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ASSESSMENT OF THE FUEL THERMAL DEGRADATION PROCESS ON THE BASIS OF THE DEPOSIT CONTENT ANALYSIS

OCENA PROCESU DEGRADACJI TERMICZNEJ PALIWA NA PODSTAWIE ANALIZY ZAWARTOŚCI OSADÓW

Jarosław Sarnecki, Bartosz Gawron, Jadwiga Głąb

Air Force Institute of Technology. Instytut Techniczny Wojsk Lotniczych

***Abstract**: The publication subject is the issue related to the assessment of phenomena occurring during the jet fuel thermal degradation process. The research in this article was carried out on a specialised laboratory station, according to the author's own methodology. The assessment of the fuel degradation process was conducted on the basis of an analysis of the content of deposits collected on filters with a diameter of 0.8* μm *and 3.0* μm. *The filters were additionally analysed under a microscope. The results indicate that a degree and intensity of the fuel thermal degradation process are affected by the technology of the tested fuel and the test temperature. The article was prepared on the basis of the results obtained within the framework of the research project No. 2011/01/D/ST8/06567 funded by National Science Centre.*

***Keywords:** thermal stability, jet fuel, turbine aircraft engines, deposits*

***Streszczenie:** Tematem publikacji jest problematyka związana z oceną zjawisk zachodzących podczas procesu degradacji termicznej paliwa lotniczego. Badania w niniejszym artykule prowadzono na wyspecjalizowanym stanowisku laboratoryjnym, według własnej autorskiej metodyki. Ocenę procesu degradacji paliwa przeprowadzono w oparciu o analizę zawartości osadów zebranych na sączkach o średnicy 0.8 μm i 3,0 μm. Sączki dodatkowo były analizowane pod mikroskopem. Wyniki wskazują, że na stopień i intensywność procesu degradacji termicznej paliwa ma wpływ technologia badanego paliwa oraz temperatura badania. Artykuł został przygotowany w oparciu o rezultaty otrzymane w ramach projektu badawczego nr 2011/01/D/ST8/06567 finansowanego przez Narodowe Centrum Nauki.*

***Słowa kluczowe:** stabilność termiczna, paliwo lotnicze, turbinowe silniki lotnicze, osady*

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1. Introduction

The continuous development of aviation associated with an increase in the number of the carried out aerial operations forces the performance of work towards new constructions of aircraft and their propulsion systems and new fuel technologies. Fuel is currently the primary source of supply of aircraft engines, but it also acts as a lubricant and a heat transfer medium. Under the influence of heat and high temperature, fuel is subject to the degradation process, which results in the problems occurring in the aircraft operation. The example results of this phenomenon were presented in the paper [1].

The jet fuel thermal degradation process was summarised in the paper [2]. It presents the course and mechanism of this process divided into three main stages.

The assessment of the jet fuel thermal stability is currently based on the test implementation on JFTOT (Jet Fuel Thermal Oxidative Tester) device in accordance with ASTM D 3241 standard [3]. However, the results obtained on the basis of this marking often do not correlate with actual problems occurring in operation. Therefore, in terms of the fuel thermal degradation process, new non-standard tests are sought.

In Air Force Institute of Technology, within the framework of the research project implementation, an innovative test rig for testing jet fuels in terms of thermal stability was created. The test rig construction was presented in detail in the papers [4, 5]. Due to the extensive measuring system of the test rig and the possibility of setting various conditions of the implementation of tests, the obtained data allow for a very comprehensive analysis and assessment of the fuel thermal degradation process.

One of the signs of the occurring fuel thermal degradation is an increase in hydroperoxide and acid numbers. The obtained test results of these parameters [6] prove that a type of the jet fuel production technology, and especially the related process of refining with an antioxidant additive, has a significant impact on the value of the hydroperoxide number, and at the same time, on the fuel degradation rate.

The petroleum fuel degradation process as a result of thermal oxidation can be also assessed with the use of a number of manufactured products in the form of deposits. The rate of oxidation processes depends on the fuel composition, the content of antioxidant additives, as well as temperature conditions and access to oxygen. Under storage conditions, the composition and content of antioxidant additives provide relatively good stability of the jet fuel.

However, in operating conditions, where there are high temperatures, the formation of deposits may be more visible.

2. Bench and laboratory tests

The tests were implemented on the test rig presented in Fig. 1 with the use of conventional jet fuel. The fuel came from from two different technological processes: Hydrotreated and Merox. The main difference in the composition of these fuels, which is particularly important in the context of an analysis of thermal degradation processes, is the content of an antioxidant additive in Hydrotreated fuel. For each bench test, 1000 ml of fuel, which was previously filtered through a membrane filter with a diameter of pores of 0.6 μm, was prepared.

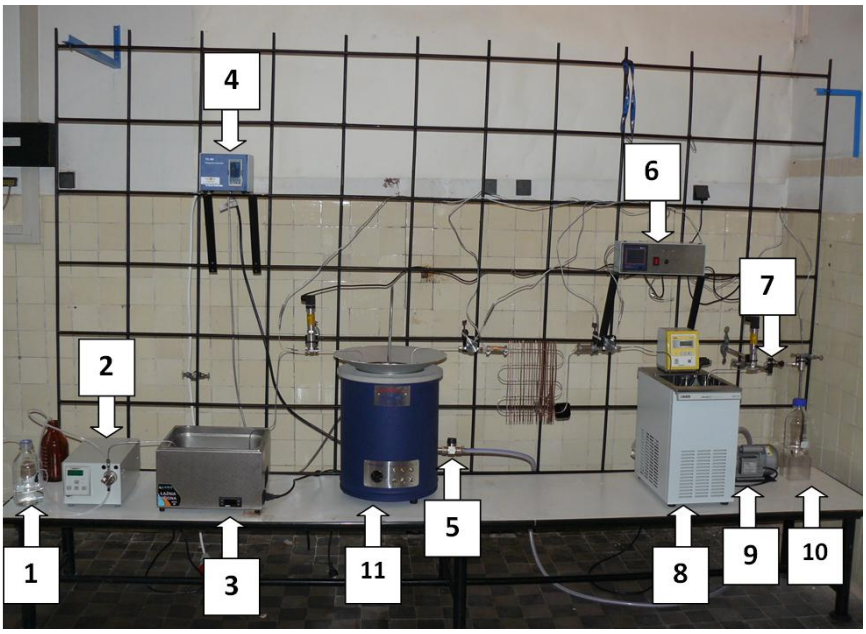

Fig. 1 General view of the test rig [6]:
1. vessel with the tested sample, 2. fuel pump, 3. water bath, 4. temperature controller in the sand bath, 5. sand bath air supply control valve, 6. recorder, 7. pressure valve, 8. cooling thermostat, 9. sand bath air dossing pump, 10. vessel for beakers / vessel for the tested sample, 11. sand bath

The general test idea involved passing of the prepared fuel sample through the test rig system in specific conditions. The fuel pumped on a given section (sand bath operating space) was subjected to thermal action, and then, it was cooled.
The time of fuel exposure to a fixed temperature value depended on the determined flow rate in the measuring system.
The adopted measuring cycle involved the performance of tests in the following conditions:

- constant pressure value in the system maintained at the level of 3.5 MPa,
- temperature values of the bath operation at the level of 300ºC, 400ºC and 500ºC,

– variable values of the fuel flow rate: 1.5 ml/min., 3.0 ml/min. and 6.0 ml/min., which allow to control the time of the thermal stimulation effect on the tested fuels.

After the bench test completion, a sample of the pumped fuel was subjected to laboratory tests in terms of assessment of the content of the formed deposits. The assessment of the quantity of the formed deposits was performed by filtering the fuel at the pressure of 80 kPa on the membrane filters with a size of pores of 0.8 μm and 3.0 μm. After filtering the fuel through the filters and retaining the formed deposits on them, they were dried at the temperature of 90±5 for 30 minutes. The total weight of the formed deposits was estimated by weight. Then, using the microscope, an image of filters was analysed.

3. Test results and their discussion

In Fig. 2 - 9, the test results of the content of deposits, obtained for Merox and Hydrotreated fuels after the ageing process at 300°C, 400°C and 500°C, carried out at various fuel flow rates, were presented.

By subjecting both jet fuels to the temperature of 300ºC, the same tendency, i.e. an increase in the quantity of the formed deposits with a decrease in time of the temperature impact on the tested fuel (i.e. with an increase in the fuel flow rate in the system), was observed. For Merox fuel subjected to the impact of the temperature of 300°C (Fig. 2-3), with an increase in the flow rate from 1.5 ml/min. to 3.0 ml/min. (i.e. reduction of time of the temperature impact on fuel by half), the quantity of the formed deposits slightly changes. The obtained quantities of deposits do not exceed 1 mg/l for both membrane filters (0.8 μm and 3.0 μm). Only at the highest value of the fuel flow rate – 6.0 ml/min. (i.e. for the shortest time of the impact of the temperature of 300ºC on the tested fuel), a noticeable and rapid increase in the content of deposits was obtained. In case of testing in analogous Hydrotreated fuel conditions (temperature of 300°C, flow rate of 1.5 ml/min., 3.0 ml/min., 6.0 ml/min.), a similar tendency (i.e. an increase in the number of formed deposits together with reduction of time of the temperature impact on the fuel) was observed. For this fuel, with an increase in the flow rate from 1.5 ml/min. to the value of 3.0 ml/min., the formation of more deposits than for Merox fuel was observed. However, at the flow rate of 6.0 ml/min., much less deposits were released in Hydrotreated fuel than in Merox fuel. The quantity of deposits obtained on both filters for Merox fuel at 400°C (Fig. 4-5) shows a decreasing tendency with an increase in the flow rate (i.e. reduction of time of the thermal stimulation impact on fuel). Hydrotreated fuel at the same temperature shows a more stable tendency of ageing processes – the quantity of the formed deposits on both filters, regardless of the flow rate (i.e. regardless of the thermal stimulation impact time) does not exceed 1 mg/l.

At the temperature of 500°C (Fig. 6-7) for Merox fuel, the similar results as in case of this fuel at 400°C were obtained, i.e. the quantity of deposits demonstrates a decreasing tendency with an increase in the flow rate (reduction of time of the temperature impact on fuel). In case of Hydrotreated fuel, the obtained results at 500°C are similar to the results obtained for this fuel at 300°C.

The increase in the quantity of the formed deposits along with reduction of the thermal impact time is observed.

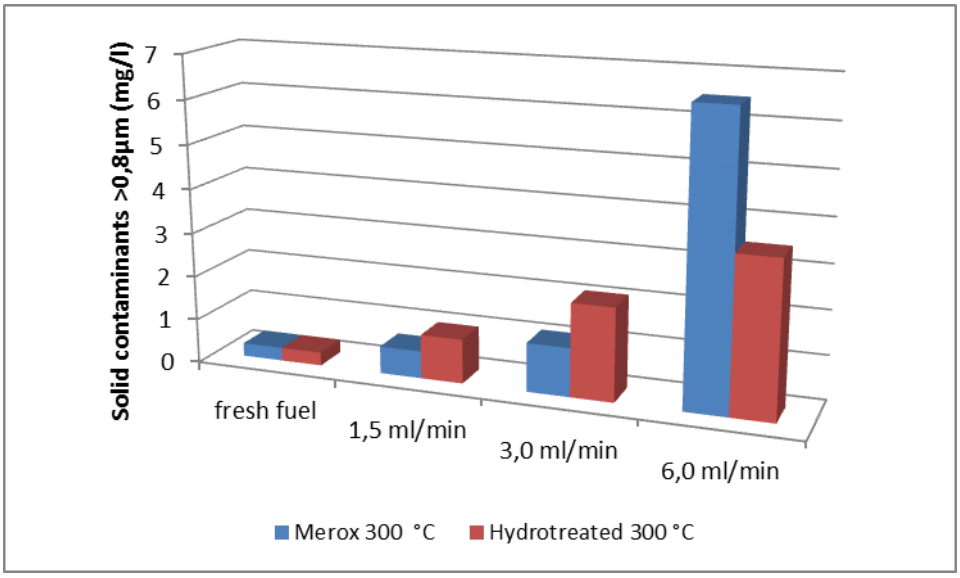

Fig. 2 Change in the content of deposits > 0.8µm of jet fuels at 300 ^{O}C, in the flow rate function

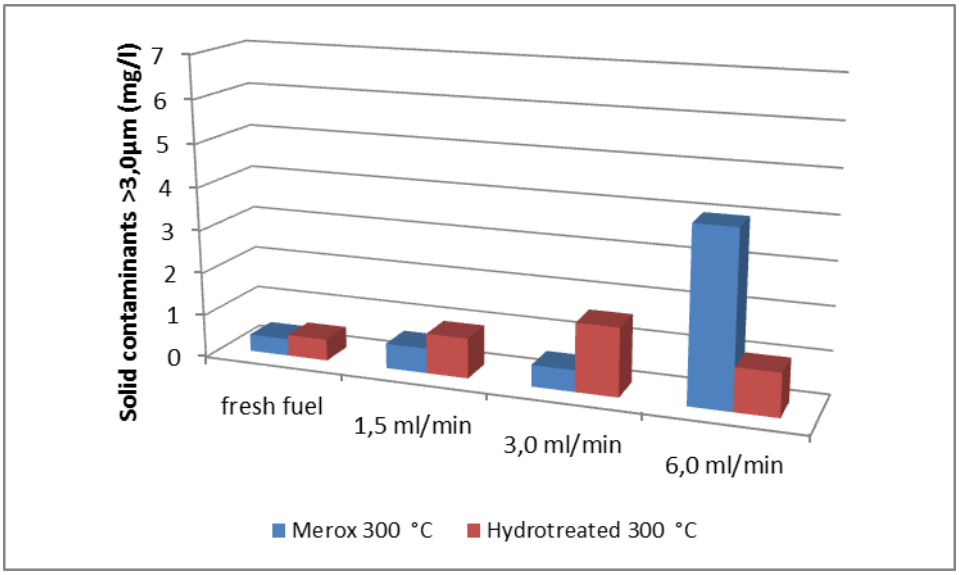

Fig. 3 Change in the content of deposits > 3.0µm of jet fuels at 300 ^{O}C, in the flow rate function

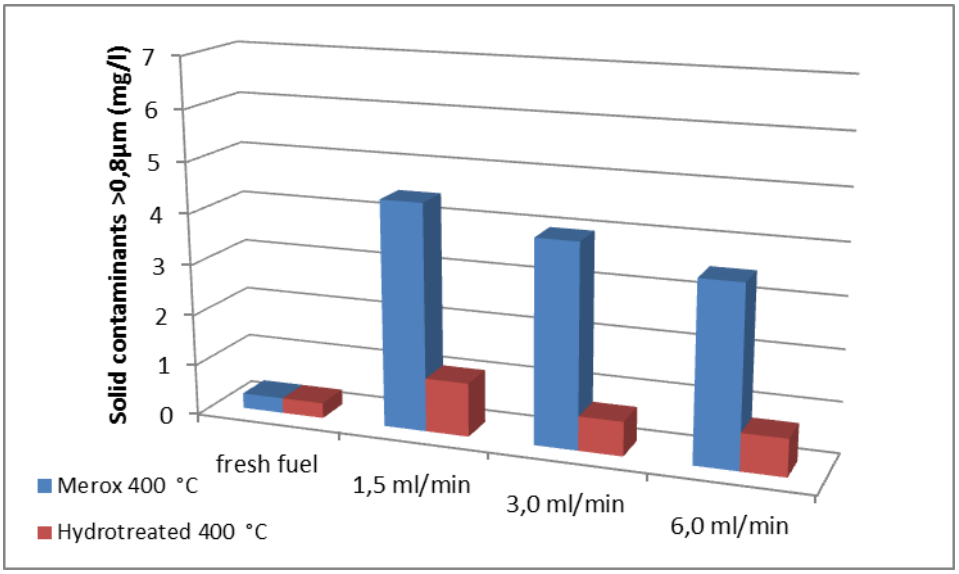

Fig. 4 Change in the content of deposits > 0.8µm of jet fuels at 400 ^{O}C, in the flow rate function

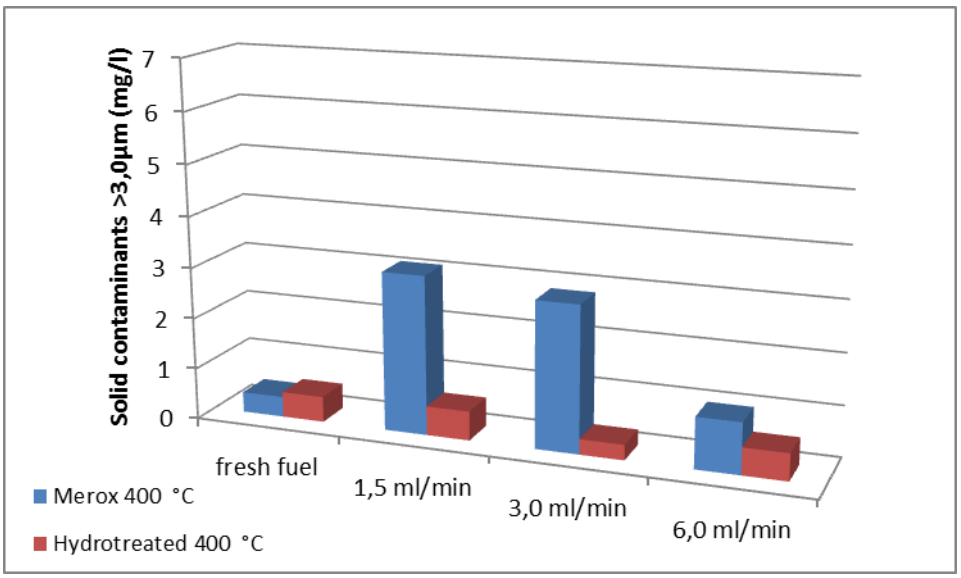

Fig. 5 Change in the content of deposits > 3.0µm of jet fuels at 400 ^{O}C, in the flow rate function

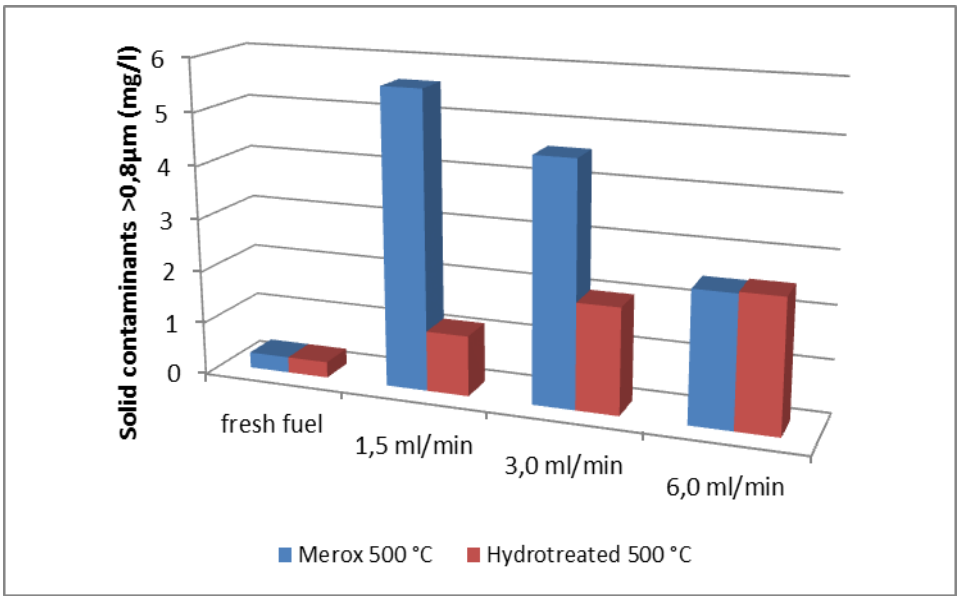

Fig. 6 Change in the content of deposits > 0.8µm of jet fuels at 500 ^{O}C, in the flow rate function

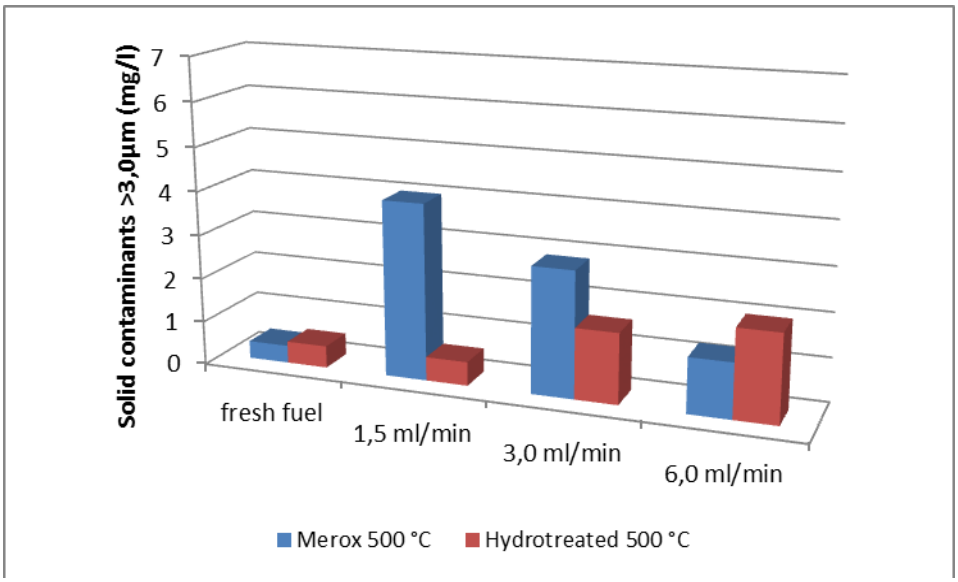

Fig. 7 Change in the content of deposits > 3.0µm of jet fuels at 500 ^{O}C, in the flow rate function

Merox fuel tested at various temperatures shows the formation of the highest quantity of deposits on both filters at 300 ^{o}C, at the same time, with the highest flow rate. At this temperature, at other flow rates, the measured quantities of deposits are slight (they do not exceed 1 mg/l).

However, at higher temperatures of the test, i.e. 400 °C and 500 °C for this fuel (with the exception of the flow rate of 6.0 ml/min.), the general formation of the higher quantity of deposits in comparison with the temperature of 300 °C is observed. Furthermore, at higher temperatures, the quantity of deposits with an increase in the flow rate demonstrates a decreasing tendency.

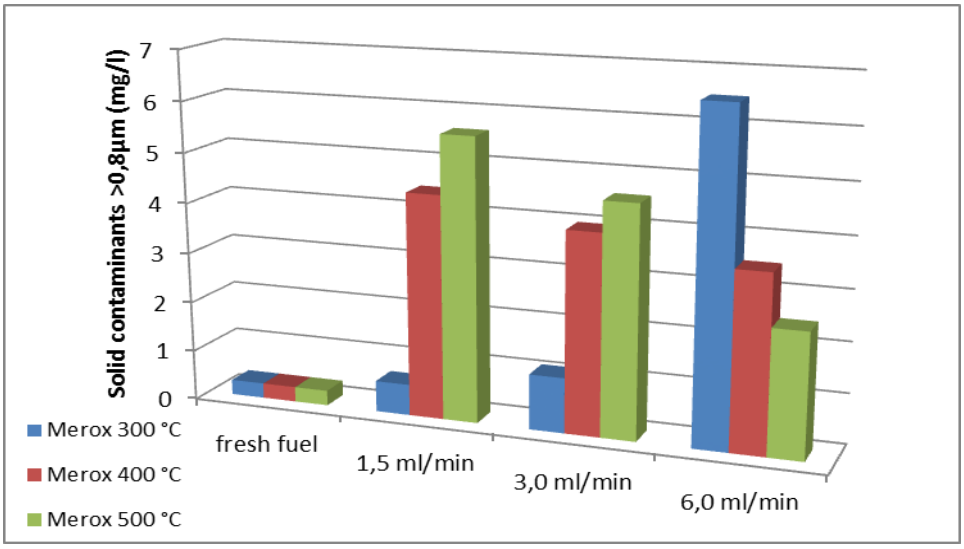

Fig. 8 Change in the content of deposits > 0.8µm for Merox fuel in various test conditions

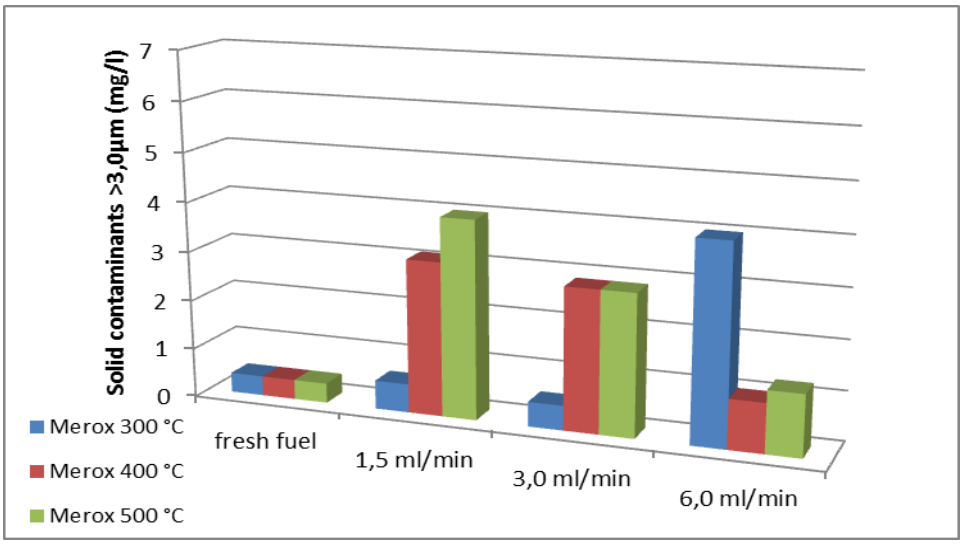

Fig. 9 Change in the content of deposits > 3.0µm for Merox fuel in various test conditions

Hydrotreated fuel while analysing the results from the filter 0.8 µm shows the formation of more and more deposits with an increase in the flow rate for the temperature of 300 °C and 500 °C. For these temperatures and a rate of 6.0 ml/min., the content of deposits is the highest. For the temperature of 400 °C for both filters, the obtained quantities of deposits are slight (they do not exceed 1 mg/l) for all the analysed flow rates.

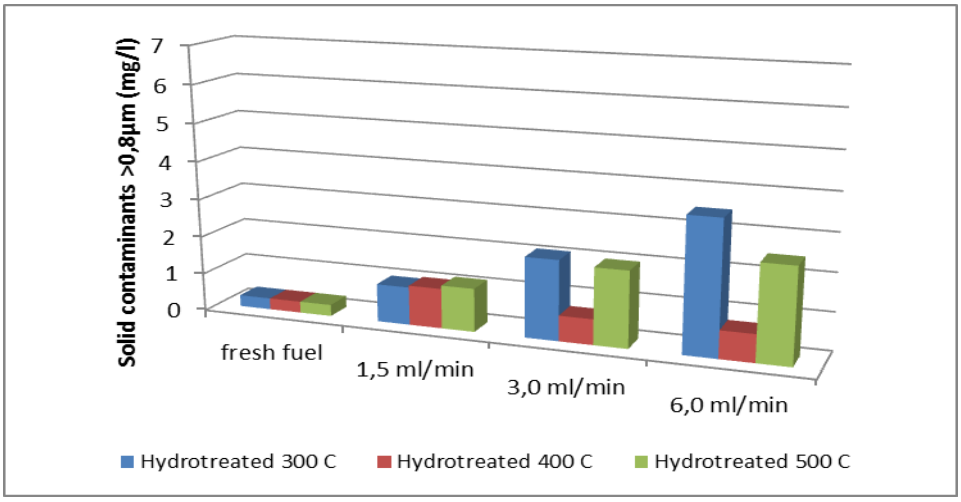

Fig. 10 Change in the content of deposits > 0.8µm for Hydrotreated fuel in various test conditions

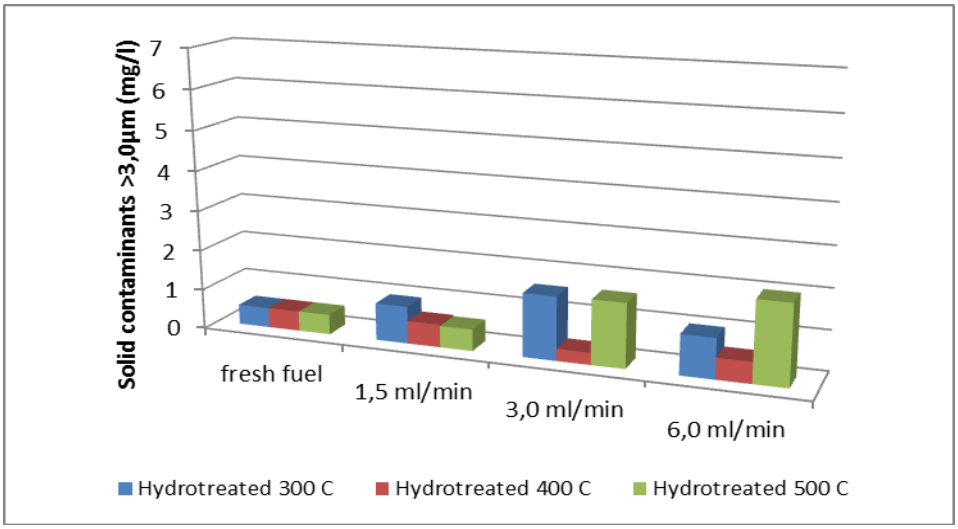

Fig. 11 Change in the content of deposits > 3.0µm for Hydrotreated fuel in various test conditions

Figures 12-15 present example microscopic images of deposits formed in Merox and Hydrotreated fuels, obtained after the ageing tests carried out at 500°C and at the flow rate of 3.0 ml/min. The images are related to the membrane filters with a size of pores of 0.8 µm and 3.0 µm. It is important to emphasise that the presented results relate only to the selected sections of the filters.

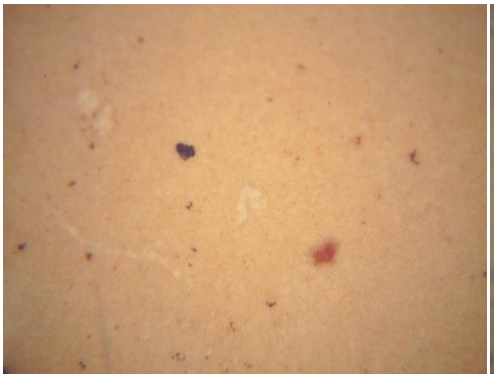

Fig. 12 Merox fuel deposits > 0.8 µm (zoom 11x)

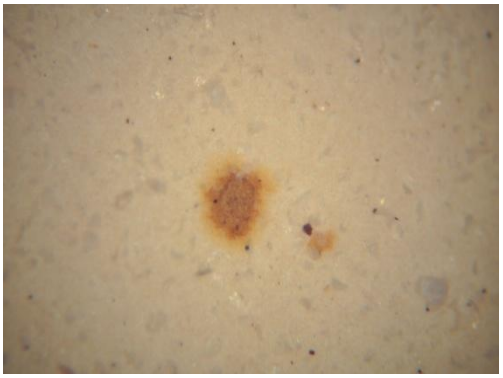

Fig. 13 Hydrotreated fuel deposits > 0.8 µm (zoom 11x)

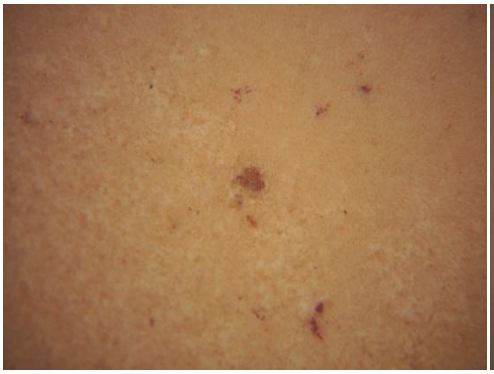

Fig. 14 Merox fuel deposits > 3.0 µm (zoom 11x)

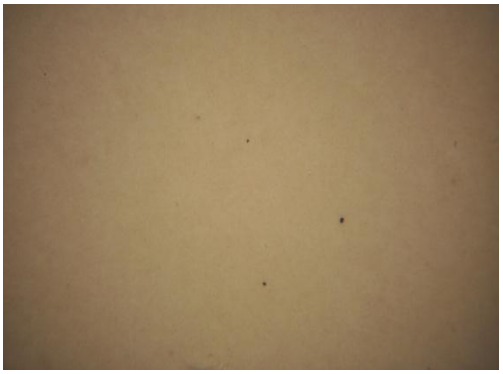

Fig. 15 Hydrotreated fuel deposits > 3.0 µm (zoom 11x)

The microscopic images present a larger number of smaller deposit stains for Merox fuel on both membrane filters with various sizes of pores (0.8 µm and 3.0 µm). This observation may confirm a greater tendency to thermal degradation of Merox fuel as opposed to Hydrotreated fuel, which is more stable in this respect.

4. Conclusion

The thermal degradation process of Merox and Hydrotreated fuels was carried out in various temperature and flow rate conditions. The tendency to thermal degradation was assessed by estimating the weight of the quantity of the formed deposits, retained on the membrane filters with different sizes of pores. The microscopic analysis of the deposit stains, retained on the membrane filters after filtration of these fuels, was also conducted.

The obtained test results show the formation of a smaller quantity of deposits in Hydrotreated fuel, which may be associated with its production technology and application of antioxidant additives. The fuel thermal degradation degree is also affected by the temperature at which the test is conducted because different ageing mechanisms operate at various temperatures. It is also possible to observe that the time of the fuel exposure to the thermal effect is crucial in the process of forming the deposits.

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***Jarosław Sarnecki**, **Ph.D., Eng.,** graduated from Military University of Technology in Warsaw. Since 1999, he has been working in Air Force Institute of Technology (1999-2002 – Diagnostics Research Division, 2002-2006 – Aero Engines Research Division, since 2006 – Fuels and Lubricants Research Division). His main areas of interest are: combustion of jet fuels, tribology and diagnostic systems for aircraft propulsion systems. Since 2007, he has been a manager of Fuels&Lubricants Research Division in the AFIT (Share* 33%).

***Bartosz Gawron, Ph.D., Eng.**, a graduate of Military University of Technology in the field of study: mechatronics, specialisation: aircraft and helicopters, in 2008-2012, a doctoral student on the third-degree studies in Military University of Technology at the Faculty of Mechatronics and Aerospace, since September 2012, a doctor of technical sciences in the scientific discipline of mechanics. Currently, a research worker in Air Force Institute of Technology (Share* 33%).

***Jadwiga Głąb, M.Sc.**, a graduate of Chemistry of the Faculty of Mathematics, Physics and Chemistry of the University of Silesia. From 1996 to 2011, she was a head of the Laboratory of Fuels in the Central Laboratory of Petroleum, and then, in the Institute for Fuels and Renewable Energy. Since 2011, a senior research and technical specialist of the Division of Propellants and Greases in Air Force Institute of Technology (Share* 33%).