During the past 15 years, scientists have been actively investigating the tendency of jet fuels to form sediment (thermal or thermochemical stability) when they are used in supersonic aircraft. It has been established by many studies that the precipitated materials are products from the oxidative condensation of the least stable components of the fuel. This naturally led to investigation of how sediment formation is influenced by the concentration of oxygen in the air in contact with the fuel.

The cruise of supersonic aircraft is performed at an altitude of about 20 km, where the air pressure is reduced to 41 mm Hg, and the weight concentration of oxygen to 17.3 g/m³, in comparison with 288.5 g/m³ at sea level [1, 2]. Let us note that, at the altitudes of 11-15 km that can be reached by subsonic aircraft, the oxygen contents of the air are 89.6 and 47.5 g/m³, respectively.

Investigation of the oxidation of commercial jet fuels by nitrogen-oxygen blends with various oxygen contents has made it possible to establish the following [3]: when the fuel was oxidized at 125-150°C by a gas mixture in which the weight concentration of oxygen corresponded to air at an altitude of 15 km, the induction period was some 1.5 to 2 times that of the same fuel when oxidized in a near-earth atmosphere. The rate and severity of oxidation were reduced significantly.

The oxygen content of the gas medium above the fuel in aircraft tanks will change, not only as the altitude increases, but also as the fuel is heated. When the fuel temperature approaches the boiling point, the oxygen solubility in the fuel drops to zero. As the partial pressure of fuel vapors increases, the oxygen concentration in the vapor space first decreases, and then the oxygen is completely displaced from the tanks with no further entry from outside [3]. The initial boiling point of jet fuel of the TS-1 or T-7 (kerosine) type with a tank pressure of 267 mm Hg is about 104°C; at an altitude of 20 km, where the pressure is 41 mm, the IBP is about 30°C.

Finally one should mention the effect of pressure as a physical factor in the fuel oxidation process. The lower the pressure in the reaction space, the less the severity of oxidation, and the more the oxidation products will tend to be the primary, fuel-soluble oxidation products [4].

All of these factors lead to a situation in which, at a temperature of 150°C and with a weight concentration of oxygen in the gas medium corresponding to the air composition at 11 km, the amount of sediment formed in standard jet fuels (T-1, TS-1, and others) drops to 1/6 to 1/20 and remains at an extremely low level that is characteristic for the operating conditions of subsonic aircraft. With an oxygen concentration in the gas medium corresponding to 15 km, the amount of sediment formed is 0.3 to 1.8 mg/100 ml, i.e., 1/5 to 1/30 that formed with low-altitude oxygen concentrations.

Nevertheless, it should be kept in mind that, at a sufficiently high temperature, a small amount of condensation products may be formed not only by means of oxidation, but also as a result of breakdown of the molecules of certain fuel constituents. It is extremely important to minimize the content of fuel components that are unstable under the given operating conditions.

In general, reducing the pressure and the weight concentration of oxygen will lead to an extremely effective reduction in the sediment-forming capability of the fuel when heated. Air, at altitudes of 11 km or higher, may be compared with an inert gas in its small oxidizing effect. This is extremely important to remember, in view of the discussions of the feasibility of using nitrogen to saturate the fuel before servicing it to the aircraft — an operation that is attended with many difficulties [5].
The maximum allowable excess pressure in fuel tanks of supersonic aircraft at a height of 20 km is considered to be 265 mm Hg [1, 6].

If we arbitrarily eliminate from consideration the effect of fuel vapors and assume that the excess pressure is provided solely by pressurizing with ambient air, then the oxygen concentration in the gas medium in the fuel tanks will be about 120 g/m$^3$ (or about 41% of that of the air at ground level). Under such conditions, fuel oxidation will be severely restricted, and this apparently will make it unnecessary to saturate the fuel with nitrogen before servicing to the aircraft. It will then be feasible to use additives to improve the thermochemical stability of the fuels, with minimal concentrations of additive. For fuels produced by hydrogenation or hydrotreating, such additives may not be necessary even when the fuel is heated to comparatively high temperatures.

The Boeing organization, using a special unit, has determined the severity of deposit formation in fuel tanks of supersonic transport aircraft at altitudes of 18.3-21.3 km under ambient pressure of 53 mm Hg and pressurization of 265 mm Hg (total pressure 318 mm Hg) when the fuel is heated to 180-225°C. These conditions correspond to cruise at 2.5-3.0 M [7]. The test fuel, a standard jet A (ASTM D 1655) intended for subsonic transport aviation, was saturated with air for 4 h before charging to the unit. The tests established that increasing the pressure in the tank increases the degree of fuel oxidation and the amount of oxidative condensation products left as deposits. Under supersonic flight conditions, thermal decomposition products from the fuels appeared in the tanks only at temperatures above 175°C. The amounts of deposits were greater at higher temperatures. From these tests, it was calculated that, after 50,000 h of operation of a supersonic airplane, the amount of deposit in the fuel tanks would be insignificant not more than 0.318 kg. Conventional fuel filters performed satisfactorily in cleaning up the fuel by removing all condensation products that had accumulated in the process of operating a supersonic transport.

All this indicates that the methods used currently to evaluate the thermochemical stability of fuels do not have an adequate basis. Bomb tests (static methods) involve a large excess of air, under pressure. With several hours of heating (4-6 h) with high weight concentrations of oxygen, under high pressures and temperatures (140-150°C), abnormally severe conditions are established, having nothing in common with service conditions. Data obtained by these methods are useful only in comparing different grades and batches of fuels, not for assessing their suitability for the end-use. To a lesser degree, these same considerations apply to dynamic methods, for example, the CFR fuel coker [8]. In tests by this method, the fuel, which is in contact with air at normal pressure, passes through the heater of the unit in only 11-12 sec, even though this time is considerably longer than the time during which fuel is heated in the oil cooler of an airplane (1 sec). In the Concorde supersonic aircraft (2.2 M), the flight duration is 3 h. The fuel reaches maximum temperature only after 1.5 sec. If the flight speed is then decreased, the fuel stays at the maximum temperature for no more than 6 min. Hence, if follows that even the dynamic method of testing the thermochemical stability of fuels is quite severe. Nevertheless, in tests on Avgur fuel (British specification D, Eng. R. D. 2494") in the CFR fuel coker at 149°C in the preheater and 205°C in the filter, the filter pressure drop after 5 h of fuel pumping normally rises to 4.3, 2.5, or 0.2 mm Hg, i.e., to values that are orders of magnitude below those allowed in the fuel specifications (76 mm Hg in British, Canadian, and French specifications, 305 mm Hg in U.S. specifications [9]).

It is evident that the results obtained in such tests are not of a limiting nature, but rather comparative.

**SUMMARY**

1. In the tanks of supersonic aircraft (2-2.5 M) at an altitude of 20 km, with a reduced pressure, a small weight concentration of oxygen, and an increased partial pressure of the vapors from the heated fuel, the sediment-forming tendency of the fuel is decreased. The most stable fuels under these conditions are those that have been upgraded by hydrogen treatment.

2. For fuels that have not been upgraded by hydrogen treatment, high-temperature service requirements may be met by the use of additives to prevent the formation (and thereby the consolidation) of solid-phase particles, and to limit the development of oxidative-condensation processes.

3. The accepted methods for long-term determination of the thermochemical stability of fuels, especially the static methods (at high temperatures under air pressure with high weight concentrations of oxygen) fail to give any full idea of the operational suitability of fuels on the basis of this index [of thermochemical stability]. The data obtained by such methods are only comparative in nature as applied to different grades and batches of fuels.

* This fuel is intended not only for subsonic aviation, but also for the Concorde.