FTD-HT-23-825-67

FOREIGN TECHNOLOGY DIVISION

SCALE FORMATION IN TURBOJET ENGINES

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1917 1967

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FTD-HT-23-825-67

EDITED TRANSLATION

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English pages: 6

SOURCE: Khimiya i Tekhnologiya Topliv i Masel.
(Chemistry and Technology of Fuels and
Lubricants), No. 1, 1964, pp. 51-55.

Translated by: F. Dion/TDBXT

UR/0065-64-000-001

TP7001117

	PREPARED BY: TRANSLATION DIVISION FOREIGN TECHNOLOGY DIVISION WP-AFB, OHIO.

FTD-HT-23-825-67

Date 29 Aug. 1967

ITIS INDEX CONTROL FORM

01 Acc Nr TP7001117	**68 Translation Nr** FTD-HT-23-825-67	**65 X Ref Acc Nr** AP4009786	**76 Reel/Frame Nr** 1881 0077

97 Header Clas UNCL	**63 Clas** UNCL, 0	**64 Control Markings** 0	**94 Expansion**	**40 Ctry Info** UR

02 Ctry UR	**03 Ref** 0065	**04 Yr** 64	**05 Vol** 000	**06 Iss** 001	**07 B. Pg.** 0051	**45 E. Pg.** 0055	**10 Date** NONE

Transliterated Title
NAGAROOBRAZOVANIYE V VOZDUSHNO-READTIVNYKH DVIGATELYAKH

09 English Title
SCALE FORMATION IN TURBOJET ENGINES

43 Source
KHIMIYA I TEKHNOLOGIYA TOPLIV I MASEL (RUSSIAN)

42 Author MARINCHENKO, N. I.	**98 Document Location**
16 Co-Author CHERTKOV, YA. B.	**47 Subject Codes** 10, 21, 01
16 Co-Author PISKUNOV, V. A.	**39 Topic Tags:** jet engine, combustion chamber, fuel nozzle, carbon, hydrocarbon
16 Co-Author NONE	
16 Co-Author NONE	

ABSTRACT: Scale formation in jet engines was studied and the particular purpose of the present work is a study of some of these problems. Deposits were investigated which accumulated on the injection fuel nozzle and on the whirler of engine I after 100 hours operation on fuel TS-1; on the injection nozzle and walls of the heat pipe of the combustion chamber in engine II after 200 hours operation on fuel T-2; and on the heat pipe of the combustion chamber of engine III after 300 hours operation on fuel T-1. The engines were operated within their warranty period under same conditions as in airplanes. Temperature of fuel nozzles and whirlers in working operations reached 250-340C while the wall temperature in the combustion chamber within the scaling zone did not exceed 250-400C; gas temperatures in front of the turbine were 500-720C. It was concluded that scaling in turbojet combustion chambers is formed in zones having inadequate temperature (250-400C) and too low oxygen concentration for adequate combustion. The scale was found to consist of multistage, consecutive, deep-destruction products of the organic molecule with considerable enrichment of carbon in the final product. The material carbonized because the deposit contained considerable quantities of sulfur, -oxygen- and nitrogen compounds. The deposit also consisted of oxidizable hydrocarbons and nonhydrocarbon organic compounds with sulfur, oxygen and nitrogen contents. At temperatures of 200-400C in an oxygen environment, oxidizing processes transform nonhydrocarbon compounds into resins and ultimately into scale. Orig. art. has: no figures, no formulas and 6 tables. English Translation: 6 pages.

SCALE FORMATION IN TURBOJET ENGINES

N. I. Marinchenko, Ya. B. Chertkov, and V. A. Piskunov

During the operation of turbojet engines scale accumlates on the fuel injectors and on the internal surfaces of the combustion chamber [1, 2].

In the fuel injector scale is most frequently accumulated on the face of the cap. In combustion chambers it is deposited on the internal walls, around openings for admitting secondary air, and on the whirler [3].

The formation of scale in a fuel injector leads to disturbance of the atomization, as a result of which the efficiency of fuel combustion is lowered. The presence of scale on the walls of heat pipes causes local overheating, buckling and cracking of the metal. Scale particles can be blown from the walls of the heat pipes and, stricking the turbine blades, cause their errosion.

The formation of scale depends upon the conditions of atomization and combustion of the fuel, its fractional, group and chemical composition [2]. The design of the combustion chamber and the operating conditions of the engine have a significant effect on scale formation. Investigations of the effect of the chemical composition of fuels on scale formation have shown that aromatic hydrocarbons have the greatest tendency to form scale [4-6].

Bicyclic aromatic hydrocarbons tend to form scale to a significantly greater degree than monocyclic compounds.

Paraffin hydrocarbons have a lower tendency to form scale. The nonhydrocarbon components of the fuel and resinous compounds can also form and deposit scale in engines.

Scale forms in insignificant quantities in engines that operate on directly distilled petroleum fuels. With the development of jet aviation, the increase in the service life of engines, the duration of flight, the inclusion of the products of direct distillation from sulfurous eastern oils in jet fuels, the increase in the content of aromatic hydrocarbons and sulfur, the problem of scale formation takes on a sharper character.

The existing data about scale formation in jet engines characterize the processes of scale formation and the composition of scale with insufficient completeness.

Some of these questions will be examined in this work.

We investigated scale from the fuel injector and whirler of engine I after 100 h of operation on TS-1 fuel, from the fuel injector and the walls of the heat pipe of the combustion chamber of engine II after 200 h of operation on T-2 fuel, and from the heat pipe of the combustion chamber of engine III after 300 h of operation on T-1 fuel.

The engines were operated within their warranty period in the actual operating conditions on aircraft. The thermal stress of the parts from which we took the scale is characterized by the following data. The temperature of the fuel injectors and whirlers on the engines attained an average of 250-340°C during the working conditions. The temperature of the walls of the combustion chamber in the scaling zone did not exceed 250-400°C. The thermal regime of the combustion chambers of the engines was characterized by a gas temperature in front of the turbine within limits of 500-720°C. The scale taken from the combustion chambers of the engines differed in external appearance. The scale taken from the walls of the combustion chambers also differed in external appearance. The scale from the walls of the combustion chamber of engine III was a solid coke deposit that attained 2-3 cm in height. In the injectors of all types of engines the scale was also solid, but easily removable with wood blades. A harder, more difficult to remove, scale was deposited on the blade whirler of engine I.

The scale was investigated according to the following method.

Scale was removed with wooden blades from the injector, the whirler and the walls of the combustion chamber; it was ground, cleaned of fuel traces with isopentane and dried to a constant weight at 105°C. Then the scale was pulverized in a jewel mortar and divided into three parts for analysis.

In the first part of the scale we determined the carbon, hydrogen, sulfur and nitrogen contents by the known methods of quantitative microanalysis.

The second part of the scale was subjected to calcination according to GOST 1461-52 at 500-550°C. The content of metals and metalloids in the ash was determined by the method of quantitative emission spectral analysis for 24 elements [7].

The third part of the scale was extracted with chloroform during boiling in a flask with a reflux condenser. It was preliminarily established that only the organic soluble part is extracted during treatment with chloroform. The compounds with ash elements are not extracted.

The products obtained after extraction were analyzed just as the initial scale was.

The characteristics of the scale taken from fuel injectors, whirlers and combustion chambers of jet engines are given in Table 1.

As is evident from the table, the scale consisted basically of carbon (72-96%) and hydrogen (1.2-2.5%). The weight ratio C:H was equal to 32:78. Thus, the scale was the products of strong carbonization of certain organic components of the fuel. The sulfur content in the scale was low, 0.1-0.9%. We should bear in mind that in these conditions sulfur compounds can be subjected to thorough combustion. The nitrogen content in the scale was 0.6-2.1%. This indicated that the products of the conversion of the nitrogen compounds in the fuel were not subjected to noticeable decomposition at 250-400°C.

The significant amount of oxygen in the scale (4.5-22.5%) indicates the participation of oxygen-containing compounds in the formation of scale and also the large roll of oxidative processes in scale formation.

The oxygen content in the scale increased with an increase in the thermal stress of the combustion chambers (Table 2).

The ash content of the scale was not great. After combustion of T-2 and TS-1 fuels, which are produced from sulfurous oils, the ash content in the scale (1.3-3.6%) was greater than in the scale formed during combustion of T-1 fuel from Baku oils (0.34%). As the sulfur content in the fuels increased, the ash content of the scale increased (Table 3).

Among the ash elements of the scale, there were large quantities of Si, Ca, and Al, elements included in ground dust, and Fe, Zn, Ti, Cr, and Ni, elements included in the materials from which the injectors and combustion chambers were produced.

Table 1. Characteristics of Scale from Fuel Injectors and Combustion Chambers of Turbojet Engines, %

Composition of the scale	Engine I (TS-1, 100 h)				Engine II (T-2, 200 h)				Engine III (T-1, 300 h)	
	fuel injector		whirler		fuel injector		combustion chamber		combustion chamber	
Quantity of scale, g/t fuel..........	0.035		0.125		–		0.139 [4]		0.28	
Elementary composition of scale, %:										
C...........	81.99-82.15		80.74-80.97		75.35-75.40		72.51-72.63		91.8-92.03	
H...........	2.50-2.64		2.11-2.19		2.39-2.40		2.08-2.14		1.20-1.28	
S...........	0.29-0.32		0.95-0.96		0.83-0.84		0.38-0.49		0.096-0.099	
N...........	1.63-1.67		0.56-0.62		0.58-0.60		1.02-1.11		1.8-2.1	
Ash elements..	0.74		2.77		1.97		1.32		0.253	
O (difference)	12.69		12.69		18.80		22.50		4.54	
Total.........	100		100		100		100		100	
Ash, %........	1.31		3.63		2.74		2.03		0.371	
Composition of the ash elements,%	for scale (×10−2)	for ash	for scale (×10^{-2})	for ash	for scale (×10^{-2})	for ash	for scale (×10^{-2})	for ash	for scale (×10^{-2})	for ash
Fe............	27.2	20.7	29.0	7.94	47.6	17.7	30.6	15.3	2.45	6.6
Cu............	5.3	4.0	2.3	1.2	1.9	0.7	2.3	1.15	0.67	1.8
Zn............	2.6	2.0	25.5	7.02	0.4	0.14	0.5	0.24	1.61	4.34
Na............	3.0	2.5	5.1	1.4	0.2	0.1	0.3	0.15	0.16	0.44
Si............	6.6	5.04	45.8	12.6	78.8	28.8	45.0	22.5	12.5	33.6
Al............	3.7	2.8	16.4	4.5	29.0	10.6	18.0	9.0	1.1	2.97
Ca............	7.27	5.52	92.8	25.5	7.7	2.82	3.2	1.6	4.35	11.7
Mg............	1.7	1.3	3.3	0.9	8.4	3.06	8.1	4.05	1.05	2.84
Pb............	1.97	1.5	1.3	0.35	3.3	1.2	2.3	1.14	0.5	1.44
Cr............	6.4	4.9	9.5	2.6	1.9	0.7	1.4	0.7	0.026	0.07
Ti............	1.1	0.9	28.8	7.92	7.4	2.7	5.8	2.9	0.057	0.1
Ni............	3.4	2.6	1.4	0.4	1.4	0.51	3.0	1.5	0.16	0.42

The scale contained traces of: Sn, Cd, Mn, Ba, V, Mo, and Co; Be, Bi, P, Ag, and Sb were absent.

The silicon content in the scale increases with an increase in the duration of engine operation (Table 4). This can be explained by the contamination of the air getting into the engine.

The scale from the blade whirler of engine I (TS-1 fuel) and from the fuel injector of engine II (T-2 fuel) was subjected to extraction by chloroform.

The characteristics of the scale and the chloroform extract are given in Tables 5 and 6.

Table 2. The Effect of the Thermal Stress of an Engine upon the Composition of Scale

Engine	Fuel	Gas Temperature in front of the turbine, °C	Content in the scale, %	
			O	C
III	T-1	500-660	4.54	91.8-92.03
I	TS-1		12.69	81.99-82.15
		650-680	12.69	80.74-80.97
II	T-2		18.80	75.35-75.40
		680-720	22.50	72.50-72.63

Table 3. The Effect of the Total Sulfur Content in Fuels upon the Ash Content of the Scale that Forms in Combustion Chambers

Fuel	Limits of the sulfur content in industrial lots of fuel, %	Ash content in the scale, %
T-1	0.02-0.09	0.37
T-2	0.05-0.19	2.03-2.44
TS-1	0.09-0.25	1.31-3.63

Table 4. Silicon Content in the Ash of Scale

Engine	Time of engine operation, hours	Silicon content in the ash of scale, %
I	100	5.04
	100	12.6
II	200	28.8
	200	22.5
III	300	33.6

Table 5. Composition of the Scale from the Fuel Injector of Engine II after Operation on T-2 Fuel, %

Elements	Initial scale	Resinous part dissolved in chloroform (5.97%)	Resinous part undissolved in chloroform (94.03%)
C........	75.38	80.79	74.56
H........	2.39	9.96	1.94
S........	0.84	1.43	0.81
N........	0.62	1.44	0.59
O (difference).	18.80	6.38	19.97
Ash elements.	1.97	Remainder	2.13
Total....	100	100	100
Ash......	2.74	Remainder	3.75

Table 6. Composition of the Scale from the Whirler of Engine I after Operation on TS-1 Fuel, %

Elements	Initial Scale	Resinous part dissolved in chloroform (7.48%)	Resinous part undissolved in chloroform (92.52%)
C........	80.85	87.09	80.57
H........	2.15	9.88	1.63
S........	0.95	0.60	0.97
N........	0.59	0.62	0.57
O (difference).	12.69	1.81	13.15
Ash elements.	2.77	Remainder	3.11
Total....	100	100	100
Ash......	2.74	Remainder	5.032

We extracted 6-7.5% of the resinous compounds with chloroform; these compounds were characterized by a high content of carbon (80-84%), hydrogen (9.88-9.96%), oxygen (2-6%), sulfur (0.6-1.43%) and nitrogen (0.62-1.44%). Judged from the elementary composition, the extracts were the products of oxidation and subsequent packing of nonhydrocarbon compounds of the fuel in the lacquers. Evidently, these lacquers are a product of the intermediate stage of conversion during scale formation. The basic mass of the scale (insoluble in cloroform) is also primarily an organic substance characterized by a high carbon content (75-80%) with hydrogen being practically absent (1.6-2%). Under the effect of high temperature in the absence of atmospheric oxygen the lacquers are subjected to deep carbonization with the formation of scale.

Conclusions

1. In the combustion chambers of jet engines scale forms in zones that have insufficiently high temperatures 250-400°C and an insufficient concentration of oxygen for full combustion of all the fuel components.

2. The scale represents the products of multistage, sequential deep destruction of organic molecules, as a result of which the final product is significantly enriched with carbon.

3. Since we observed a greater amount of sulfur, oxygen and nitrogen in the chloroform extract of the scale, we can consider that the material that is subjected to thorough combustion, together with oxidized hydrocarbons of the fuel, is nonhydrocarbon organic sulfur-, oxygen- and nitrogen-containing compounds.

4. In an oxygen-containing medium at 250-400°C oxidative processes play the important role during conversion of the nonhydrocarbon compounds of the fuel into lacquers and then into scale.

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