W M Diesel Engine Lubricant Contamination and Wear, Scientific and Laboratory Services Department Pall Corporation, New York
[6] *** https://woodstockpower.com/blog/what-is-engine-blow-by/
[7] Katiyar J K, Bhattacharya S, Patel V K and Kumar V 2019 Automotive Tribology, Springer, Singapore
[8] *** http://www.uslube.com/contamination.html
[9] *** https://www.indiamart.com/proddetail/lubricant-oil-testing-services-9429767730.html
[10] *** https://www.blackstone-labs.net/soot-how-much-is-too-much/?session-id=kq3laxbw2ksudq45jxyf3t45&timeout=20&bslauth=&urlbase=https%3a%2f%2ffwww.blackstone-labs.net%2fBstone%2f(%kq3laxbw2ksudq45jxyf3t45)%2f
[11] *** https://www.reddit.com/r/mildlyinteresting/comments/5h9av9/coolant_contaminated_motor_oil_from_a_car_that/
[12] *** https://commons.wikimedia.org/wiki/File:SIGAUS_aceite.jpg
[13] Williams J 2005 Wear and wear particles - Some fundamentals, Tribology International 38(10) 863-870
[14] *** https://www.substech.com/dokuwiki/doku.php?id=mechanisms_of_wear
[15] *** http://reiloyusa.com/processing-tips/screw-barrel-wear/abrasive-wear/
[16] *** https://www.globalspec.com/reference/54781/203279/12-3-adhesive-wear
[17] *** https://www.ms-motorservice.com/en/technipedia/post/damage-to-engine-bearing-corrosion/
[18] *** http://www.partinfo.co.uk/articles/278
[19] *** https://www.substech.com/dokuwiki/doku.php?id=engine_bearing_failurehttps://www.substech.com/dokuwiki/doku.php?id=engine_bearing_failure