MODELLING OF ALKALINITY CHANGES IN LUBRICATING OILS USED IN MARINE DIESEL ENGINES

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Abstract

As the time is passing, lubricating oil in marine engine lubricating oil system loses its quality because of oil deterioration process.

Lubricating oil quality influences the wear of tribological system elements. The total base number (TBN) is one of the most important oil quality properties. During operation of diesel engines the TBN decreases as alkaline additives are exhausted mainly through neutralization of fuel burning acid products. So as to improve lubricating oil properties an engineer uses some maintenance methods.

One of these methods is refilling process. The paper presents theoretical researches of total base number changes modelling at various lubricating oil refilling methods. Theoretical model of oil-deterioration process was worked out on the basis of mass balance equation of total base number.

The method of solving the problem, structural model of experimental unit, total base number change in case of constant refilling process, calculating example, total base number changes in PIELSTICK 12PC2-5V engine oil versus parameter d, percentage changes of total base number in PIELSTICK 12PC2-5V engine oil versus parameter d are presented in the paper.

***Keywords**: transport, marine diesel engines, total base number, refilling process*

1. Introduction

As the time is passing, lubricating oil in marine engine lubricating oil system loses its properties. One of these properties is the total base number (TBN), an index of oil alkalinity. During operation of diesel engines the lubricating oil alkalinity decreases as alkaline additives are exhausted mainly through neutralization of fuel burning acid products.

The refilling process is one of used methods applied to improve lubricating oil properties. The amount of fresh oil added to lubricating oil system always balances its consumption, but the way of refilling depends on marine engineer. He can add small portions of fresh oil at short intervals or big ones at large intervals. It is always possible to maintain constant amount of oil in lubricating oil system by continuous refilling.

The article aim is to determine the influence of lubricating oil-refilling methods on total base number changes. The international literature review [1-2, 5, 7, 9] and author's experience show that lubricating oil alkalinity level considerably influences corrosive wear of tribological system elements. For that reason scientific researches leading to determine the influence of lubricating oil refilling method on alkalinity level in lubricating oil have, according to author's opinion, an important meaning either cognitive or practical.

2. The method of solving the problem

Lubricating oil properties changes versus operating time can be examined theoretically using its mass balance equations. In these equations the tested property velocity change is the algebraic sum of inflow and outflow factors intensity, which determine its temporary value.

$$\frac{dW}{dt} = \sum d_i - \sum o_i \,, \tag{1}$$

where:
W - examined lubricating oil property,
d_i - intensity of inflow factors which influence considered lubricating oil property,
o_i - intensity of outflow factors which influence considered lubricating oil property.

In case of lubricating oil used in trunk piston marine diesel engines the following phenomena determine the right side of equation (1):
- marine diesel engine internal processes which cause decrease or increase of some lubricating oil components,
- lubricating oil maintenance (purifying, filtering, refilling),
- lubricating oil consumption.

In accordance with the above mentioned phenomena, the total base number change in lubricating oil during operation can be submitted as mass balance equation where the following factors determine considered lubricating oil property:
- neutralization of fuel burning and lubricating oil oxidation acid products,
- adsorbing alkalinity additives on hard mechanical impurities and their removing by filtering and purification,
- burning of alkalinity additives together with lubricating oil,
- refilling process.

Figure 1 presents a structural model of experimental unit (trunk piston marine diesel engine) which takes into consideration the above mentioned factors.

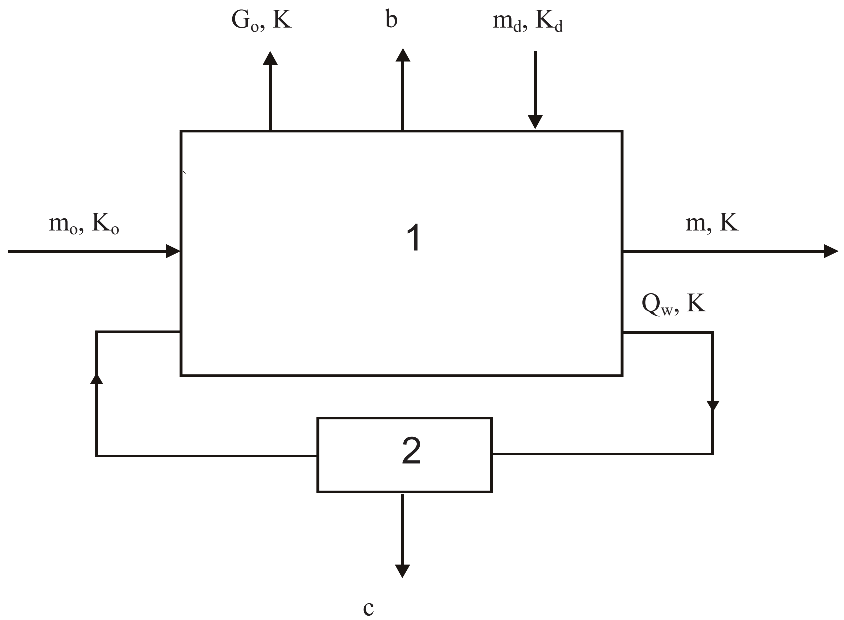

Fig.1. Structural model of experimental unit: 1- trunk piston marine diesel engine, 2 - centrifuge, b - velocity of alkalinity additives consumption used on neutralization of acid products [mg KOH/h], c - velocity of alkalinity additives removed by purifying devices [mg KOH/h], G_o - lubricating oil consumption per hour [kg/h], K - current value of lubricating oil total base number [mg KOH/g], K_d - total base number of added oil [mg KOH/g], K_o - initial value of lubricating oil total base number [mg KOH/g], m - current mass of lubricating oil in engine lubricating oil system [kg], m_o - initial mass of lubricating oil in engine lubricating oil system [kg], m_d - mass of added oil per hour [kg/h], Q_w - capacity of lubricating oil centrifuge [kg/h]

Taking into account the above model the process of total base number change can be described by equation (2):

$$\frac{d(mK)}{dt} = m_d \cdot K_o - G_o \cdot K - b - c, \tag{2}$$

where:
t - lubricating oil working time [h].

Because:

$$m = m_o - (G_o - m_d) \cdot t, \tag{3}$$

then the equation (2) has the following form:

$$[m_o - (G_o - m_d) \cdot t] \frac{dK}{dt} = m_d \cdot K_o - G_o \cdot K - b - c. \tag{4}$$

In real marine diesel engines operation the refilling of lubricating oil goes on periodically after the consumption of some amount of oil working in lubricating oil system, that is between refillings $m_d = 0$. Then equation (4) has the following form:

$$(m_o - G_o \cdot t) \frac{dK}{dt} = -b - c. \tag{5}$$

So as to solve equation (5) the parameters G_o, b and c should be steady in time. However these simplifying assumptions require a commentary.

In real operation, the lubricating oil consumption G_o depends on engine technical condition, its revolutions and load. Taking into account that particular functional systems of the engine are overhauled periodically we can assume its mean, constant technical condition. The velocity of alkalinity additives consumption used on neutralization of acid products depends on sulphur content in fuel, fuel consumption and sulphur conversion coefficient [8]. The sulphur conversion coefficient depends on engine design (two-stroke or four-stroke engine) and cylinder temperature [4]. Considered trunk piston engine is the main propulsion engine co-operating with controllable pitch propeller. If a given engine is fed by determined fuel and runs with constant load and revolutions it can be assumed that the velocity of alkalinity additives consumption b and lubricating oil consumption G_o are constant. The velocity of alkalinity additives removed by purifying devices c, depends on lubricating oil centrifuge efficiency characterized by parameter $Q_w \psi$ (product of lubricating oil centrifuge capacity Q_w and purifying coefficient ψ) and ability of these additives to adsorb on solid impurities and centrifuge's elements surfaces. The purifying coefficient is defined by the following formula:

$$\psi = \frac{x - x_\psi}{x}, \tag{6}$$

where:
x_ψ - mass concentration of solid impurities in lubricating oil behind the centrifuge [%].

Physically, centrifuge efficiency determines a part of whole lubricating oil stream (flowing through the centrifuge) that undergoes complete cleaning. It changes versus operating time and depends on rate of centrifuge contamination (assuming constant capacity of centrifuge and intensity of impurities inflow into engine lubricating oil system). If professional technical staff ensures required cleanness of lubricating oil centrifuge it can be assumed that the parameter $Q_w \psi$ is constant in time. The ability of alkalinity additives to adsorb on solid impurities and centrifuge's elements surfaces is a problem still waiting for solving.

Taking into account the above mentioned assumptions we have the following solution of equation (5):

$$K = K_o + \frac{b+c}{G_o} \cdot \ln\left|1 - \frac{G_o \cdot t}{m_o}\right|, \text{ for: } 0 \le t < \frac{m_o}{G_o}. \tag{7}$$

In real operation the lubricating oil refilling goes on periodically after consumption of some oil in lubricating oil system. In that case the changes of total base number in lubricating oil between following refilling run according to monotonously falling logarithmic curve presented as equation (7). The refilling process causes the increase of the total base number, which depends on the amount and alkalinity level of added oil (for simplification it is assumed that refilling time $t_d \rightarrow 0$). Received in that way characteristic assumes the shape of the so-called "saw-shape" curve and was presented in Fig. 2.

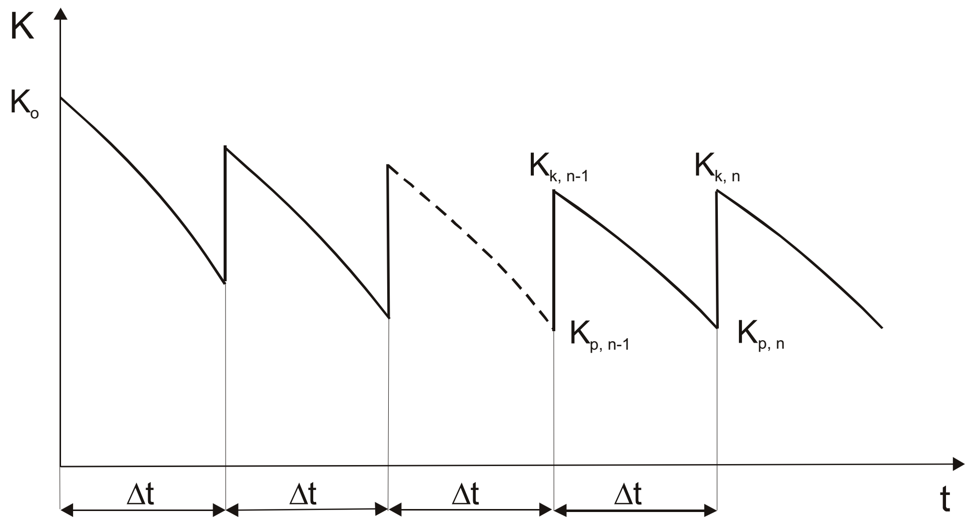

Fig. 2. Total base number change in case of constant refilling process

For the practical reasons it is important to determine the average value of total base number versus refilling method, which is defined by parameter *d*. That parameter determines the amount of added oil related to initial oil amount in lubricating oil system. Equation (8) shows its definition:

$$d = \frac{G_o \cdot \Delta t}{m_o}, \text{ for } 0 < \Delta t < \frac{m_o}{G_o}, \tag{8}$$

where:

Δt - time between the following refilling [h].

If, for simplification, we consider that (see Fig. 2):

- the refilling process is constant, it means the amount of added oil m_d and time between the following refilling Δt are constant,
- alkalinity levels after time $t = n \cdot \Delta t$, it means at the end of *n* period Δt are marked: $K_{p,n}$ - before adding the fresh oil, $K_{k,n}$ - after adding the fresh oil.

Then on the basis of Fig. 2 and equations (7) and (8) we can write:

$$K_{p,n} = K_{k,n-1} + \frac{b+c}{G_o} \cdot \ln|1 - d|, \tag{9}$$

$$K_{k,n} = (1-d) \cdot K_{p,n} + d \cdot K_o. \tag{10}$$

Hence we obtain:

$$K_{p,n} = K_o + \frac{1-(1-d)^n}{d} \cdot \frac{b+c}{G_o} \cdot \ln|1-d|, \qquad (11)$$

$$K_{k,n} = K_o + \frac{\left[1-(1-d)^n\right]\cdot(1-d)}{d} \cdot \frac{b+c}{G_o} \cdot \ln|1-d|. \qquad (12)$$

Analysing equations (11) and (12) we can notice that when lubricating oil operating time approaches infinity (number of the refilling $n \to \infty$) then the expression $(1-d)^n$ approaches zero. In that case actual, instantaneous values of lubricating oil alkalinity (just before and after adding the fresh oil) stabilise on the following levels:

$$K_{p,\infty} = K_o + \frac{1}{d} \cdot \frac{b+c}{G_o} \cdot \ln|1-d|, \qquad (13)$$

$$K_{k,\infty} = K_o + \frac{1-d}{d} \cdot \frac{b+c}{G_o} \cdot \ln|1-d|. \qquad (14)$$

The average value of lubricating oil total base number can be presented in the following form:

$$\overline{K} = \frac{K_{p,\infty} + K_{k,\infty}}{2}. \qquad (15)$$

Taking into consideration equations (13) and (14) we obtain:

$$\overline{K} = K_o + \left(\frac{1}{d} - \frac{1}{2}\right) \cdot \frac{b+c}{G_o} \cdot \ln|1-d|. \qquad (16)$$

Analysing the equation (16) we can notice that the average level of total base number depends on applied refilling method (quantity and frequency of refilling determined by parameter *d*). We can than assume that there is such a value of parameter *d* that initial total base number change in lubricating oil $\left|K_o - \overline{K}\right|$ is the smallest, according to the formula:

$$\Delta K = \left|K_o - \overline{K}\right|. \qquad (17)$$

Considering expression (16) equation (17) takes the following form:

$$\Delta K = \left|\left(\frac{1}{2} - \frac{1}{d}\right) \cdot \frac{b+c}{G_o} \cdot \ln|1-d|\right|. \qquad (18)$$

Mathematical model presented as equation (18) enables to estimate initial total base number change in trunk piston marine diesel engine lubricating oil versus applied refilling method characterised by parameter *d*.

3. Calculating example

In order to determine the influence of applied refilling method on the total base number change in lubricating oil, according to equation (18), the numerical simulation for main propulsion trunk piston marine diesel engine PIELSTICK 12PC2-5V was carried out. The engine was fed with high sulphur fuel (sulphur contents 2%). Fig. 3 presents the results of the simulation:

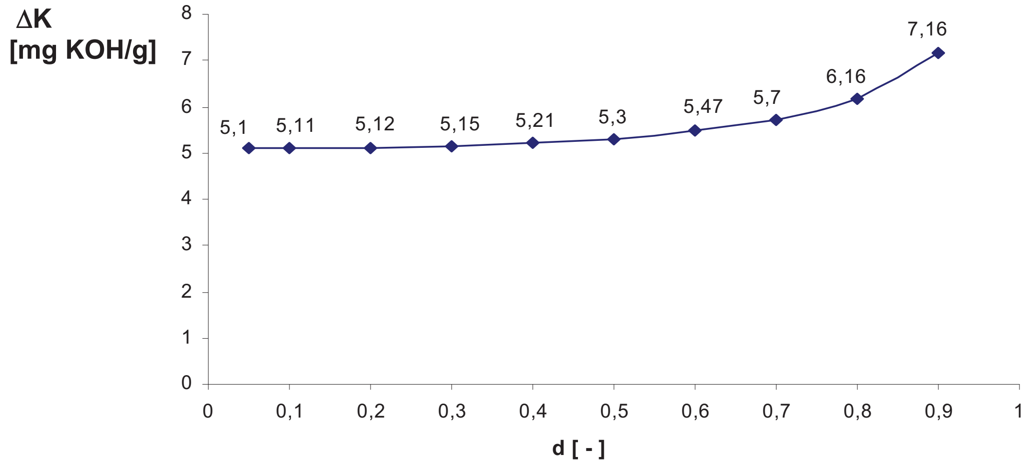

Fig. 3. Total base number changes in PIELSTICK 12PC2-5V engine oil versus parameter d

Analysing Fig. 3 we can notice that the smallest change of lubricating oil total base number (related to the fresh oil) – 5.1 mg KOH/g was obtained for the method of the smallest portions of added oil (d = 0.05). Total base number of the fresh oil was in that case 30 mg KOH/g. As a result the average level of alkalinity obtained for 5% refilling was 24.9 mg KOH/g. Increase of the parameter *d* (relative quantity of refilling) causes bigger alkalinity drop which could enlarge the corrosive wear of engine elements. Therefore, bearing in mind the average level of total base number, which should be the highest, the method of the smallest portions of added fresh oil $d = d_{min}$ appears to be the best.

Percentage changes of total base number in PIELSTICK 12PC2-5V engine lubricating oil (related to fresh oil total base number level) for various refilling methods were presented in Fig. 4.

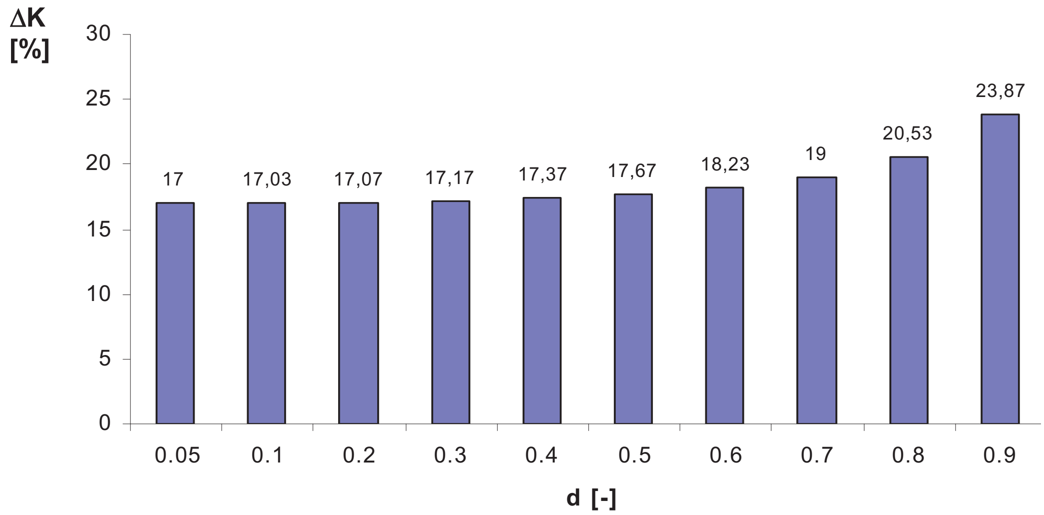

Fig.4. Percentage changes of total base number in PIELSTICK 12PC2-5V engine oil versus parameter d

We can see that in range of parameter *d* permissible changes, which for considered engine are restricted by value $d_{max} \approx 0.5$ [3] the influence of realized refilling method on alkalinity level is irrelevant. In case of 5% refilling ($d = 0.05$) 17% drop of total base number was obtained (related to fresh oil alkalinity), whereas for 50% refilling ($d = 0.5$) that drop was 17.67%. Therefore, lubricating oil alkalinity changes caused by different refilling methods are not so important from the point of view the ability to neutralize the acids.

4. Summary

Theoretical researches of lubricating oils (used in trunk piston marine diesel engines) quality changes modelling and consequently achieved optimum lubricating oil maintenance methods can be used in real operation of marine engines. The mathematical models worked out during these researches should take into account possible wide collection of oil properties, changeable working conditions of marine engines and parameters describing lubricating oil systems.

The mathematical model worked out in that article allows determining the influence of applied refilling method on total base number change in lubricating oil. Bearing in mind the average alkalinity, which should be the highest, the method of the smallest portions of added oil at short intervals appears to be the best. The optimum and simultaneously real (in marine engines operating conditions) range of parameter *d* changes could be determined as follows: $d_{opt} = d_{min} \in (0; 0.05\rangle$

Results of modelling present ambiguous influence of used refilling method on lubricating oil properties. The method of the smallest portions of added oil at short intervals advantageously influences the alkalinity level but disadvantageously affects mass concentration of solid impurities [10]. Moreover, changes of the above-mentioned properties in permissible (because of engine safety) range of parameter *d* variations are irrelevant. It would suggest that when choosing the lubricating oil refilling method, others factors should also be taken into account, for example: the amount of oil in engine lubricating oil system, velocity of oxidation process or efficiency of purifying devices.

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