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THE INFLUENCE OF MICROORGANISMS INHABITING IN THE ENVIRONMENT OF DIESEL AND LUBRICATING OIL TO THE OPERATION OF MACHINERY AND MARINE EQUIPMENT

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Abstract

In this article, the problem of microbial contamination occurring in the fuels and oils was presented. It shows the types of microorganisms and the conditions for their growth. Then the factors influencing the growth of bacteria in petroleum products were described in detail. In the next section the symptoms, development and contamination of petroleum products was discussed. The influence of microbial contamination on the marine engine fuel system and the problems that this brings were also presented. In the following part of the article, the impact of microbial contamination of fuel tanks and purifiers was described. Then the causes of sludge were discussed and contamination layers in the settling tanks were presented. In the next part of the article the fuel impact modelling of microbial contamination on filtration efficiency was performed. The modelling presented in the article is an example showing how undesirable phenomenon is the microbial contamination and how pollution affects the other elements of the entire system. As part of the modelling, numerical model of filtration with the solution was presented. Then analysis results on the basis of the impurities concentration characteristics in the fuel as a function of the fouling thickness in the partition of the filter is performed. The development of impurities was divided into three stages. For each case the line trend and forecast further growth after the application of measures to prevent the proliferation of microorganisms were designated. The article was completed applications, of which the most important is the need to combat harmful microorganisms. And besides, there is a need to find new methods of combating microbial contamination that will not destroy beneficial microorganisms and will be environmentally friendly.

Keywords: *microorganisms, petroleum products, fuel system, oil system, modelling, settling tanks, filters*

1. Introduction

The dynamic development of the automotive industry as well as aircraft and marine industry has an impact on the growth of demand for hydrocarbon fuels. This in turn led to increased interest in the phenomena of development of microorganisms in fuels and oils and fuel and lubricating oil systems [4, 3].

Many species of bacteria and fungi have the ability to grow in the petroleum products that are a source of carbon and energy. Therefore, the activity of living microorganisms cause degradation of hydrocarbons and additives, and secretion into the fuel: water, sulphur compounds, surface-active substances. This results in changes in the chemical composition of the fuel and the values of certain physical parameters, such as boiling point, acid value or the viscosity.

Biofilm formed on metal surfaces creates conditions especially conducive to corrosion processes in the fuel tanks and fuel and lubricating oil systems [7].

This article discusses basic issues related to the negative impact of microorganisms living in the environment of diesel and lubricating oil.

2. Microbial fuels and oils contamination

The microorganisms are present in all types of environments (e.g. water, soil, air), from which, at various stages of production, distribution, storage and exploitation get into the oil and its products [14].

Frequently appearing in the research groups of microorganisms are aerobic bacteria, mold fungi, yeast and anaerobic bacteria. The condition for the growth and development of microorganisms in fuels is the availability of nutrient – organic carbon compounds (hydrocarbons) and biogenic elements (nitrogen, phosphorus, sulphur). However, the most important factor affecting the growth of microorganisms and microbial contamination is the presence of water. In spite measures applied, physically it is not possible completely to remove water from fuels and oils [6].

2.1. Factors influencing the growth of microorganisms in petroleum products

The basic factors that influence the growth of microorganisms include the presence of water, oxygen availability, temperature, and the content of nutrients and toxic substances.

Water can get into the tanks in the form of steam, rain or ground water, and also arise due to sudden temperature changes (the tanks wall condensation) [13].

In addition, microorganisms suspended in air, water vapour or dust gets together with them into fuels or oil tanks, where they create sediments in the bottom layer. Therefore, the most intense development occurs at the water-fuel interface and water-oil interface. Water, along with dissolved minerals and organic origin contaminants, is a substances magazine needed for the development of the harmful microflora. In the bottom layer of the tank, microorganisms, besides water, are provided with access to nutrients (source of carbon and energy) [14].

Interfacial fuel-water, oil-water formation of biofilm processes take place, and produced substances and waste products serve as binders, conducive to the further proliferation. The thus produced biofilm comprises bacteria and fungi, which in metabolic processes can degrade hydrocarbons in the fuel. As a result of intensive development of microorganisms and consumed by them oxygen, created favourable conditions for development anaerobic sulphate-reducing bacteria. Sulphates are the main cause of the corrosion serious problems of fuel and lubricating oil system components [13].

2.2. Symptoms and effects of petroleum products contamination

Introduced in recent years, bio-supplements contribute to the development of microbial life in the tanks. As a result, it can lead to serious problems with the smooth flow of petroleum products through the filters (and even stop the flow), as well as significantly accelerate the corrosion of the tank walls [1].

Fig. 1. Filter clogged biological sludge consists of living and dead microorganisms [14]

Unfortunately, more often the result is clogged, by green – brown gelatinous mass, a filter in distributor. This „gelatinous mass" is a biological sludge consisting of long fibrous chains containing live and dead cells (Fig. 1).

To the effects of microbial contamination include, among others: distribution of hydrocarbons, corrosion of the fuel tank and fuel lines, an increase in the sulphur content of the fuel, reducing the calorific value of the fuel, change the colour and door of fuel, increasing the acid number due to the secretion by the microorganisms acidic substance, change of the fuel low-temperature properties (cloud point, pour point) [5, 14].

3. The microbial contamination impact on marine engine systems

The presence of microorganisms in the systems of the engine is associated with a number of undesirable effects, which cause a decrease in engine performance and greater wear of its components. Shorten the service life of the filters, in most cases, is the first symptom of uncontrolled microbial contamination of the tank. Unfortunately, this is due to a number of processes taking place long before blocking filter and testifies to the advanced growth of microorganisms. Most often, this leads to long-term problems that result in an increase in operating costs, and even the engine immobilisation. Symptoms of filtration systems blockage during engine operation are primarily its instability, sudden stopping or starting problems [9].

Life processes of microorganisms growing in the fuel will always cause changes in its chemical composition. This problem has a marginal importance in everyday vehicles whose tanks are often emptying and filling. Intermittently operated vehicles are more susceptible the phenomena described, for example, military and first of all storage tanks, furthermore settling and settling-service tanks. Longer storage times microbiologically contaminated fuel can result in large enough increase in the concentration of pollutants, the physical parameters of the fuel (e.g. boiling point and viscosity) begin to differ significantly from the standards. In many cases, the observed foaming, clouding and darkening of the fuel, which in normal circumstances should be clear and transparent [10].

4. Influence of microbial contamination of the fuel tanks and purifiers

Microbial contamination of diesel and lubricant is such big problem that it is also in the properly operated and maintained tanks, where the oil is stored. In the tanks take place an uncontrolled growth of the microflora, and change the properties of fuel and oil, to such an extent that it is often not suitable for use in the engine and cause excessive wear of its components.

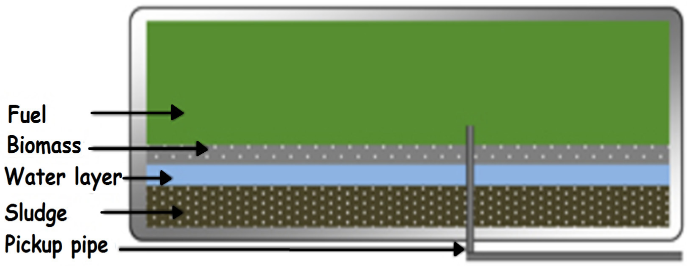

Fig. 2. Contaminants layers location in the settling-service or settling tanks [15]

Fig. 3. Settling tank with visible corrosion caused by microbial contamination [12]

The problem of microbial contamination generally occurs in the case of large tanks, with longer storage periods, for example settling tanks (Fig. 2). Fuel and oil stored in this way then go to the purification devices. Then, they enter the system together with the microflora contained therein, and the harmful products of metabolism, consequently becoming a source of contamination of the fuel, and lubricating system [6].

In the fuel oil, microbial contamination can lead to an unstable aging fuel. Generally, the most important consequence is microbiologically induced corrosion of the storage tanks and the pipes, and creating layers of microorganisms. This causes blocking of filters and fuel pipes, and increases the usage of the pumps. Besides microbial slurry may include dirt, dust, sand, pieces of other filters such as article or cotton, worn pumps parts, corrosion and debris material removed from the tank or worn seals pipe parts, such as glass fibres. The tanks corrosion from the inside and the fuel system can be intense if there is a microbiological contamination (Fig. 3) [2, 14].

5. Modelling the impact of microbial contamination of fuel on filtration efficiency

For proper operation of the fuel system, it is necessary to provide an internal combustion engine fuel of suitable amount and appropriate quality. To remove contaminants from petroleum products are used appropriate filters differing in design and operating principle. The simplest type of filter is a baffle filter whose essential element is porous partition. On the baffle of the filter particles with a diameter larger than the diameter of the pores are stopped. Thus, trying to obtain a high purity fuel, use a baffle in which the pore diameters are as small as possible. In addition to filtering efficiency, a very desirable feature of the fuel filter is as small as possible throttling the flow of fuel. Flow resistances are mainly dependent on the type of filter that is, from its design, dimensions or type of cartridge filter. The use of a filter is determined by reaching the limit value for the flow resistance of the filter. The flow resistance of the filter is usually expressed as a pressure drop across the filter. The value of the pressure drop across the filter can be easily measured with a simple manometer liquid. Contaminations created in the settling tank have a significant impact on the earlier increase in the concentration of pollutants in porous baffle. Some of them, which are smaller than the diameter of the pores get to other devices such as fuel separator, pumps, and finally to the engine. There, they further develop as a result causing early wear of filters and are also the cause of failures in the systems [7, 8].

5.1. The filtration numerical model

In the process of filtering contaminants, balance equation connects the change dynamics in the degree of contaminants in the fluid filtered with the change dynamics in the concentration contaminants accumulated in the porous baffle. On the basis of change in concentration of contaminants in the filtered liquid conducted to the desired depth baffle can be estimated concentration change deposits accumulated in the baffle of the filter at that depth. The concentration of the contaminants in the filtered liquid is expressed as a weight by volume. The mass balance equation, in the case of constant speed in a cross-section of the filtrating barrier and the one-dimensional flow, has the following form [11]:

$$\frac{\partial\sigma(t,d)}{\partial t} + \varepsilon_o\frac{\partial C(t,d)}{\partial t} + v\frac{\partial C(t,d)}{\partial d} = \mathrm{D}\frac{\partial^2 C(t,d)}{\partial d^2}, \tag{1}$$

where:

σ – mass concentration of impurities in the filter at time „t“ at a depth „d“, g/m^3,
ν – filtration velocity, m/h,
ε_o – porosity of the barrier filter,
D – dispersion coefficients, m^2/s,
C(t, d) – concentration of impurities in the liquid at time „t“ at a depth „d“, g/m^3.

Assuming that the second component of equation (1) equals zero and ignoring dispersion the simplest form of mass balance equations is obtained [3]:

$$v\left(\frac{\partial C(t,d)}{\partial d}\right)+\left(\frac{\partial \sigma(t,d)}{\partial t}\right)=0. \tag{2}$$

The kinetic of the filtration process can be described in different ways. The simplest way to describe the kinetic of removal of contaminants from the filtered fluid as it passes through the barrier using the concept of filtration coefficient, determining the effectiveness of contaminant removal. One of the forms the kinetic equation is the change in the concentration of impurities in the filtered liquid per unit depth of the baffle proportional to the concentration. Kinetic equation is as follows [11]:

$$\frac{\partial C(t,d)}{\partial d}=-\lambda C(t,d), \tag{3}$$

where λ – filtration coefficient, 1/m.

Filtration coefficient is a measure of the efficiency of the filter and is dependent on parameters such as the type and diameter of pores, filtration speed, physicochemical properties of the liquid filtered and concentration of the contaminants retained in the baffle. The function has the following form [3]:

$$\lambda=\lambda(\lambda_o,\sigma(t,d),v(t)), \tag{4}$$

where:

λ_o – filtration coefficient initial value, 1/m,

expressing filtration coefficient by its initial value. The most popular model is in the form [3]:

$$\lambda=\lambda_o\left(1+\frac{\beta\sigma(t,d)}{\varepsilon_o}\right)^x\left(1-\frac{\sigma(t,d)}{\varepsilon_o}\right)^y\left(1-\frac{\sigma(t,d)}{\sigma_u(v)}\right)^{z(v)}, \tag{5}$$

where:

β – growth coefficient of contaminations on the filter surface,

σ_u – contractual concentration of contaminations for which $\lambda = 0$.

In this model, three types of factors that influence the value of filtration were included, and besides, its value depends on the exponents of power series of x, y, z, determined experimentally.

The first factor in parentheses included an increase in the specific surface area of the baffle filter, due to the contaminants deposited on the baffle. The second one takes into account the reduction of the porosity of the barrier at the time of filtration as compared to its initial porosity due to the deposition of contaminants in the pores of the baffle. The third factor takes into account the increase in the average filtration speed resulting from the reduction of the cross-section the pores by the deposition of impurities on the baffle. In the description of the filtration process, assuming additivity of the pressure loss when flowing through the clean filtering barrier and the pressure losses resulting from the accumulation of contaminants in the baffle, the pressure equation is of the form [3]:

$$\frac{\partial p(t,d)}{\partial d}=1-\frac{K_o\mu v(1-\varepsilon_o)^2}{\rho g\varepsilon_o^3\psi^2 d_s^2}-\left(\frac{6(1-\varepsilon_o)}{\psi d_s}\right)^{0,9}v^{0,4}\sigma_o(t,d), \tag{6}$$

where:

p(t, d) – the pressure in the filter baffle at the time „t“ at the depth „d“ from the boundary condition h(t, 0) = h_o, where h_o is the pressure on the surface of the baffle, mH_2O,

K_o – Kozeny constant,

ρ – specific mass of the liquid, g/m^3,

μ – the coefficient of dynamic viscosity of the liquid, g/m·s,

ψ – the pores shape factor,

d_s – effective diameter of the pores in the filter baffle, mm,

g – acceleration of gravity, m/s^2,

σ_o(t, d) – volume concentration contaminants, g/m^3.

5.2. Numerical solution of equations of filtration

Model of the filtration process is a set of three differential equations with partial derivatives, preset initial conditions and boundary, defining function C(t, d), σ(t, d) and p (t, d), whose arguments are continuous. For numerical solution of the model equations, as well as to identify its parameters, it is necessary discretization arguments occurring in these functions. According to the shape of the area where certain functions are considered, discretization on a uniform rectangular grid was adopted. The row number of the array corresponds to a fixed point in time, and the column number corresponds to a fixed depth in the baffle filter. The discrete version of the model equations was adopted the simplest – differential – approximation of partial derivatives occurring in these equations by difference quotients:

$$\frac{C(k,i)-C(k,i-1)}{\Delta d} = -\lambda\big(\sigma(k,i)\big)C(k,i), \tag{7}$$

$$\frac{\sigma(k,i)-\sigma(k-1,i)}{\Delta T} = v(k-1)\,\frac{C(k-1,i)C(k-1,i-1)}{\Delta d}, \tag{8}$$

$$\frac{p(k,i)-p(k,i-1)}{\Delta L} = k_1\sigma(k,i) + k_2. \tag{9}$$

Solving equations in the variables of the so-called more discreet argument is obtained:

$$C(k,i) = \frac{C(k,i-1)}{1+\Delta d\lambda\big(\sigma(k,i)\big)}\,, \tag{10}$$

$$\sigma(k,i) = \sigma(k-1,i) + \Delta t v(k-1)\lambda\big(\sigma(k-1,i)\big)C(k-1,i), \tag{11}$$

$$p(k,i) = p(k,i-1) + \Delta d k_1\big(\sigma(k,i)\big) + \ k_2. \tag{12}$$

For example, in the article analysis of the results for the concentration of contaminants in the fuel as a function of the thickness of deposition on baffle filter was made.

5.3. Analysis of simulation results

Marine diesel oils are purified in stages, which includes gravity sedimentation, filtration and centrifugation. Fuel, before the filtration, is stored in settling tanks. As a result of a long period storage of fuel, occurs the growth of microorganisms and consequently the level of microbial contamination of the fuel increases.

Depending on the amount of microorganisms in the fuel, there are three stages in the development of contamination [4, 6]:

- no contamination, low,
- growing, medium,
- very tall.

Progressive microbiological contamination affects the sedimentation contaminants on the filter baffle. If dirt particles are smaller than the pore diameter to penetrate with the fuel to the engine fuel system, causing rapid wear and, consequently, its malfunction. The simulation results of the filtration process in graph function C(d) were shown in Fig. 4. Analysing the form of the function C(d) it can be noted that at the beginning of the process linear increase in function has performed. The concentration contaminants were about $3{\cdot}10^{-6}$ [g/ml] at a depth 0.5 [cm]. Then this growth had exponential course and concentrations of pollutants reached the level about $4{\cdot}10^{-5}$ [g/ml], the last stage again had linear course and concentration contaminants at a depth of 1.5 [cm] was around $4.5{\cdot}10^{-5}$ [g/ml]. Presented course may be related to the development of microorganisms. At the beginning of a slight increase, because the level of microbial contamination is very low. In the second stage, there is an increase of impurities, which results in faster deposition of the deeper layers of the filter increasing concentrations. In the last stage of the level of pollution, it is very high; there is a blocking filter, which is contaminated with whole. Despite the development of contaminants, course characteristic is linear, because due to increasing contaminants the filtration process slowly stops, which will involve increasing pressure drop across the filter. In order to prevent to interrupt flow fuel, the filter should be cleaned or replaced. Therefore, to the fuel are added additives, including biocides, in practice rarely achieves the case.

Unfortunately, biocides are compounds, synthetic or natural origin to combat harmful organisms, which unfortunately also destroy beneficial organisms and cause adverse changes in the composition of microorganisms. Despite a number of benefits arising from the use of biocides, it is now a strong tendency to limit their use [5]. They are caused by the fear of the harmful effects of highly concentrated substances on the environment. There is therefore a need to find new methods for to combat of microbial contamination, which will not destroy the useful microorganisms and they will be environmentally friendly.

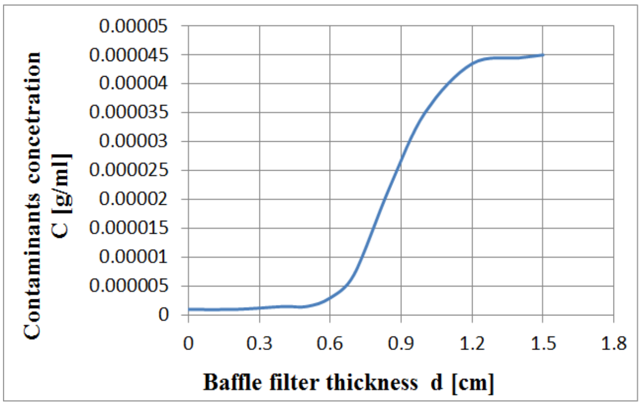

Fig. 4. Course of characteristic as a function of the concentration of contaminants in the deposition thickness of baffle filter

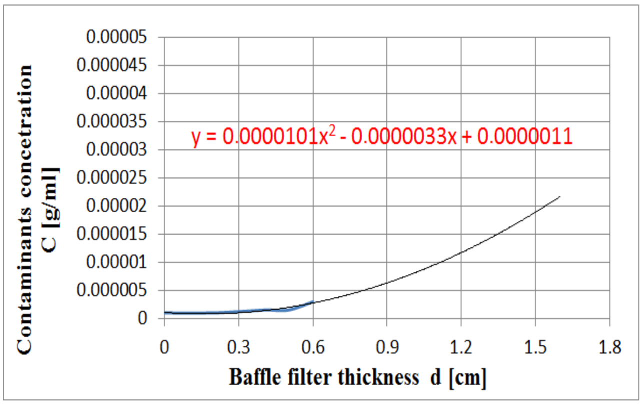

Fig. 5. Course of characteristic in the first stage of contaminants development together with the trend line and the development forecast after application of the countering microorganisms

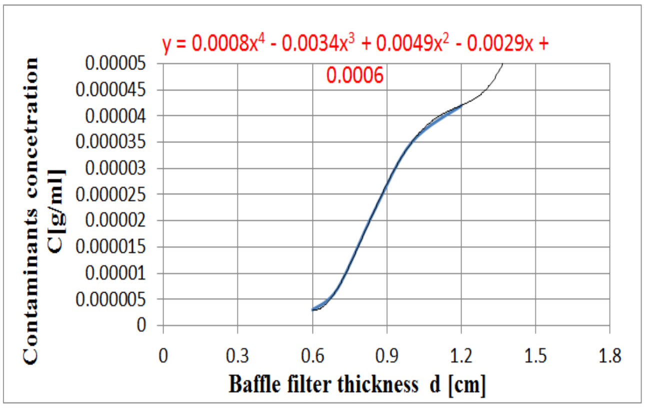

Fig. 6. Course of characteristic in the second stage of contaminants development together with the trend line and the development forecast after application of the countering microorganisms

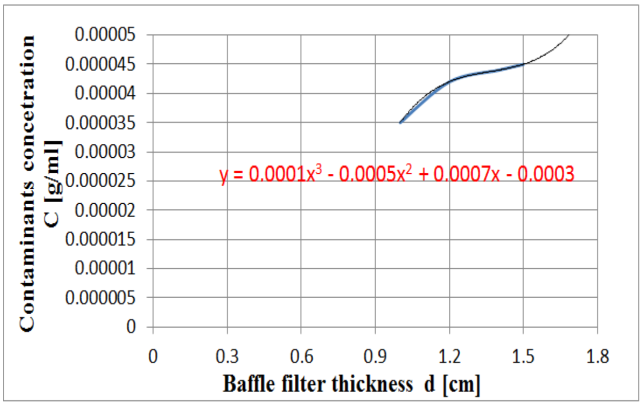

Fig. 7. Course of characteristic in the third stage of contaminants development together with the trend line and the development forecast after application of the countering microorganisms

Besides, for each stage of the filtration process trend line and the equation that describes it has been designated. They were also forecast, how would run characteristics, if at any stage the process of increasing contaminants would be stopped.

Forecasts show that the process of filter contamination is slower and contamination after the first stage is $2 \cdot 10^{-5}$ [g/ml], in comparison with $4.5 \cdot 10^{-5}$ with the process without the use of additives, which is shown in Fig. 5. While Fig. 6 shows the predicted course, which is further exponential and the process of total contamination occurs much later, because the particles are smaller in size, which affects the delay-blocking filter. Fig. 7 shows a course of concentration of a pollutant, which is not linear, and if the filter had the barrier of greater thickness this filtration process would continue and only greater accumulation contaminants would cause interrupt of the filtration process.

4. Conclusions

1. Microbial contamination of the fuel and the lubricating oil is so big a problem that it appears even in a properly operated and maintained containers in which the oils are stored.
2. Progressive microbial contamination has a significant impact, for example on the status of all fuel and lubricant systems components, causing the corrosion. Growing contaminations cause excessive clogging of the filter barrier, resulting in a faster wear of the filter. If dirt particles are smaller than the pore diameter for penetrate with the fuel to the engine fuel system, causing rapid wear and, consequently, its malfunction.
3. Application of measures to prevent the proliferation of microbes is fully justified. Currently, the most popular means are biocides, whose use, despite a series of benefits arising from their use is restricted. This is due to the fear of the harmful effects of highly concentrated substances on the environment. There is therefore a need to find new methods for to combat microbial contamination, which will not destroy the useful microorganisms and they will be environmentally friendly.

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