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APPROBATION OF FUEL CATALYSTS FOR AIRCRAFT ENGINES

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Abstract

A study of the impact of fuel catalysts of the Ukrainian company "Auto-Eco-Titan", which were previously tested on reciprocating internal combustion engines of various modes of transport (road, rail, maritime) and showed a significant improvement in technical, economic and environmental performance. The possibility of using these catalysts in gas turbine aviation has been studied on aircraft gas turbine engines.

Kyewords: fuel catalyst; gas turbine engine; test bench

1. Introduction

Gas turbine engines are the most common for the formation of modern aircraft power plants [1-3]. The working process of gas turbine engines (isobaric) differs significantly from reciprocating internal combustion engines (isochoric).

Physicochemical processes that take place during combustion are the heat release processes and a number of heat and mass transfer processes accompanies them. The fuel combustion is a redox process by the chemical nature. Its essence lies in the fact that the mobile electrons of the combustible elements of hydrogen and carbon are transferred to the molecules and ions of oxidizing elements (oxygen of the air) with the formation of stable combustion products (water vapour, carbon dioxide, etc.) [4]. Rate of such chemical transformation and heat release during combustion is no more than a millisecond, while the substance (air fuel mixture) gets special properties: very hot (temperature is 2000-3000 K and more), chemically excited, partially ionized. It physically represents a low-temperature plasma. The intensity of combustion is due to its chain character. During the chain chemical process, active particles (free atoms and radicals, which have lost 1 - 2 electrons) are created and distributed. They involve the entire mass of the air -fuel mixture in the combustion process, link by link. The heat transfer from the flame by both diffusion and mechanical movement of the initial material, intermediate and final combustion products, maintains the reaction until the fuel is used up.

The use of fuel catalysts KT-4, KT-13, KT-14 for reciprocating internal combustion engines gave a significant improvement in the technical, economic and environmental characteristics of engines [5, 6, 7]. Therefore, it was decided to study this.

The purpose of the study is to determine the effect of the fuel catalyst on the gas turbine engine operational (throttling) performance. An important (mandatory) feature of the fuel catalysts of the company "Auto-Eco-Titan" using is their connection to the fuel line being in front of the fuel manifold at the entrance to the piston engine cylinders. A similar scheme was used to install a catalyst at the inlet to the fuel manifold in front of the combustion chamber of a gas turbine engine.

The fuel catalyst is a chamber-cassette device contains a housing with an inlet and outlet, in the middle of which there are three honeycomb filters based on compositions of molybdenum compounds, aluminium oxide, silicon dioxide and titanium sponge compounds [8]. It should be noted that spongy titanium is located at the inlet of each honeycomb filter, other components of the composition are connected to the surface of basalt fibbers, while the first honeycomb filter at the inlet additionally contains ammonium of molybdenum oxides, the next honeycomb filter contains ammonium vanadium oxides, the next honeycomb filter contains silver and (or) zinc. Beside this, the components of the honeycomb filters are additionally connected to the surface of the pumice and (or) asbestos and contain silica gel. A layer of spongy aluminium is located at the inlet of each honeycomb filter. All this ensures the getting of physicochemical processes that improve the quality of fuel combustion. The catalytic properties of active fillers of honeycomb filters, the potential difference between hydrocarbon ions and these fillers leads to the break of enlarged hydrocarbon chains and their grinding. Structural isomerization, dehydrogenation and aromatization of the fuel take place. The broken bonds of these chains have an increased electrical potential, and the formed cations more actively combine with oxygen. This also lowers the ignition temperature. The result is more efficient fuel combustion in the engine and less harmful exhaust gases such as carbon monoxide and soot.

2. Experimental part

2.1. Tests at the scientific and production center of unmanned aviation

In 2018, the fuel catalyst KT-4 was given to the scientific and production center of unmanned aviation "Virazh" of NAU, where its tests were carried out on an unmanned aerial vehicle M-22D "Aerotester" equipped with a two-stroke gasoline piston engine.

The tests were carried out in two stages: without using and with using of the fuel catalyst KT-4. The engine operation at idle and maximum modes with a certain volume of fuel 1 liter was studied. The test results are summarized in Table 1.

Table 1

Results of tests of the fuel catalyst KT-4 on the unmanned aerial vehicle M-22D "Aerotester"

Test stage	Flowmeter capacity, *l*	Engine run time, *min*	fuel consumption, *l/min*	Efficiency, %
Without fuel catalyst	1	19,46	0,05139	
With fuel catalyst	1	21,05	0,04751	7,55

2.2. Tests of the upgraded kerosene fuel catalyst KP-13KM

At the beginning of October 2018, Research Training Center "Aerospace Center" of the Aerospace faculty of the National Aviation University received from firm "Eco-Auto-Titan" a proposal for testing the fuel catalyst KP-13KM at the gas-dynamic test bench of the engine test station. To test the fuel catalyst KP-13KM (modified) a turboshaft engine TV2-117A test bench was selected (Fig. 1).

Fig.1. A turboshaft engine TV2-117A test bench

The tests were carried out in accordance with TTU 34.3-31909330.002.2002 without a catalyst and with a fuel catalyst KP-13KM when the engine was running at idle and takeoff modes at a cycle of four minutes. The kerosene was fed from a measuring container (flowmeter) with a volume of 15 liters.

Table 2

Results of tests of the fuel catalyst KP-13KM in the turboshaft engine TV2-117A test bench

Test stage	Absolute fuel consumption, l	Test bench operating time, min	Fuel consumption, l/min	Efficiency, %
Without fuel catalyst	7,5	4	1,875	
With fuel catalyst	7,0	4	1,750	6,667

Note: the efficiency is determined relative to the minute fuel consumption without using fuel catalyst KT-13KM

Measurement of the exhaust gas temperature was carried out with a thermal imaging unit Testo 975. It showed a decrease in the temperature and the smoke of the exhaust gases (Fig. 2, 3).

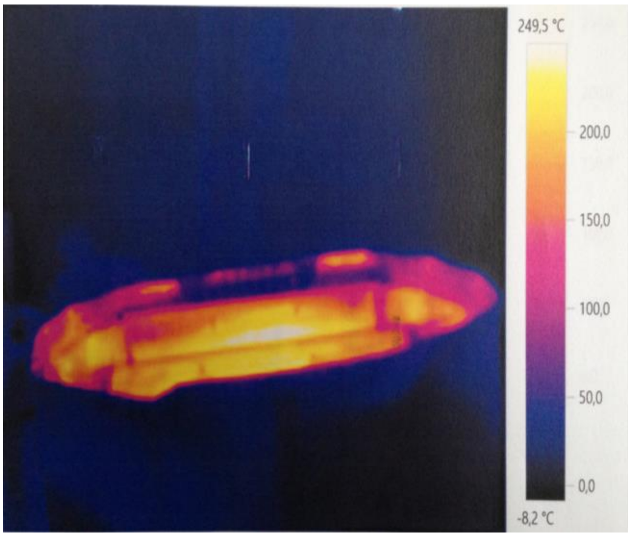

Fig. 2. Temperature field of the exhaust gases of the gas generator of TV2-117A at working on conventional fuel (without catalyst)

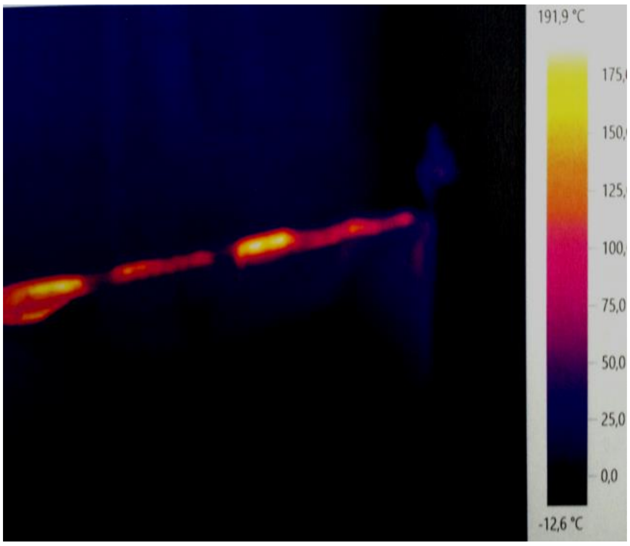

Fig. 3. Temperature field of the exhaust gases of the gas generator of TV2-117A at working on treated fuel (with catalyst)

2.3. Tests of the upgraded kerosene fuel catalyst KP-14KM

The purpose of the test: to determine the economic efficiency of the using of KP-14KM on aircraft gas turbine equipment.

Tests were conducted at the motor test station of the state enterprise "Aircraft Repair Plant 410 CA". An auxiliary power plant AI-9B is installed on the bench. Test bench is equipped with certified equipment. It was metrological certificated in accordance with international standards PART-145 (Fig. 4, 5).

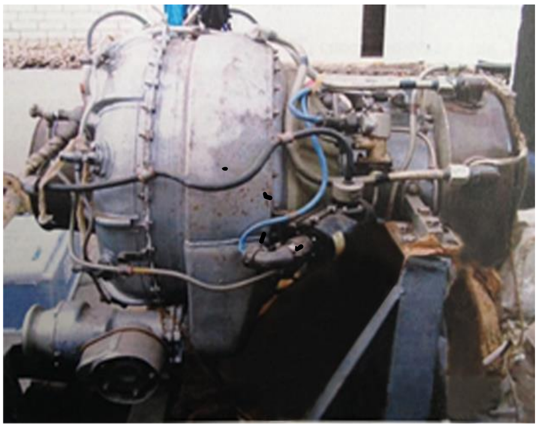

Fig. 4. Auxiliary power plant AI-9B

Fig. 5. Operator control panel

In accordance with the program, the tests were performed in three stages on two modes of engine operation (idle mode, load mode). The first stage was done without connection of the fuel catalyst. The initial characteristics of the auxiliary power plant AI-9B were obtained at the specified modes.

In the second stage, the fuel catalyst was connected to the AI-9B fuel system.

In the third stage of testing, the characteristics of the auxiliary power plant AI-9B were observed in accordance with the load mode, as in the first stage of the test.

According to the obtained data, the comparative characteristics of the fuel catalyst were constructed (Fig. 6), where P_C – the air pressure behind the compressor, T_T– the gas temperature (working fluid) behind the turbine, $P_{f\ wi}$ – the fuel pressure at the working injectors, G_f – fuel consumption.

On the basis of the presented characteristics it is possible to draw also conclusions that with use of the fuel catalyst fuel economy makes 1-2 l/h. Accordingly, the specific fuel consumption decreased in the range of 1.0 ÷ 1.9%.

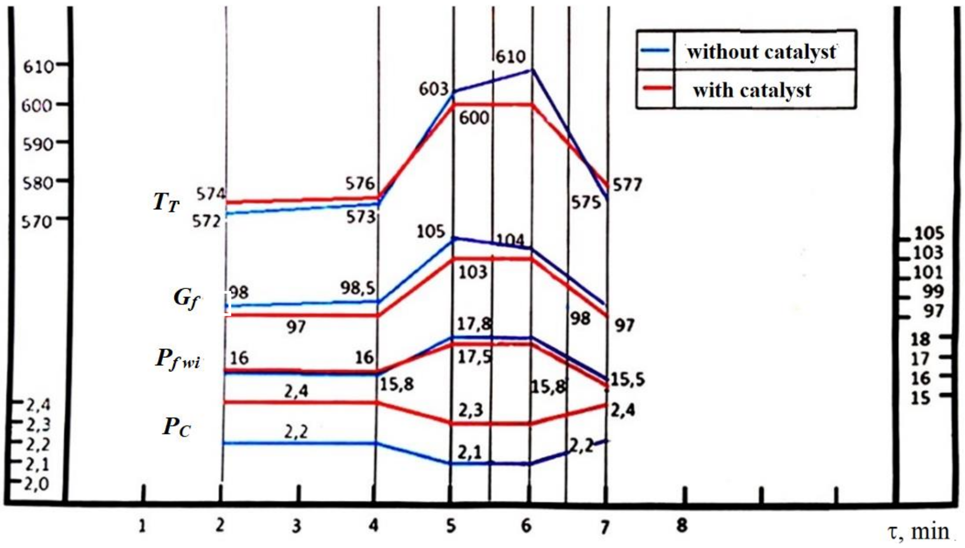

Fig.6. Comparative characteristics of the study of the fuel catalyst in the auxiliary power plant AI-9B

2.4. Tests in the Zaporozhye Machine-Building design bureau "Ivchenko-Progress"

To test the fuel catalyst a gas turbine aircraft engine was upgraded to ensure the appropriate fuel consumption. The engine was equipped with a device that allows you to remotely switch it (Fig. 7).

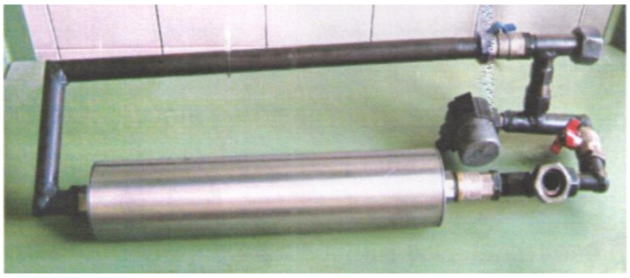
Fig.7. Fuel catalyst KT-14KM with remote control device

The tests were conducted on November 20-21, 2019 on the turboprop engine AI-450CP-2 (Fig. 8). This engine is designed for use on light aircraft and unmanned aerial vehicles.

A feature of the test bench is the presence of an automated control system and registration of parameters.

On November 20, 2019, calibration tests were done according to the standard program to obtain engine original throttling characteristics. On this day, the engine was tested to obtain its original throttle characteristics, after that the fuel catalyst was mounted on the test bench and tests were performed with the fuel catalyst. Every cycle consisted of starting, warming up the engine at ground idle power, switching to flight idle rating, maximum cruise rating, maximum continuous rating, take-off rating, for the test of acceleration flight idle rating and again at take-off, then maximum cruise rating, flight idle, ground idle rating and shutdown.


Fig.8. Turboprop engine AI-450CP-2

A feature of the second cycle was the long operation of the engine at maximum cruise mode (for 10 minutes) to test the flow capacity of the fuel system.

A comparison of the obtained characteristics revealed a slight decrease in the specific fuel consumption in the modes of ground idle and flight idle ratings in the range of 1÷2%. No impact of treated fuel was observed in other ratings.

Then it was decided to change the test program. On November 21, 2019, the cruising mode (Kr) was introduced in the first half of the test cycle; the second half of the cycle was similar to the first test program. In addition, in each mode, switching was performed in the fuel system, i.e. first, we work without a fuel catalyst, then with a catalyst.

Experimental data (fragment) are presented in table 4, table 5.

Table 4

Test without catalyst

Rating	$n_{gg\ r}$, rpm	$N_{efT\ r}$, hp	$C_{ef\ r}$, kg/hp·h
ground idle	28583.1	34.6	1.281
flight idle	29599.6	41.0	1.118
maximum cruise	42914.5	566.7	0.224
flight idle	29755.8	42.3	1.101
ground idle	28591.3	34.7	1.260

Table 5

Test with fuel catalyst

Rating	$n_{gg\ r}$, rpm	$N_{efT\ r}$, hp	$C_{ef\ r}$, kg/hp·h
ground idle	28630.3	34.7	1.276
flight idle	29654.7	41.4	1.106
maximum cruise	42961.7	562.6	0.226
flight idle	29730.8	42.0	1.077
ground idle	28586.1	34.7	1.260

From the experimental data for this cycle, we see the effect on the specific fuel consumption at the ground idle and flight idle ratings in the range of 2÷0.5%, then we do not see the difference.

To analyze the effect of the fuel catalyst on the operating process of the gas turbine engine, the dependences of the reduced power of the free turbine $N_{efT\ r}$, (hp) and the reduced specific fuel consumption $C_{ef\ r}$, kg/(hp time) on the reduced speed of the rotor of the gas generator $n_{gg\ r}$, rpm. The dependences were approximated by the least squares method. The dependence of the free turbine power on the speed of the gas-generator rotor was described by a piecewise linear function. Using untreated fuel in the catalyst, the dependence takes the form:

$$N_{efT\ r} = \begin{cases} -150.48 + 0.006476\, n_{gg\ r} \\ \quad \text{at } n_{gg\ r} < 36850 \\ -3439.231 + 0.09324\ n_{gg\ r} \\ \quad \text{at } n_{gg\ r} \geq 36850 \end{cases},$$

and when using a catalyst

$$N_{efT\ r} = \begin{cases} -156.132 + 0.0066698\, n_{gg\ r} \\ \quad \text{at } n_{gg\ r} < 36850 \\ -3467.608 + 0.09391\ n_{gg\ r} \\ \quad \text{at } n_{gg\ r} \geq 36850 \end{cases}$$

The dependence of the specific fuel consumption on the speed of the gas-generator rotor was described by a polynomial of the second degree.

When working on ordinary (untreated) fuel, the dependence takes the form:

$$C_{ef\ r} = 8.8399 - 0.00039359877\, n_{gg\ r} + \\ + 0.000000004493501\, n_{gg\ r}^2\ ,$$

and when using a catalyst

$$C_{ef\ r} = 8.74405 - 0.00038850959\, n_{gg\ r} + \\ + 0.000000004427652\, n_{gg\ r}^2\ .$$

As can be seen from the above results, the use of a catalyst does not change the throttle characteristics. The deviation of the throttle characteristics when using the catalyst from the characteristics of the engine that uses conventional fuel is within the error of the measured parameters.

3. Conclusions

Preliminary tests on unmanned aerial vehicles with a reciprocating engine in Kyiv have confirmed the economic efficiency of the fuel catalyst of the company "Auto-Eco-Titan" using.

The test results of fuel catalysts on aircraft gas turbine equipment differ significantly from each other because the tests were performed on different programs and places of connection of the fuel catalyst in the fuel system of the gas turbine engine.

Thus, when testing the catalyst KP-13KM according to the control test program of the engine TV2-117A in operation with the catalyst installation in front of the fuel tank of the combustion chamber we have a reduction in fuel consumption to approximately 6.667% and emission, as evidenced by scanning temperature of exhaust gases.

When testing the catalyst KP-14KM on the engine AI-9B with a short fuel system and the installation of the catalyst at the entrance to the fuel system of the engine at working mode, we have a reduction in specific fuel consumption of 2.0%.

When testing the catalyst KP-14KM on the engine AI-450CP-2 with a long fuel system and installation of the catalyst at the entrance to the fuel system of the engine, in accordance with a typical program of calibration tests, at first glance significant impact on neither hourly nor specific fuel consumption and other gas-dynamic parameters not detected. Which indicates the effect of hydraulic resistance of the fuel catalyst and reactivation of the processes of fragmentation long fuel molecules before entering the combustion chamber.

That is, the fuel catalyst must be installed in the fuel system directly in front of the fuel tank of the combustion chamber so as not to break the new formation of molecular bonds.

References

[1] Inozemczev A.A., Sandraczkij V.L. (2006). *Gazoturbinnye dvigateli* [Gas turbine engines] Perm: OAO «Aviadvigatel», 1204 p. (In Russian)

[2] Tereschenko Yu.M. (2013). *Teoriya aviacionnykh gazoturbinnykh dvigatelej* [Theory of aircraft gas turbine engines] / Yu.M. Tereshchenko, L.G. Bojko, L.G. Volyanskaya ta in; Za red. Yu.M. Tereshchenka. – K.: NAU, 596 p. (In Russian)

[3] Loziczkij L.P., Vetrov A.N., Doroshko S.M. i dr. (1992). *Konstrukcziya i prochnost` aviaczionny`kh gazo-turbinny`kh dvigatelej* [Design and strength of aircraft gas turbine engines] M.: Vozdush. transport, 536 p. (In Russian)

[4] Reznikov M.E. (20040 *Aviaczionny`e topliva i smazochny`e materialy` (aviaczionnaya khimmotologiya)* [Aviation fuels and lubricants (aviation chemmotology)]. Pod red. A.G.Krutilina: uchebnik. – M.: Voennoe izdatel`stvo, 323 p. (In Russian)

[5] Danilyan A.G., Maslov I.Z., Zalozh V.I., Rudenko M.I. (2017). *Puti snizheniya vredny`kh vy`brosov v otkhodyashhikh gazakh sudovy`kh dizelej* [Ways to reduce harmful emissions in the exhaust gases of marine diesel engines]//International Scientific and Practical Conference "WORLDSCIENCE" #7(23) Vol.2. – p. 24-31. (In Russian)

[6] Maslov I.Z., Danilyan A.G (2018). *Modelirovanie proczessa tekhnicheskogo sostoyaniya sudovy`kh dvigatelej po programme «dizel` – RK»* [Modeling the process of technical condition of ship engines under the "Diesel - RK" program]// "WORLDSCIENCE" #5(33) Vol.1, May. p. 25-29. (In Russian)

[7] *SertifIkat pro tipove shvalennya na katalIzator palnogo (fIltr-katalIzator palnogo) KT-14DM dlya dvigunIv vnutrishnogo zgoryannya # STS-224-3-106-17 vId 25.04.2017 shvaleniy Registrom sudnoplavstva Ukrayini.* [Certificate of standard approval for fuel catalyst (fuel catalyst filter) KT-14DM for internal combustion engines № STS-224-3-106-17 from 25.04.2017 approved by the Register of Shipping of Ukraine] (In Ukrainian)

[8] Lyubenko P. I. (2017). *KatalIzator-modifIkator palnogo. Patent na korisnu model* #120789 (Ukrayina) F02M 27/02 vId 27.11.2017, Byul. # 22. [Catalyst-modifier of fuel. Patent for utility model 20120789 (Ukraine) F02M 27/02 dated 11/27/2017, Bull. №22] (In Ukrainian)

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Апробація каталізаторів палива на авіаційних двигунах

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Проведено дослідження впливу каталізаторів палива української фірми «Авто-Эко-Титан», що пройшли перед тим випробування на поршневих двигунах внутрішнього згорання різного виду транспорту (автомобільного, залізничного, морського) та показали суттєве покращення техніко-економічних та екологічних показників. Можливість використання даних каталізаторів у газотурбінній авіації досліджувалась на авіаційних газотурбінних двигунах.

Ключові слова: паливний каталізатор; газотурбінний двигун; випробувальний стенд

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Апробация катализаторов топлива на авиационных двигателях

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Проведено исследование влияния катализаторов топлива украинской фирмы «Авто-Эко-Титан», прошедшие перед тем испытания на поршневых двигателях внутреннего сгорания различного вида транспорта (автомобильного, железнодорожного, морского) и показали существенное улучшение технико-экономических и экологических показателей. Возможность использования данных катализаторов в газотурбинной авиации исследовалась на авиационных газотурбинных двигателях.

Ключевые слова: топливный катализатор; газотурбинный двигатель; испытательный стенд

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