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FEASIBILITY STUDIES OF JET FUELS USING AS A LOW-TEMPERATURE ADDITIVE TO STRAIGHT-RUN DIESEL FUELS

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Abstract

The article considers the feasibility of using jet fuel as a low-temperature additive for diesel fuels. The main physicochemical properties and operational characteristics of straight-run diesel fuel sample, jet fuel sample, and their blends have been experimentally determined. It has been established that the use of jet fuel as a low-temperature additive allows producing summer diesel fuel brands. Moreover, it has been established that the use of jet fuel in combination with a depressant-dispersant additive allows producing interseasonal diesel fuel.

***Keywords**:* diesel fuel; jet fuel; blend; low-temperature properties; cetane index; additive.

1. Introduction

Diesel fuel (DT), today, is one of the most common types of motor fuel, in addition to passenger cars, diesel fuel is used on small crafts and electric power generators.

To ensure reliable and environmentally friendly operation of a diesel engine, it is necessary to have high-quality diesel fuel of a certain composition, which is characterized by specified physicochemical properties and operational characteristics. On the Russian Federation territory, the production of diesel fuels is regulated by the government, according to the following requirements documents USS 305-2013 "Diesel fuel. Specifications" [1] and the Technical Regulations of the Customs Union TR TS 013 2011 "Requirements to automobile and aviation gasoline, diesel and ship fuel, jet engine fuel and furnace oil" [2], which has the highest priority in the field of turnover and production motor fuels. Meanwhile, the use of diesel fuel is limited in areas with a cold climate, in the northern and Arctic territories. This is due to contained in diesel fuel paraffin hydrocarbons, which forms crystals at low temperatures and adversely affects the operation of the engine.

There are various ways to improve the low-temperature properties of diesel fuels. The catalytic dewaxing process can significantly improve the pour point of diesel fuels, but this method is applicable only in large industries. It is worth noting that motor fuels in remote, northern areas, as a rule, are produced at local medium and small enterprises.

The most common and effective way to improve the low-temperature properties of diesel fuel is the use of depressant and dispersant additives, as well as additive substances, characterized by good low-temperature properties.

One of the possible additives for improves the low-temperature properties of diesel fuel is jet fuel [3-10]. Jet fuel (JF) is characterized by exceptional low-temperature properties, so according to the USS 10227-2013 "Jet fuels. Specifications" [11], which regulates the production of jet fuels in the Russian Federation, the freezing point of jet fuel must be, not higher than 60°C.

However, jet fuels as an additive to improve the low-temperature properties of diesel fuel is used sparingly. This is due to the negative impact of jet fuel on other operational characteristics of diesel fuel, in particular – on the flammability of the blend, characterized by a cetane index.

Thus, the purpose of this work is to study the physicochemical properties and operational characteristics of diesel and jet fuels, as well as look into the possibility of using jet fuels as a low-temperature additive to straight-run diesel fuels.

2. Object and methods of research

The objects of research in the work were: a sample of straight-run diesel fuel obtained from one of the Western Siberia fields of the Russian Federation, and a sample of jet fuel, granted by LLC "Tomsk Airport."

Using the described above petroleum products, blends have been prepared. The percentage in blends of jet and diesel fuels is presented in Table 1. The numerical codes from 1 to 3 have been assigned to blends, in order of increasing percentage of their jet fuel.

Table 1. Recipes of blends of jet and diesel fuel

Blend	Content, %vol.	
	Jet fuel	Diesel fuel
Blend 1	5	95
Blend 2	10	90
Blend 3	20	80

For the studied samples of jet fuel and diesel fuel, the following physicochemical properties and operational characteristics were determined: fractional composition, density, viscosity, sulfur content, low-temperature properties (cold filter plugging point, pour point), and also cetane index was calculated.

The determination was carried out according to the test methods presented below. Depending on the origin, jet fuel and diesel fuel can have various fractional composition and wide boiling ranges.

The test method presented in ISO 3405:2011 "Petroleum products. Determination of distillation characteristics at atmospheric pressure" [12] was used to determining the fractional composition of jet and diesel fuel samples.

The summary of this test method is as follows: 100 cm^3 of the test sample is distillated under conditions consistent with the nature of the product and conducted continuous observations of the thermometer readings and the volume of condensate.

The density of the fuel is the most important physicochemical property of the fuel that allows one to indirectly judge particular operational characteristics. For the jet fuel, density is an indicator that determines the flying range. Therefore, attempts are being made to obtain fuels with the highest possible density [13]. The determination of the density of the studied oil products in work was carried out using a hydrometer. Studies were conducted according to the requirements presented in the ISO 3675:1998 "Crude petroleum and liquid petroleum products. Laboratory determination of density. Hydrometer method" [14].

The summary of this test method for determining the density is as follows: a hydrometer is immersed in a cylinder filled with the studied oil product after that researcher takes readings the scale of the hydrometer.

The viscosity of the fuel, as a rule, determine the dispersibility of the fuel, its pumpability in the fuel system and the wear of the pump plungers. The lower the viscosity, the better the fuel is atomized and the higher the dispersion of the microdroplets. The pumpability of the fuel also improves with a decrease its viscosity [15].

The kinematic viscosity of jet fuel and diesel fuel samples of was determined by the method presented in ISO 3104:1994 "Petroleum products. Transparent and opaque liquids. Determination of kinematic viscosity and calculation of dynamic viscosity" [16].

The summary of this test method of determination the kinematic viscosity is as follows: the time (in seconds) the expiration of a certain volume of liquid in the capillary of a glass viscometer under the influence of gravity at a constant temperature of 20°C is measured.

One of the most strictly regulated environmental indicators of fuel quality is the sulfur content. This is due to the fact that sulfur in its pure form and sulfur-containing compounds in the composition of petroleum products are extremely toxic impurities, characterized by corrosivity, which reduces the service life of the metal engine parts.

Determination of sulfur content in the studied samples was carried out according to the method presented in the ASTM D4294-16 "Standard test method for sulfur in petroleum and petroleum products by energy dispersive X-ray fluorescence spectrometry" [17].

The summary of this test method for determining the total sulfur content in petroleum and petroleum products is as follows: a sample is placed in a beam of rays emitted by an x-ray tube. The resulting excited characteristic X-ray radiation is measured and compared the received pulse counter signal with the signals obtained when testing pre-prepared calibration samples. In results, it is obtained the total sulfur content in % wt. or mg/kg.

The most important operational characteristics of diesel and jet fuels, which allow concluding that it is possible to use fuel at reduced temperature, for example, at altitude, in winter and arctic conditions are their low-temperature properties.

The pour point of jet and diesel fuel of samples was determined by the method presented in ISO 3013:1997 "Petroleum products. Determination of the freezing point of aviation fuels" [18].

The summary of the method for determining the pour point is to place the tube with the test sample in a cryostat with a coolant (ethanol) and cool it to the expected pour point. At this temperature, the tube with the oil product is tilted at an angle of 45°, and the level of the liquid is monitored. Thus, it is found the temperature at which the level of the sample in a test tube, tilted at an angle of 45°, remains stationary for a certain time. This temperature is the pour point of the sample.

The cold filter plugging point (CFPP) of the jet and diesel fuel samples was determined according to the method presented in ASTM D6371-17 "Standard test method for cold filter plugging point of diesel and heating fuels" [19]. The summary of the method is as follows: the fuel sample is cooled, pumped over a standardized wire mesh filter under controlled vacuum, and it is filled the pipette up to the mark. Continuing to cool the fuel, this procedure is repeated at intervals of 1°C. The test is continued to a temperature at which the number of paraffin crystals released from the solution slows down the flow of fuel so that the pipette filling time exceeds 60 seconds. The temperature at which the fuel was last filtered is taken as the cold filter plugging point of the fuel.

The calculation of the cetane index of jet and diesel fuel samples was carried out according to the method presented in the ISO 4264 "Petroleum products – Calculation of cetane index of middle-distillate fuels by the four variable equation" [20], since it was established [21] that this method of calculation is the most accurate:

$$\begin{gathered} CI = 45.2 + 0.0892 \cdot T_{10N} + (0.131 + 0.901B) \cdot T_{50N} + \\ +(0.0523 - 0.42B) \cdot T_{90N} + [0.00049 \cdot (T_{10N}^2 - T_{90N}^2)] + 107B + 60B^2; \\ T_{10N} = T_{10\%} - 215;\ T_{50N} = T_{50\%} - 260;\ T_{90N} = T_{90\%} - 310; \\ B = [\exp(-0.0035 \cdot D_N)] - 1;\ D_N = D - 850 \end{gathered} \quad (1)$$

where CI is a cetane index, points; $T_{10\%}$, $T_{50\%}$, $T_{90\%}$ are boiling temperatures of 10 vol. %, 50 vol. % and 90 vol. % of diesel fraction, respectively,ºC; D is a density of diesel fuel at 15ºC, kg/m^3.

3. Results

3.1. Physicochemical properties and operational characteristics of straight-run diesel fuel

Using the described test methods, the physicochemical properties and operational characteristics of straight-run diesel fuel sample were determined. The results are presented in Table 2.

Table 2. The results of determination the characteristics of straight-run diesel fuel sample

№	Parameter	Value
1	Density at 15°C, kg/m^3	842.3
2	Kinematic viscosity at 20°C, mm^2/s	4.424
3	Content of total sulfur, % wt.	0.242
4	Fractional composition,°C:	
	initial boiling point	151
	10 % vol. boils at a temperature	183
	50 % vol. boils at a temperature	271
	90 % vol. boils at a temperature	359
	95 % vol. boils at a temperature	360
5	Cetane index, points	50,6
6	Pour point,°C	-18
7	Cold filter plugging point,°C	-3

3.2. Physicochemical properties and operational characteristics of jet fuel

Using the described test methods, the physicochemical properties and operational characteristics of jet fuel sample were determined. The results are presented in Table 3.

Table 3. The results of determination the characteristics of jet fuel sample

№	Parameter	Value
1	Density at 20°C, kg/m^3	792.0
2	Kinematic viscosity at 20°C, mm^2/s	1.508
3	Content of total sulfur, % wt.	0.034
4	Fractional composition,°C:	
	initial boiling point	140
	10 % vol. boils at a temperature	154
	50 % vol. boils at a temperature	185
	90 % vol. boils at a temperature	215
	98 % vol. boils at a temperature	226
5	Freezing point, C	-65

It should be noted that the sample of jet fuel is not frozen at the maximum freezing temperature of the cryostat (-80°C).

3.3. Physicochemical properties and operational characteristics of straight-run diesel fuel and jet fuel blends

For the prepared blends, using the described methods, physicochemical properties, and operational characteristics were also determined. The results are presented in Table 4.

Table 4. The results of determination the characteristics of straight-run diesel fuel and jet fuel blends

№	Parameter	Blend 1	Blend 2	Blend 3
1	Density at 15°C, kg/m^3	838.3	837.3	834.3
2	Kinematic viscosity at 20°C, mm^2/s	4.087	3.437	3.137
3	Content of total sulfur, % wt.	0.218	0.217	0.197
4	Fractional composition,°C:			
	initial boiling point	147	146	145
	10 % vol. boils at a temperature	182	179	176
	50 % vol. boils at a temperature	258	255	246
	90 % vol. boils at a temperature	344	340	338
	95 % vol. boils at a temperature	360	358	356
5	Cetane index, points	49.1	48.7	47.4
6	Pour point,°C	-35.0	-35.3	-36.0
7	Cold filter plugging point, C	-4	-4	-5

From the results which are presented in Table 4, it follows that with increase the part of jet fuel in the blend, the values of such characteristics as cetane index, density, sulfur content, and kinematic viscosity decreases, and also the fractional composition is lightened. At the same time, the addition of jet fuel to straight-run diesel fuel improves its low-temperature characteristics.

4. Results and discussion

4.1. Conformity assessment of the straight-run diesel fuel characteristics to the requirements of standards

Comparison of the straight-run diesel fuel sample characteristics with the requirements [1], regulating the production of diesel fuels in the Russian Federation, is presented in Table 5. According to [1], diesel fuel is classified into 4 brands, depending on its characteristics: S – summer, IS – interseasonal, W – winter, A – arctic.

Table 5. Conformity assessment of the straight-run diesel fuel sample characteristics to the requirements [1]

№	Parameter	DF test sample	DF brand			
			S	IS	W	A
1	Cetane index, points, min.	48.4	45.0			
2	Density at 15°C, kg/m^3, max.	842.3	863.4		843.4	833.5
3	Kinematic viscosity at 20°C, mm^2/s	4.424	3.0-6.0		1.8-5.0	1.5-4.0
4	Fractional composition, C, max.:					
	50 % vol. boils at a temperature	271	280			255
	95 % vol. boils at a temperature	360	360			
6	Cold filter plugging point,°C, max.	-3	-5	-15	-35	-45
7	Content of total sulfur, % wt., max.	0.242	0.2			

As can be seen from Table 5, the investigated diesel fuel meets the requirements of [1] for all brands in such characteristics as the cetane index and boiling point 95 % vol. Based on characteristics such as density, viscosity and boiling point of 50 % vol. investigated diesel fuel can be classified to S, IS, and W brands. However, based on such characteristics as the content of sulfur and CFPP, the investigated diesel fuel does not meet the requirements of any brand, and according to [1] cannot be realized on the territory of the Russian Federation.

4.2. Conformity assessment of the jet fuel characteristics to the requirements of standards

Comparison of the jet fuel sample characteristics with the requirements [11], regulating the production of jet fuel in the Russian Federation, is presented in Table 6.

Table 6. Conformity assessment of the jet fuel sample characteristics to the requirements [11]

№	Parameter	RT test sample	TS-1 brand	RT brand
1	Density at 20 °C, kg/m^3, min.	792.0	775.0	
2	Fractional composition, °C max.:			
	initial boiling point	140	150	135-155
	10 % vol. boils at a temperature	154	165	175
	50 % vol. boils at a temperature	185	195	225
	90 % vol. boils at a temperature	215	230	270
	98 % vol. boils at a temperature	226	250	280
3	Freezing point, °C, max.	-65	-60	
4	Content of total sulfur, % wt., max.	0.034	0.1	
5	Kinematic viscosity at 20 °C, mm^2/s, min	1.508	1.25	

As can be seen from Table 6, the investigated jet fuel sample meets all the requirements of [11], for the TS-1 and the RT brands. The results of investigations allow us to conclude that the test sample of jet fuel provided by LLC "Airport TOMSK" is characterized by high quality.

4.3. Conformity assessment of the straight-run diesel fuel and jet fuel blends characteristics to the requirements of standards

Comparison of the blends characteristics, which have been prepared of straight-run diesel fuel and jet fuel for investigation, with the requirements [1], regulating the production of diesel fuels in the Russian Federation, is presented in Table 7.

Table 7. Conformity assessment of the straight-run diesel fuel and jet fuel blends characteristics to the requirements [1]

<table>
<tr><th rowspan="2">№</th><th rowspan="2">Parameter</th><th rowspan="2">Blend 1</th><th rowspan="2">Blend 2</th><th rowspan="2">Blend 3</th><th colspan="4">DF brand</th></tr>
<tr><th>S</th><th>IS</th><th>W</th><th>A</th></tr>
<tr><td>1</td><td>Cetane index, points, min.</td><td>47.6</td><td>47.3</td><td>46.6</td><td colspan="4">45.0</td></tr>
<tr><td>2</td><td>Density at 15°C, kg/m^3, max.</td><td>838.3</td><td>837.3</td><td>834.3</td><td colspan="2">863.4</td><td>843.4</td><td>833.5</td></tr>
<tr><td>3</td><td>Kinematic viscosity at 20°C, mm^2/s</td><td>4.087</td><td>3.437</td><td>3.137</td><td colspan="2">3.0-6.0</td><td>1.8-5.0</td><td>1.5-4.0</td></tr>
<tr><td>4</td><td colspan="8">Fractional composition,°C, max.:</td></tr>
<tr><td></td><td>50 % vol. boils at a temperature</td><td>258</td><td>255</td><td>246</td><td colspan="3">280</td><td>255</td></tr>
<tr><td></td><td>95 % vol. boils at a temperature</td><td>360</td><td>358</td><td>356</td><td colspan="4">360</td></tr>
<tr><td>6</td><td>Cold filter plugging point,°C, max.</td><td>-4</td><td>-4</td><td>-5</td><td>-5</td><td>-15</td><td>-35</td><td>-45</td></tr>
<tr><td>7</td><td>Content of total sulfur, % wt., max</td><td>0.218</td><td>0.217</td><td>0.197</td><td colspan="4">0.2</td></tr>
</table>

From the results which are presented in Table 7 it can be seen that the addition of 20 % vol. jet fuel to diesel fuel allows to reduce the CFPP by 2°C (up to -5°C), which meets the requirements [1] for CFPP to brand of diesel fuel S, and allows realize this fuel in the Russian Federation.

It should be noted that adding even 20 % vol. jet fuel to diesel fuel, the cetane index of blend meets the requirements of [1], which suggests that adding jet fuel to diesel fuel does not significantly much reduce the flammability.

Further still, the adding of 20 % vol. jet fuel to blend allows: to reduce the sulfur content to the required level, and bring in line with requirements for A diesel fuel brand, such characteristics as viscosity and boiling point of 50 % vol.

At the next stage of the work, the authors investigated the possibility of producing interseasonal diesel fuel brand (IS), applying the integrated use of an additive (jet fuel) and a depressant-dispersant additive (Diesel Flieβ Fit).

For this purpose, a depressant-dispersant additive for diesel fuel "Diesel Flieβ-Fit", manufactured by LIQUI MOLY, was added to the blend of diesel and jet fuels number 3, at a concentration recommended by the manufacturer (0.3 mL of additive per 100 mL of fuel). For the obtained blend (blend number 3.1), CFPP was determined (using the same test method [19]). The obtained results showed that the addition of low-temperature additives simultaneously with 20 % vol. jet fuel allows you to reduce CFPP of straight-run diesel fuel by 20 °C (up to -23°C), which meets the requirements of CFPP, to the brand IS diesel fuel brand [1].

The results indicate the feasibility of using jet fuel (including in combination with depressant-dispersant additives) as an additive, which improves low-temperature properties of straight-run diesel fuels.

5. Conclusion

The physicochemical properties and operational characteristics of jet fuel sample (fractional composition, density, viscosity, sulfur content, low-temperature properties) have been investigated. It has been established that the analyzed jet fuel in its properties meets all the requirements of [11], both for the TS-1 and for the RT brands. It is shown that the sample of jet fuel, provided by LLC "Airport TOMSK", is characterized by high quality.

The physicochemical properties and operational characteristics of straight-run diesel fuel sample have been investigated. It was established that the test sample of straight-run diesel fuel meets the requirements of [1] for all brands in such characteristics as cetane index, density and boiling point of 95 % vol.; for brands S, IS and W only by viscosity and boiling point of 50 % vol. At the same time, it was established that such characteristics as the content of sulfur and CFPP of analyzed straight-run diesel fuel does not meet the requirements of any diesel fuel brads and cannot be realized on the Russian Federation territory.

The physicochemical properties and operational characteristics of blends of jet and diesel fuels have been investigated. It is shown that with an increase the content of jet fuel in the blend, the cetane index, density, viscosity and sulfur content of diesel fuel decrease, the fractional composition is lightened, CFPP becomes more negative. It is established that addition of 20 % vol. jet fuel to diesel fuel allows to reduce the sulfur content in the blend to 0.197 % wt., CFPP to 2°C (up to -5°C); the addition of a depressant-dispersant additive together with 20 % vol. jet fuel to diesel fuel allows to reduce the CFPP to 20°C (up to -23°C).

It is shown that the addition of jet fuel to straight-run diesel fuel makes it possible to obtain commercial diesel fuel brand S, together with a depressant-dispersant additive – commercial diesel fuel brand IS. It has been established that it is reasonable to use jet fuel (including in together with depressant-dispersant additives) in as a low-temperature additive to straight-run diesel fuels.

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List of symbols

DF	*diesel fuel;*	*CI*	*cetane index, points;*
JF	*jet fuel;*	$T_{10\%}$	*boiling point of 10 % vol. fraction, °C;*
CFPP	*cold filter plugging point;*	$T_{50\%}$	*boiling point of 50 % vol. fraction, °C;*
S	*summer diesel fuel brand;*	$T_{90\%}$	*boiling point of 90 % vol. fraction, °C;*
IS	*interseasonal diesel fuel brand;*	*D*	*density at 15°C,* kg/m^3*;*
W	*winter diesel fuel brand;*	*RT*	*jet fuel brand;*
A	*arctic diesel fuel brand;*	*TS-1*	*jet fuel brand.*

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