Review

MODEL OF FILLING-UP, RENEWAL AND DEGRADATION OF LUBRICATING MEDIUM IN THE COMBUSTION ENGINES

J. Stodola

Military Academy in Brno PS 13, K201, 612 00 Brno, Czech Republic
Tel/ Fax: +420973442278, e-mail:jiri.stodola@vabo.cz

Abstract. *Decrease of lubricating medium is a normal phenomenon and it may appear due to various reasons. With modern engines, leakage of oil through greater defective tightness can be almost excluded. Loss of oil in the lubricating system during operation results in a necessity to perform regular checks and filling-up. Oil filling-up greatly affects an immediate quality of lubricating filling and a level of utilization of operating characteristics of oil. Regeneration of oil during filling-up has the following effects: additional additivity, i.e. regeneration of properties acquired by additives added to the basic oil and dilution, i.e. decrease of concentration of mechanical impurities. The article presents a mathematical model of operational filling-up and renewal of lubricating medium. Model was verified on statistically significant set of vehicle combustion engines.*

Key words: *oil consumption, lubrication system, three-phase model, scavening, operation, equilibrium, assessment, oil filling-up, oil degradation, oil renewal, oil regeneration*

Introduction

Consumption of engine oil is a very important indicator of the combustion engine operation cost-effectiveness. Oil consumption does not only indicate various losses but it undesirably impacts on a creation of deposits, growth of octane number, damage of λ - probe, catalyzer, etc. Decrease of lubricating medium is a normal phenomenon and it may appear due to various reasons. With modern engines, leakage of oil through greater defective tightness can be almost excluded. However, oil may leak from the combustion area around the piston, piston rings, valves, and it also may appear a leakage owing to combustion, vaporization into the gas outlet, induction of oil vapor and drops at artificial ventilation of crankshaft, etc. Loss of oil in the lubricating system during operation calls for regular checks and filling-up. Oil filling-up has a great effect on an immediate quality of the lubricating filling and on a level of utilization of the operating characteristics of oil. Regeneration of oil during filling can contribute to the additional additivity, i.e. renewal of properties acquired by additives added to the basic oil and the dilution, i.e. decrease of concentration of mechanical impurities. The practice shows that even the specialists cannot explain how filling-up impacts the renewal of initial amount of oil in the lubricating system. Opinion that oil can be completely renewed in the lubricating system by summing all amounts of filled-up oil equivalent to the volume of oil is obviously incorrect.

Model of Oil Filling-up and Renewal

A problem of operational filling-up of oil can be mathematically modeled by using geometric progression. For this we use nominal volume of oil V_0 in the lubricating system and the amount ΔV of same oil that is filled-up into the lubricating system during technical maintenance. Let be a filled-up amount of oil ΔV same at each filling-up. Loss of oil in the lubricating system between two fillings of oil is expressed by a coefficient

$$q = 1 - \frac{\Delta V}{V_0}. \quad (1)$$

Prior the first oil filling-up the initial amount V_0 decreases to

$$V_0^{(1)} = V_0 - \Delta V = V_0 . q .$$

And this amount is filled-up by ΔV to the initial volume

$$V_0 = V_0^{(1)} + \Delta V .$$

Prior second filling-up the amount of initial and refilled oil decreases in the same ratio

$$V_0^{(2)} = \left[V_0^{(1)} + \Delta V\right] q = V_0 q^2 + \Delta V q .$$

This amount is again filled-up by ΔV to the initial volume and before the third refill we obtain

$$V_0^{(3)} = \left(V_0^{(2)} + \Delta V\right) q = V_0 q^3 + \Delta V \left(q^2 + q\right).$$

We go further on and after n-th filling-up of amount ΔV in the lubricating system will be the following amount of lubricating oil

$$V_0 = V_0^{(n)} + \Delta V = V_0 q^n + \left[q^{n-1} + q^{n-2} + ... + q^2 + q + 1\right]. \quad (2)$$

In accordance with relation (1) q = 1, and that is why in the brackets of the second summand in relation (2) there is convergent geometrical progression for which it holds:

– sum of infinite number of series is

$$S = \frac{1}{1-q} \tag{3}$$

– sum of the first „n“ of the members of series is

$$S_n = \frac{1-q^n}{1-q} \tag{4}$$

Then, from relation (2) it is possible to establish at which k-th filling-up of oil in the lubricating system the volume of initial point and volume of refilled oil is in equilibrium, and when it holds

$$V_0 q^k = \Delta V \sum_{i=0}^{n-1} q^i . \tag{5}$$

After arrangement of relation (5) and after substituting $\Delta V/V_0 = 1 - q$ we may obtain

$$q^k = z \cdot \tag{6}$$

And volume of initial and refilled oil is in equilibrium when filling-up

$$k = \frac{\ln z}{\ln q} \tag{7}$$

where V_0 nominal volume of lubricating system,
ΔV average refilled amount of oil,
q quotient of geometric progression,
k number of oil refills,
z initial oil volume and refilled oil volume ratio.

The above-mentioned relations facilitate solving of a problem of the effect of filling-up of oil into the lubricating system of engine and oil renewal. Further we shall mention several examples of their practical application at the vehicle combustion engines that are commonly used in the Czech Republic. It refers to the following volumes of lubricating system in dm^3 (2.65, 6.2, 15, 18, 22, 33).

Figure 1 shows how the above-mentioned mechanisms influence a course of decrease of the initial amount of oil and how it is increased when filling the oil at two various values of ΔV for the engine T928. The dependence is calculated in accordance with (2) at gradual increase of „n“. For „n“ of corresponding crossing point of both curves for certain ΔV the amount of initial oil equals to the amount of refilled oil.

Figure 2 depicts a dependence between filled-up amount ΔV and number of oil fillings at which in the lubricating system the amount of initial and filled-up oil is in equilibrium. Values „k“ are calculated in accordance with (7).

Figure 1 and 2 show that volume of initial lubricating filling in the system is regenerated more quickly if the filled-up amount ΔV is greater. If fillings are more frequent but the amounts are smaller, then renewal of initial filling is slower.

Figure 3 shows values at which after ten or twenty fills the amount of initial oil would be equalized. The amount of filled-up oil can be determined as an addition to the amount V_0. It is evident from Figure 3 that no overall renewal of oil appears in the lubricating system when a great amount of oil is filled-up

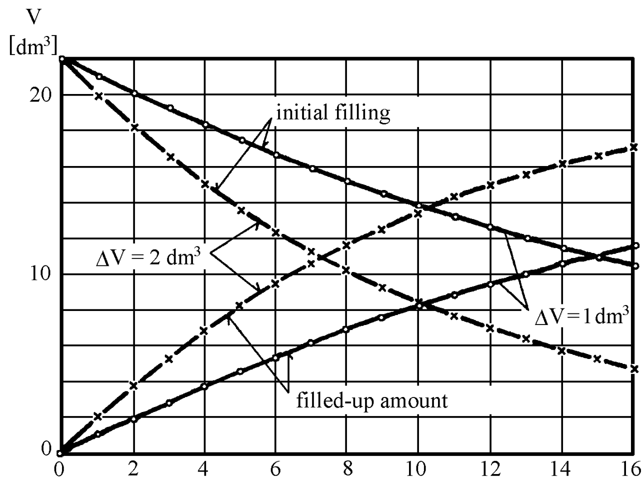

Figure 1. Dependence of decrease of initial filling of oil and increase of filled-up oil on the number of fillings „n“ for the engine T928 and filled-up amounts ΔV

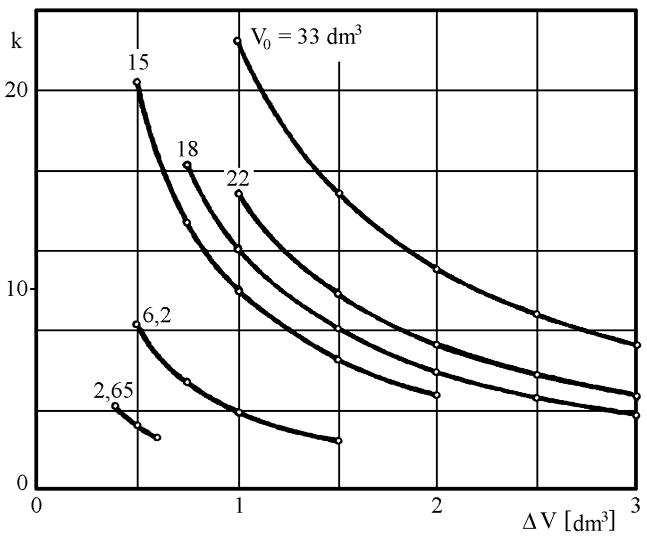

Figure 2. Dependence of a number of oil fillings „k“, during which the amount of initial and filled-up oil equalizes with the filled-up amount ΔV for various size of filling of the lubricating system V_0

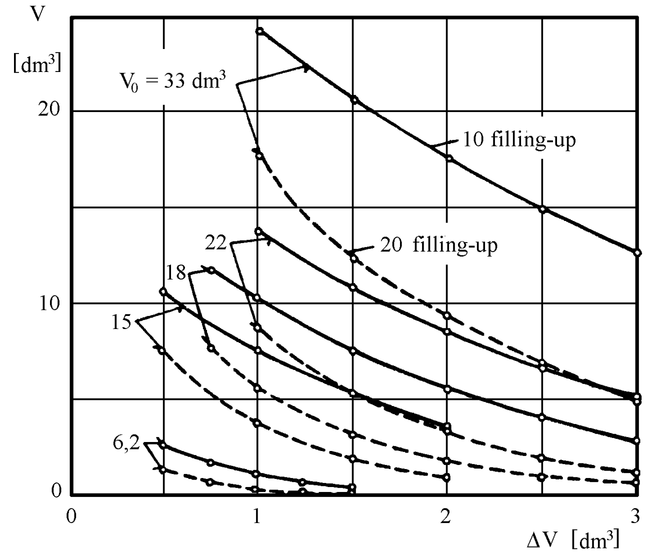

Figure 3. Values at which after ten or twenty fillings of lubricating system the amount of initial oil is in equilibrium with various content of V_0 for various filled-up amounts ΔV

into the system even if it is higher than a capacity of the lubricating system.

Model of Operational Assessment of Lubricating Medium

Based on the experimental verification it is possible to generalize inherent laws and to quantify a process of lubricant degradation. The results show a three-phase model of degradation. For this, the experiment results were used where Conradson Carbon Residue Test (CCT) was a diagnostic parameter that characterizes the lubricating oil in terms of its liability to creation of carbon residues at high temperatures. CCT is a weight quotient of the oil residue that is produced by thermal disintegration of oil without an access of the air under defined conditions [8], or [9]. We can characterize individual phases of model as follows:

1st phase – SCAVENGING – it is carried out in a relatively short period of time after filling-up of an engine by fresh oil and it is completed after first short operation of an engine. Scavenging effect can be achieved after several hundreds of km of operation. It is step change of quality of the lubricating medium. The actual design of combustion engine, rest of old filling that remained in the engine after discharge during oil exchange has an important influence. In the first phase, values of physical and chemical characteristics of the lubricating medium change by nearly 25 %. It is the greatest intensity of degradation of lubricant after putting into the operation. Theoretically with this intensity of degradation processes, the lubricant would degrade after an operation of hundreds or thousands of km depending on the type of engine - see Figure 4.

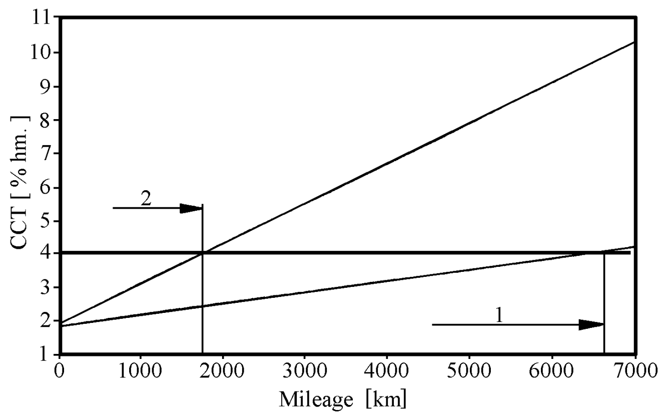

Figure 4. First phase of engine oil degradation (1 – ML 636, 2 – Ikarus)

2nd phase – OPERATION – it begins immediately after a completion of phase 1 and its duration depends on an intensity of degradation processes. During this phase there appears another decrease of nearly 50% in physical and chemical properties of oil. The limit values are achieved during several thousand of km, Figure 5. In fact - after 5 – 20 thousands of km. The decisive factor for phase 2 of degradation is a overall condition of the engine, especially mechanical condition of friction surfaces and sealing elements. This phase considerably shortens for the engines with higher mileage.

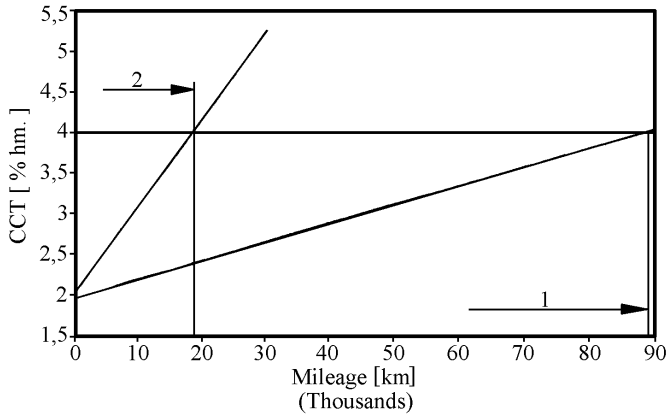

Figure 5. Second phase of oil degradation (1 – ML 636, 2 – Ikarus)

3rd phase –EQUILIBRIUM – this phase takes place when regeneration processes eliminate the progress of degradation of the lubricating medium of the combustion engine. At the engine in a working order it can be expected that initial filling of the engine oil can fully fulfill its functions for several tens or hundreds thousand km without any provable deterioration in quality. It can be explained by the fact that refilling of oil enables to improve periodically its quality and compensate the degradation deterioration. Deterioration in quality of the lubricating medium is very small, (Figure 6) and it may be paradoxically stated that quality of oil is improving during operation.

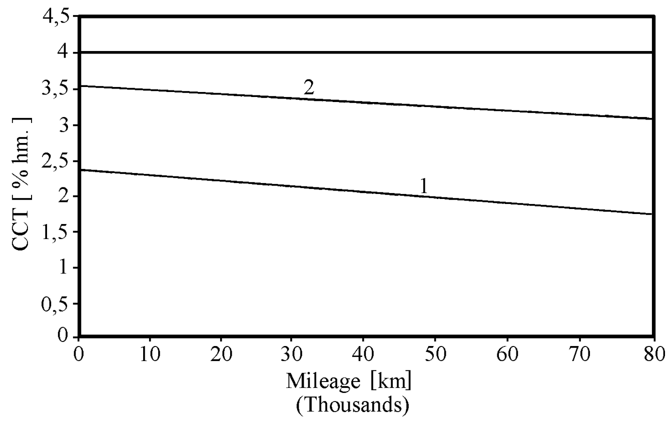

Figure 6. Third phase of degradation of engine oil (1 – ML 636, 2 – Ikarus)

General view of a three-phase model of degradation of the lubricating medium can be seen in Figure 7. The model provides to establish an optimum interval of oil exchange based on the actual conditions of operation at single users. The degradation process of lubricating medium for the same type of engine can have a different behavior depending on the operating conditions (city traffic, long distance travel, terrain, etc.).

The principle of solution is based on evaluation of time series of results (monitored tribo-diagnostic parameters) when the limit recommended value for an appropriate engine and type of lubricating oil is plotted in the diagram. If this value - constant (line) crosses the appropriate trend line or time series of results of any parameter then this value on the axis of mileage is indicated as the limit interval of oil exchange. It will mean that the limit values of important parameter were exceeded sooner before the third phase (equilibrium) in the system occurred and, further operation is forbidden. Establishment of the interval has a probability character and in order to establish it, it is necessary to meet the statistical requirements for the range of selection, etc.

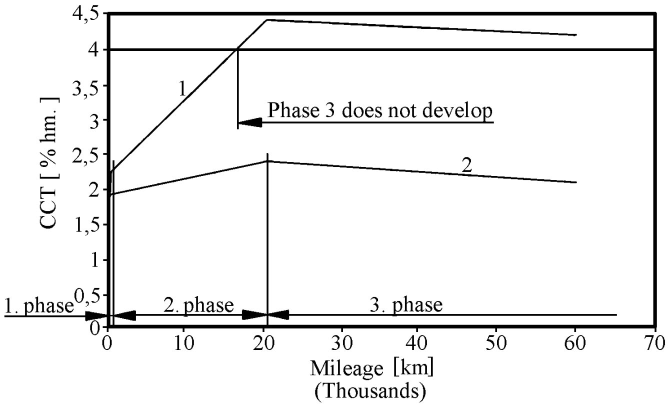

Figure 7. Three-phase model of lubricant degradation (1 – ML 636, 2 – Ikarus)

Conclusion

It may be stated that the initial oil is improved when filling-up of smaller amount of oil in shorter intervals, its decrease is slower and it accomplishes its functions for a longer period of time or, there is more oil in the engine at the time of exchanging of oil. This oil is a bearer of richer information on the mode of wear as a result of higher amount of initial oil. The oil will have better quality if greater amount of oil is filled-up in longer intervals than when filling-up smaller amounts. The ratio of filled-up (better quality) oil to the initial oil will be more favorable. If greater amounts of oil are filled-up then oil exchange intervals can be longer. This conclusion shall be valid for tribological analysis and pertinent type of engine. There are two facts that may affect a rate of regeneration of oil filling:

– average filled-up amount of oil into the lubricating system ΔV.
– mode of filling-up of oil into the system to the required volume.

Through experiments were verified theoretical conclusions of the model of operational evaluation of lubricant consisting of three phases of degradation processes that include so-called phase of short scavenging, relatively long phase of operation and potential phase of equilibrium with assumed regeneration effects.

The intensity of degradation processes occurring in lubricating medium during operation differs in dependency on operating conditions of engine (vehicle). Regeneration processes significantly impact the intensity of degradation and operation usability of the lubricant. Optimization of tribological mode can bring a significant economic effect to the users. Extending of oil exchange interval can bring for example nearly two thirds saving of oil consumption.

Three-phase model of degradation of the lubricating medium will provide to perform linearization of e.g. some exponential changes of physical and chemical parameters (total alkalinity and acidity value TBN, TAN, etc.). Its implementation will also assure optimization of exchange intervals of oil filling or to implement so called filling for the whole service life, etc.

References

[1] BARTOŠ, J.: Vliv doplňování oleje do mazacího systému motoru na jeho obměnu. (Influence of Refilling of Oil into the Lubricating System of Engine on its Renewal). Sborník VA, řada B č. 3/1990, Brno 1990
[2] BARTOŠ, J.- STODOLA, J.- JETMAR, J.: Tribologické sledování motorů T-930. (Tribologic Monitoring of Engines T-930). Sborník VA řady B, č. 2/1991, Brno 1991.
[3] JETMAR, J.: Tribotechnická diagnostika složitých strojních skupin mazaných olejem s aplikací na vozidlové spalovací motory. (Tribo-technical Diagnostics of Complex Machine Groups with Application to Vehicle Combustion Engines) HP, VA Brno, 1993
[4] STODOLA, J.- JETMAR, J.: Tribologie a jejich aplikace v technické diagnostice automobilů. (Tribology and its Application in Technical Diagnostics of Vehicles). VA Brno, S-2067, 1991
[5] STODOLA, J.: Tribotechnická diagnostika vozidlových spalovacích motorů. (Tribotechnical Diagnostics of Vehicle Combustion Engines). Grantový projekt GAČR ev.č. 101/99/1396, Brno 2001
[6] STODOLA, J.: Modeling of Degradation Process of Combustion Engine. 2001 Fall Fuels and Lubrication Meeting. San Antonio, U.S.A. Technical Papers Series 2001
[7] STODOLA, J.: The Results of Ferrography Tests and their Evaluation. Tribotest Jurnal 8-September 2001 (8) 73 ISSN 1354-4063 Leaf Coffin France/England
[8] ČSN 65 6212: Establishment of Conradson Carbon Residue
[9] ČSN 65 6063: Ash Content