ТРАНСПОРТ
05.22.01 – Транспортные и транспортно-технологические системы страны, ее регионов и городов, организация производства на транспорте;
05.22.08 – Управление процессами перевозок;
05.22.13 – Навигация и управление воздушным движением;
05.22.14 – Эксплуатация воздушного транспорта

УДК 621.45.04
DOI: 10.26467/2079-0619-2021-24-6-8-16

THE JET FUELS ANTI-WEAR PROPERTIES INDICATOR

K.I. GRYADUNOV[1], A.N. TIMOSHENKO[1], K.E. BALISHIN[1], U.V. ERMOLAEVA[1]
[1] Moscow State Technical University of Civil Aviation, Moscow, Russia

There are three main fuel brands for jet engines of civil aviation used: domestic TS-1 and RT and foreign, produced in relatively small volumes in Russia, JET A-1 (JET A-1). Since the end of the 2000s, foreign manufacturers have made claims to the quality of the mass-used domestic fuel brand TS-1, and these claims have not been specified. However, the service life of a number of foreign engines operating on TS-1 fuel has been reduced by 50%. This circumstance can be caused by both subjective reasons – commercial and political interests of equipment manufacturers, and the objective ones. The main objective reason may be that recently several Russian plants producing TS-1 fuel have begun to produce composite propellant under the same name, where products of secondary oil refining processes are added to the straight-run fractions. These fuels meet the requirements of the standard (GOST 10227-86), which does not contain an indicator that characterizes the anti-wear properties of jet fuels. In the standard for JET A-1 fuel, anti-wear properties are normalized, and they are also normalized in the standard for domestic fuels for supersonic aviation. The article presents comparative tests of anti-wear properties of samples of jet fuels used in the civil aviation. The article substantiates the relevance of the anti-wear properties indicator in the standard for domestic brands of jet fuels for subsonic aircraft introduction, as well as the comparative analysis of the anti-wear properties of fuels produced by various Russian oil refineries. Indicators and methods for assessing the anti-wear properties of aviation fuels can be different. As such an indicator, it is proposed to use the anti-wear properties indicator calculated after testing fuel samples on a four-ball friction machine.

Key words: aviation, jet fuel, aviation fuel, anti-wear properties of aviation fuels, four-ball friction machine, anti-wear properties indicator.

INTRODUCTION

Jet fuels are used in all the jet engines, providing us with a set of functions, one of which is lubrication [1–7] on which the operational reliability of fuel system friction pairs depends on. The friction pair of the high-priced plunger-lift equipment (inner cylinder – wobble plate; inner cylinder – shroud) is the one to be the most runover susceptive. Meanwhile the friction pair inner cylinder – wobble plate is the indicative one [2, 5–7].

The jet fuels of the TS-1, RT domestic brands by the GOST 10227-86[1] and of the foreign one JET A-1 by the GOST 32595–2013[2] are now produced for the civil aviation on the Russian petroleum processing plants. Nevertheless, there is the indicator of the lubricating ability in the standard for JET A-1, and there is no such an indicator in the standards for TS-1 and RT. It should also be noted, that the lubricating ability is normalized in the standard for the Russian supersonic aircraft fuel brands (GOST 12308-2013[3]).

[1] GOST 10227-86. (1986). Jet fuels. Moscow: Standartinform. 18 p.
[2] GOST 32595-2013. (2014). Aviation Turbine Fuel Jet A-1. Specifications. Moscow: Standartinform. 39 p. At the same there is also a national GOST R 52050-2006 (2014). for the given product. Moscow: Standartinform. 39 p.
[3] GOST 12308-2013. (2013). Thermostable Fuels T-6 and T-8B for Jet Engines. Specifications. Moscow: Standartinform. 22 p.

I.e., the lubrication ability of TS-1 and RT fuel brands was being estimated only by the classificatory methods of clearance while bringing them into service – decades ago. Nowadays the latter basic materials and formulation of these fuel brands differ from the former.

There are the claims to the quality of TS-1 in the Airworthiness Directives of the ASA – European Aviation Safety Agency (EU) of the administrative and executive aims relating to flight operating safety, and primarily, to the anti-wear properties of aviation fuels: EASA AD No.: 2017-0065[4], EASA PAD No.: 17-023[5], EASA CRD of PAD No. 17-023[6]. Thus, the durability of the range of foreign engines, run on TS-1, has been reduced by 50%[7] [8, 9, 10]. These claims are not specified; therefore, the given circumstance can be caused by both subjective, and objective reasons. The introduction of the indicator, which characterizes the fuel anti-wear properties, to the standards for jet fuels could serve to the solution of the problem. The choice of such an indicator is a topical issue.

Let us review the probable objective reason.

The anti-wear properties of aviation fuels depend on many factors: carbonic speciation, the presence of heteroatomic compounds, total purity, the presence of SAS, etc. The straight distillation and hydrogenolysis respectively have been the processes of TS-1 and RT jet fuel generation by the moment of estimating the lubrication ability by the classificatory methods of clearance. The range of agents, including the anti-wear ones, which have also changed nowadays [7, 11], is to be implied obligatory in the fuels, submitted to hydrotreating, deprived of natural components, which increase the lubricating ability.

The range of the Russian petroleum plants – in fact those streamlined plants, which widely implemented oil treatment secondary processes – produce, the so-called, composite propellant TS-1, which contains the products, generated by both the straight oil distillation and by means of the secondary oil treatment processes [12]. These factors, obviously, affect the fuel lubricating ability, which is not controlled.

It should also be noted, that there is no data on directly and indirectly distilled components formula in the mixed TS-1 fuel, as well as data on implying any agents into such a fuel. It seems impossible to distinguish the composite propellant from the un-mixed one – as they are produced according to the same standard under the same designation.

Nowadays the problem is widespread in Russia and affects all the petrol, oil, and lubricants – the same brand can be produced according to the various technologies out of the different raw materials [7].

It is also known [5], that conducting the full range of qual tests was obligatory while changing the raw material and making any modifications of the jet fuel production technology until the 1990s.

FRAMEWORK

There is a wide variety of estimation methods of petrol, oil and lubricants lubricating characteristics, many of these methods may be used for estimating the lubricating characteristics of the aviation fuel. The foreign (American) method BOCLE (GOST 333906-2016[8], ASTM D 5001-10[9]) is allowed

4 EASA AD No.: 2017–0065. (2017). EASA Airworthiness Directive. ATA 73 – Engine Fuel and Control – Hydro-Mechanical Units – Operational Limitations. 3 p.
5 EASA PAD No.: 17–023. (2017). EASA Notification of a Proposal to Issue an Airworthiness Directive – ATA 73 – Engine Fuel and Control – Hydro-Mechanical Units – Operational Limitations. 1 p.
6 EASA CRD of PAD No. 17–023. (2017). EASA Comment Response Document– Notification of a Proposal to Issue an Airworthiness Directive – ATA 73 – Engine Fuel and Control – Hydro-Mechanical Units – Operational Limitations. 7 p.
7 Kovba L.S. (2019). The Evaluation of the Fuel Quality Impact on Aircraft Sustainability Based on Maintenance Best Practices // InfoTech 2019.
8 GOST 33906-2016. (2019). Aviation Turbine Fuels. Determination of Lubricity by the Ball-on-cylinder Lubricity Evaluator (BOCLE). Moscow: Standartinform. 37 p.

under the standards for estimating the lubricating features of the domestic jet fuels for the supersonic aircraft and JET A-1 fuel along with many other foreign fuels [13–17]. The appropriate apparatus is produced by the only international manufacturer.

However, it does not have any advantages over many other methods [5, 18]. It does not emulate the work of the aircraft gas-turbine engines friction pairs, as demonstrated by the phrase in the given standard: "The BOCLE clearance method is not the direct reflection of the operating environment of the engine parts operation". There is also a remark: "The range of fuels rich in some sulphur compounds may indicate the abnormal results of the test". Therefore, the given method is not preferential for the TS-1 and JET A-1 sulphide fuels.

The simple and reliable four-ball friction machine (FFM – 1) (fig. 1 and fig. 2) can be used for comparative evaluation of aviation fuel lubricating characteristics.

The essence of the method is in the calculation of the critical load – such a load, which leads to the loss of the fuel lubricating characteristics, – by the results of consequent loading by the abrupt increase in diameters of the wear scars, left by the upper shiftable ball 2 on the numb balls 1 (fig. 2) stuck in the securing clamp.

It is important to mention, that the given apparatus allows us to obtain the results, correlating well with the fuel control unit inner cylinders wear [5].

There are also such advantages of the method as: its simplicity and the low price of the technical equipment and expendable products, relatively high speed of the performance of the experiment (the loading is carried out in 10 seconds), the technical equipment is completely domestic, the short subject fuel consumption (up to 15 ml), relatively small size of the apparatus, etc. The covered method has the same advantages over the ones for the classificatory evaluation of the aviation fuel anti-wear characteristics, made for slightly different tasks.

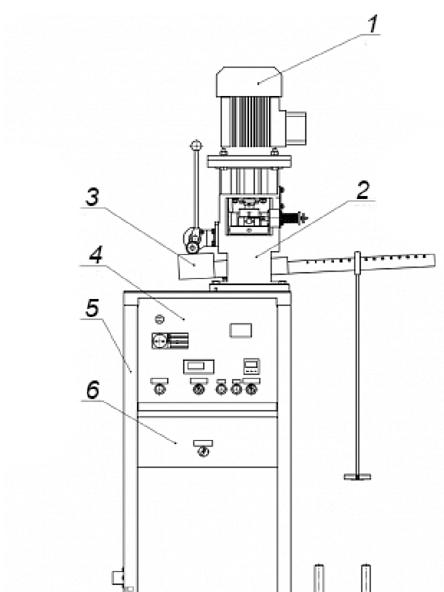

Fig. 1. The four-ball friction machine block diagram: *1* – braking motor with the hand-held arrester; *2* – molded case; *3* – the lever arm for axle loadings in friction joint; *4*, *6* – operation panel; *5* – body frame

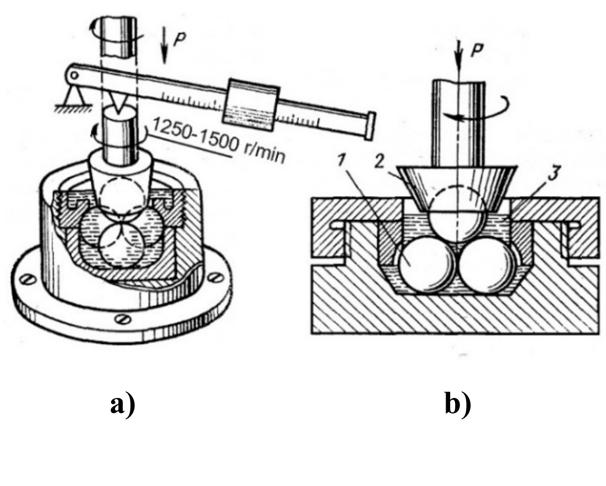

Fig. 2. The four-ball friction machine operation principle: *a)* the friction joint loading chart; *b)* the machine friction joint; *1* – the fixed balls; *2* – the rotative ball; *3* – test fuel

[9] ASTM D 5001–10. (2014). Standard Test Method for Measurement of Lubricity of Aviation Turbine Fuels by the Ball-on-cylinder Lubricity Evaluator (BOCLE). 14 p.

EXPERIMENTAL SET UP

The comparative evaluation was made for the three articles of aviation fuels of different brands and for the article of the composite propellant (TS-1 + RT), sampled from the aircraft tanks, according to the standardized tear (GOST 9490-75[10]).

There are the results of the experiment in Figure 3. It can be seen, that the given articles of the fuel have the similar values of critical loads. Meanwhile the article of RT fuel has shown us the best anti-wear properties in the given test environment, the article of JET-A1 – the worst ones.

The different criterion may be used as an indicator of aviation fuel lubricating ability: the critical load, the diameter of the wear scars, the wear criteria, etc. The specified rate of the anti-wear properties in percentage terms, proposed by A.F. Aksenov [4]:

$$К = \frac{Р^{и}_{кр}}{Р^{э}_{кр}} \cdot \frac{И_{э}}{И_{и}} \cdot 100,$$

where K – the anti-wear properties indicator, %;

$Р^{и}_{кр}$ – the critical load of metal friction shift from the fluid to the boundary in the subject fuel, kgf;

$Р^{э}_{кр}$ – the critical load of metal friction shift from the fluid to the boundary in the canonical fluid, kgf;

$И_{э}$ – the metal wear in the canonical fuel, mm;

$И_{и}$ – the metal wear in the subject fuel, mm.

The metal wear is the average diameter of the wear scars in this very case.

On the basis of the experimental data, the indicators of the anti-wear properties of the aviation fuel articles under review are reflected in Table 1. The RT fuel brand, which has the best anti-wear properties among the given articles, is taken as a gold standard (100%) in this very example. The composite propellant has demonstrated the stronger performance, but is not a fuel brand, so that is why the indicator has not been calculated of anti-wear properties for it.

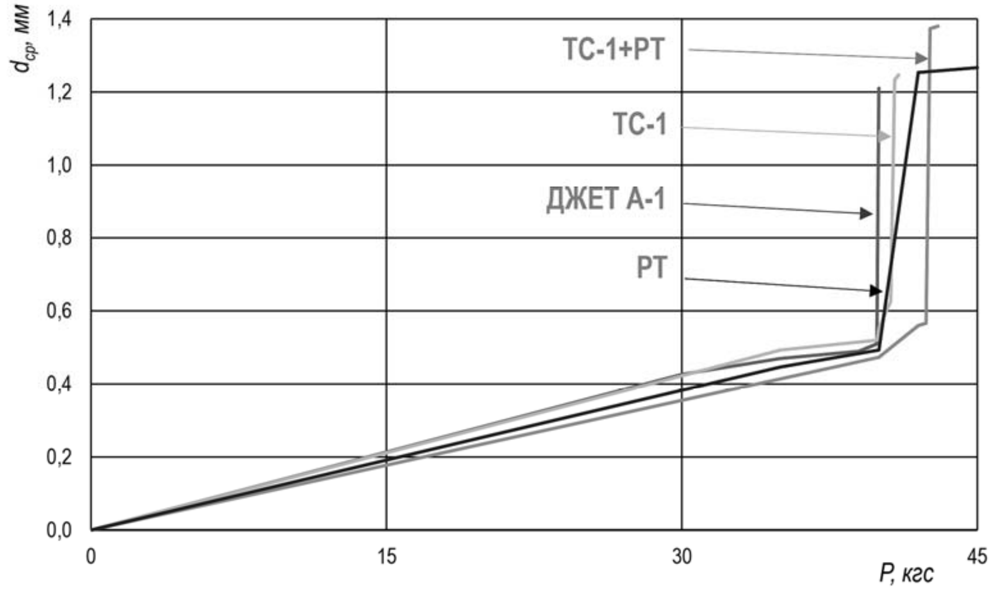

Fig. 3. The critical load of different fuel brands determining

[10] GOST 9490-75. (1975). Liquid Lubricating and Plastic Materials. Method of Test for Lubricating Properties on Four Ball Machine. Moscow: Standartinform, 40 p.

Table 1

Antiwear properties indicator of Aviation fuels

The aviation fuel brand	Antiwear properties indicator K, %
RT (РТ)	100
TS-1 (ТС-1)	98
JET A-1 (ДЖЕТ А-1)	96

DISCUSSION OF THE EXPERIMENTAL RESULTS

The experiment is the introductory one. It shows us the opportunity of the domestic four-ball friction machine use for the jet fuel anti-wear properties evaluation, which is extremely relevant nowadays. The specified rate by A.F. Aksenov is proposed as the rate of the anti-wear properties.

The RT brand has the best anti-wear properties among the provided commercial fuel articles. The TS-1 of the straight-run distillation and JET A-1 proceed by the anti-wear properties reduction. Nevertheless, all the brands have the similar valuations of the anti-wear properties in the conditions of the performance of the experiment. The composite propellant – the fuel, which was collected from the aircraft tankage – has shown us the better anti-wear properties, than the fresh RT fuel. This can be explained by the effect of many factors, one of which is the following: the fuel in the aircraft tankage oxygenates in operation, as a result, the highly molecular oxidation products (methacrylate resins) afford in it, increasing the fuel lubricating ability.

The further development of the study is the solution of the following problems: comparison of the anti-wear properties of the commercial fuel, which is produced at the different Russian oil-processing plants using different technologies; determination of the relevant indicator, characterizing the jet fuel anti-wear properties; determination of the indicator permissible limits for the civil aviation fuel; display of the initiative for the implementation of the indicator in the standard for the jet fuel.

CONCLUSION

1. The aviation fuel anti-wear properties depend on many factors and represent the operational reliability of fuel system friction pairs in the aviation engines. The anti-wear properties of the TS-1 fuel may reduce as it is laced with products of the secondary oil treatment processes and must be controlled, due to the widespread production of this fuel brand.
2. The aviation fuel anti-wear properties may be evaluated by the different indicator using the different methods. Including the anti-wear properties indicator, resulted with the four-ball friction machine.
3. The experiments showed us, that the selected aviation fuel articles have the similar anti-wear properties. The RT article has the best ones, and the JET A-1 – the worst ones. Comparative estimate of the anti-wear properties of the aviation fuel, which is produced at the different Russian oil-processing plants is relevant.
4. Control of the anti-wear properties of the civil aviation jet fuel of domestic brands is relevant, thus it is necessary to implement the lubrication ability indicator in the standard for the jet fuel.

REFERENCES

1. **Seregin, E.P.** (2018). *Razvitiye khimmotologii* [Development of chemmotology]. Moscow: Pervyy tom, 880 p. (in Russian)

2. **Piskunov, V.A. and Zrelov, V.N.** (1978). *Vliyaniye topliv na nadezhnost reaktivnykh dvigateley samoletov: khimmotologicheskaya nadezhhnost* [The fuel influence on the aircraft jet engines reliability: chemmotological reliability]. Moscow: Mashinostroyeniye, 270 p. (in Russian)

3. **Bratkov, A.A., Seregin, E.P., Gorenkov, A.F. and others.** (1978). *Himmotologiya raketnykh i reaktivnykh topliv* [Chemmotology of rocket and jet fuels]. Moscow: Khimiya, 304 p. (in Russian)

4. **Aksenov, A.F.** (1970). *Aviatsionnyye topliva, smazochnyye materialy i spetsialnyye zhidkosti* [Aviation fuels, lubricants and special liquids]. Moscow: Transport, 256 p. (in Russian)

5. **Gureev, A.A., Seregin, E.P. and Azev, V.S.** (1984). *Kvalifikatsionnyye metody ispytaniy neftyanykh topliv* [Qualification testing methods for petroleum fuels]. Moscow: Khimiya, 200 p. (in Russian)

6. **Bratkov, A.A. (Ed.).** (1985). *Teoreticheskiye osnovy khimmotologii* [Theoretical foundations of chemmotology]. Moscow: Khimiya, 320 p. (in Russian)

7. **Gryadunov, K.I.** (2021). *Khimmotologiya aviatsionnykh goryuche-smazochnykh materialov* [Chemmotology of aviation fuels and lubricants]. Moscow: Izdatelskiy Dom Akadimii Zhukovskogo, 184 p. (in Russian)

8. **Timoshenko, A.N.** (2009). *Chastnyye pretenzii k TS-1 ostayutsya bez razresheniya* [Private claims to the TS-1 remain without resolution]. Aviaglobus, no. 2 (118), p. 12–13. (in Russian)

9. **Uryavin, S.P. and Timoshenko, A.N.** (2010). *O rabote po otmene ogranicheniy na primeneniye aviatopliva TS-1 so storony zarubezhnykh dvigatelestroitelnykh korporatsiy* [On the work on lifting restrictions on the TS-1 jet fuel usage by foreign engine-building corporations]. Assotsiatsiya OATO GA, no. 5, p. 32–33. (in Russian)

10. **Gryadunov, K.I., Timoshenko, A.N., Melnikova, I.S. and Ermolaeva, U.V.** (2020). *Relevance of introduction of an indicator characterizing antiwearing properties of aircraft kerosenes into the Russian standard.* Novyye materialy i perspektivnyye tekhnologii: sbornik materialov Shestogo mezhdistsiplinarnogo nauchnogo foruma s mezhdunarodnym uchastiyem [New materials and promising technologies: a collection of materials of the Sixth Interdisciplinary Scientific Forum with International Participation]. Moscow: Avtonomnaya nekommercheskaya organizatsiya sodeystviya razvitiyu innovatsionnoy deyatelnosti "Tsentr nauchno-tekhnicheskikh resheniy", p. 180–183. (in Russian)

11. **Litvinov, A.A.** (1987). *Osnovy primeneniya goryuche-smazochnykh materialov v grazhdanskoy aviatsii. Uchebnik dlya VUZov* [Bases of fuels and lubricants application in civil aviation: Textbook for Universities]. Moscow: Transport, 308 p. (in Russian)

12. **Likhterova, N.M., Shatalov, K.V., Kondratenko, V.V. and Baevskiy, D.F.** (2014). *The problem of evaluating the anti-wear properties of modern domestic jet fuels*. Nauchnyy Vestnik MGTU GA, no. 206, p. 37–42. (in Russian)

13. **Liberio, P.D. and Garver, J.M.** (1995). *Lubricity of military jet fuels*. Lubrication Engineering, vol. 51, p. 27–32.

14. **Blizard, N.C. and Bennett, P.A.** (1996). *A Comparison of modified elevated temperature HFRR test data with scuffing BOCLE results*. SAE Transactions, vol. 105, p. 1401–1411.

15. **van Leeuwen, H.J.** (2017). *Diesel fuel lubricity testing revisited: Tests von Dieselkraftstoffschmierfähigkeit erneut betrachtet*. In book: 12. Arnold Tross Kolloquium. Germany: Shaker-Verlag, p. 212–240.

16. **Delgado, J., Gadea, M., Esarte, C. and Peláez, A.** (2020). *HFRR and SL-BOCLE lubricity of paraffinic diesel fuels considering different origins and final formulations with biodiesels and additives*. Energy Fuels, vol. 34, issue 3, p. 2654–2664. DOI: 10.1021/acs.energyfuels.9b03169

17. Lapuerta, M., García-Contreras, R. and Agudelo, J. (2010). *Lubricity of ethanol-biodiesel-diesel fuel blends*. Energy Fuels, vol. 24, issue 2, p. 1374–1379. DOI: 10.1021/ef901082k

18. Kondratenko, V.V., Suzikov, V.V. and Nikitin, I.M. (2019). *Optimizatsiya rezhima ispytaniya metoda otsenki protivoiznosnykh svoystv reaktivnykh topliv na ustanovke PST-3* [Testing mode optimization of the method for evaluating the anti-wear jet fuels properties at the PST-3 installation]. "55 let khimmotologii – osnovnyye itogi i napravleniya razvitiya": sbornik tezisov dokladov Mezhvedomstvennoy nauchno-tekhnicheskoy konferentsii ["55 years of chemotology – the main results and directions of development": Interdepartmental Scientific and Technical Conference: collection of abstracts]. Moscow: 25 GOSNII khimmotologii MO RF, p. 97–100. (in Russian)

INFORMATION ABOUT THE AUTHORS

Konstantin I. Gryadunov, Candidate of Technical Sciences, Associate Professor of Moscow State Technical University of Civil Aviation, the Aircraft Fuel Supply and Repair Chair, k.gryadunov@mstuca.aero.

Andrei N. Timoshenko, Candidate of Technical Sciences, Associate Professor of Moscow State Technical University of Civil Aviation, the Aircraft Fuel Supply and Repair Chair, a.timoshenko@mstuca.aero.

Kirill E. Balishin, Lead Engineer of Moscow State Technical University of Civil Aviation, the Aircraft Fuel Supply and Repair Chair, knpnlll@ya.ru.

Uliyana V. Ermolaeva, Master's Degree Student of Moscow State Technical University of Civil Aviation, ulyana13m@me.com.

ПОКАЗАТЕЛЬ ПРОТИВОИЗНОСНЫХ СВОЙСТВ РЕАКТИВНЫХ ТОПЛИВ

К.И. Грядунов[1], А.Н. Тимошенко[1], К.Э. Балышин[1], У.В. Ермолаева[1]
[1]Московский государственный технический университет гражданской авиации, г. Москва, Россия

Для реактивных двигателей гражданской авиации используются три основные марки топлива: отечественные ТС-1 и РТ и иностранная, вырабатываемая в относительно небольших объемах в России, ДЖЕТ А-1 (JET A-1). С конца 2000-х гг. производители иностранной техники выдвигают претензии к качеству массово применяемой отечественной марки топлива ТС-1, причем эти претензии не конкретизируются. Однако ресурс ряда зарубежных двигателей, эксплуатирующихся на топливе ТС-1, сокращен на 50 %. Данное обстоятельство может быть вызвано как субъективными причинами – коммерческими и политическими интересами производителей техники, так и объективными. Основная объективная причина может состоять в том, что с недавнего времени ряд российских заводов, производящих топливо ТС-1, начали выпускать смесевое топливо под тем же наименованием, где в прямогонные фракции добавляются продукты вторичных процессов переработки нефти. Данные топлива отвечают требованиям стандарта (ГОСТ 10227-86), в котором отсутствует показатель, характеризующий противоизносные свойства реактивных топлив. В стандарте на топливо ДЖЕТ А-1 противоизносные свойства нормируются, также они нормируются и в стандарте на отечественные топлива для сверхзвуковой авиации. В статье приведены сравнительные испытания противоизносных свойств образцов применяемых в ГА реактивных топлив. Обоснована актуальность введения показателя противоизносных свойств в стандарт для отечественных марок реактивных топлив для дозвуковых воздушных судов, а также проведения сравнительных анализов противоизносных свойств топлив, произведенных различными российскими нефтеперерабатывающими заводами. Показатели и методы оценки противоизносных свойств авиационных топлив могут быть различными. В качестве такого показателя предложено использовать показатель противоизносных свойств, рассчитываемый после проведения испытаний образцов топлив на четырехшариковой машине трения.

Ключевые слова: авиация, реактивное топливо, авиационное топливо, противоизносные свойства авиационных топлив, четырехшариковая машина трения, показатель противоизносных свойств.

СПИСОК ЛИТЕРАТУРЫ

1. **Серегин Е.П.** Развитие химмотологии. М.: Первый том, 2018. 880 с.

2. **Пискунов В.А., Зрелов В.Н.** Влияние топлив на надежность реактивных двигателей самолетов: химмотологическая надежность. М.: Машиностроение, 1978. 270 с.

3. **Братков А.А., Серегин Е.П., Горенков А.Ф. и др.** Химмотология ракетных и реактивных топлив. М.: Химия, 1987. 304 с.

4. **Аксенов А.Ф.** Авиационные топлива, смазочные материалы и специальные жидкости. М.: Транспорт, 1970. 256 с.

5. **Гуреев А.А., Серегин Е.П., Азев В.С.** Квалификационные методы испытаний нефтяных топлив. М.: Химия, 1984. 200 с.

6. Теоретические основы химмотологии / Под. ред. А.А. Браткова. М.: Химия, 1985. 320 с.

7. **Грядунов К.И.** Химмотология авиационных горюче-смазочных материалов. М.: ИД Академии Жуковского, 2021. 184 с.

8. **Тимошенко А.Н.** Частные претензии к ТС-1 остаются без разрешения // Авиаглобус. 2009. № 2 (118). С. 12–13.

9. **Урявин С.П., Тимошенко А.Н.** О работе по отмене ограничений на применение авиатоплива ТС-1 со стороны зарубежных двигателестроительных корпораций // Ассоциация ОАТО ГА. 2010. № 5. С. 32–33.

10. **Грядунов К.И.** Актуальность введения показателя, характеризующего противоизносные свойства авиационных керосинов, в российский стандарт / К.И. Грядунов, А.Н. Тимошенко, И.С. Мельникова, У.В. Ермолаева // Новые материалы и перспективные технологии: сборник материалов Шестого междисциплинарного научного форума с международным участием. Москва, 23–27 ноября 2020 г. Москва: Автономная некоммерческая организация содействия развитию инновационной деятельности «Центр научно-технических решений», 2020. С. 180–183.

11. **Литвинов А.А.** Основы применения горюче-смазочных материалов в гражданской авиации: учебник для вузов. М.: Транспорт, 1987. 308 с.

12. **Лихтерова Н.М.** Проблема оценки противоизносных свойств современных отечественных реактивных топлив / Н.М. Лихтерова, К.В. Шаталов, В.В. Кондратенко, Д.Ф. Баевский // Научный Вестник МГТУ ГА. 2014. № 206. С. 37–42.

13. **Liberio P.D., Garver J.M.** Lubricity of military jet fuels // Lubrication Engineering. 1995. Vol. 51. P. 27–32.

14. **Blizard N.C., Bennett P.A.** A Comparison of modified elevated temperature HFRR test data with scuffing BOCLE results // SAE Transactions. 1996. Vol. 105. P. 1401–1411.

15. **van Leeuwen H.J.** Diesel fuel lubricity testing revisited: Tests von Dieselkraftstoff-schmierfähigkeit erneut betrachtet. In book: 12. Arnold Tross Kolloquium. Germany: Shaker-Verlag, 2017. P. 212–240.

16. **Delgado J.** HFRR and SL-BOCLE lubricity of paraffinic diesel fuels considering different origins and final formulations with biodiesels and additives / J. Delgado, M. Gadea, C. Esarte, A. Peláez // Energy Fuels. 2020. Vol. 34, iss. 3. P. 2654–2664. DOI: 10.1021/acs.energyfuels.9b03169

17. **Lapuerta M., García-Contreras R., Agudelo J.** Lubricity of ethanol-biodiesel-diesel fuel blends // Energy Fuels. 2010. Vol. 24, iss. 2. P. 1374–1379. DOI: 10.1021/ef901082k

18. **Кондратенко В.В., Сузиков В.В., Никитин И.М.** Оптимизация режима испытания метода оценки противоизносных свойств реактивных топлив на установке ПСТ-3 // 55 лет химмотологии – основные итоги и направления развития: сборник тезисов докладов Межведом-

ственной научно-технической конференции. Москва, 27 ноября 2019 г. М.: 25 ГОСНИИ химмотологии МО РФ, 2019. С. 97–100.

СВЕДЕНИЯ ОБ АВТОРАХ

Грядунов Константин Игоревич, кандидат технических наук, доцент кафедры авиатопливообеспечения и ремонта ЛА МГТУ ГА, k.gryadunov@mstuca.aero.

Тимошенко Андрей Николаевич, кандидат технических наук, доцент кафедры авиатопливообеспечения и ремонта ЛА МГТУ ГА, a.timoshenko@mstuca.aero.

Балышин Кирилл Эдуардович, старший техник кафедры авиатопливообеспечения и ремонта ЛА МГТУ ГА, knpnlll@ya.ru.

Ермолаева Ульяна Владимировна, обучающаяся магистратуры МГТУ ГА, ulyana13m@me.com.

Поступила в редакцию	10.03.2021	Received	10.03.2021
Принята в печать	25.11.2021	Accepted for publication	25.11.2021