JET AIRCRAFT FUEL ADDITIVES (A REVIEW)

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By means of additives (substances added to fuels in small quantities), fuel quality may be improved without resorting to complex and costly refining processes. In some cases, additives will impart properties to the fuels that cannot be achieved by any other means. The effectiveness of additives and the possible savings are the reasons why additives are being used more and more. Increasing efforts are being put forth in the search for new fuel additives for widely different purposes.

The majority of additives may be classed as surfactants that, if present in excess amounts, may complicate the separation of water, filtration, pumping, and settling of fuel; such additives, if lyophilic, may lead to the formation of stable water-in-fuel emulsions.

Additives must be freely soluble in fuel at the use concentration, staying in solution at temperatures below $-60^\circ C$ and resisting extraction by water. The additive's chemical structure, concentration, and efficiency must be retained during prolonged storage of the fuel. Finally, the additive must not harm any fuel quality index that is required by GOST [All-Union State Standard] and by aviation fuel specifications.

The following additives are known currently: antioxidants, metal deactivators, corrosion inhibitors, antistatic additives, additives promoting the rapid removal of solid contaminants (coagulant additives), additives to reduce the fire hazard of aviation fuels (thickeners), additives to improve the chemical stability of fuels, biocides, and smoke suppressants to reduce atmospheric pollution by products of incomplete combustion.

Thus far, primary attention has been given to additives with one or (more rarely) two functions. Meanwhile, aviation fuels need simultaneous improvement of many properties, particularly in the case of fuels for supersonic aircraft. When several different additives are used, it is necessary to resolve problems of compatibility and problems connected with the unduly high total concentration of additives in the fuel. A need for multifunctional additives is becoming apparent.

The use of additives should not be considered as a method of correcting deficiencies in the fuel refining methods. It is more correct to consider that additives should be used to improve fuel properties when this simply cannot be achieved by the applicable refining methods. This means that fuel of the highest possible quality should be obtained as a base stock for additive blending.

Let us examine typical additives that are used or recommended for present-day jet fuels.

Antioxidants. Classed as antioxidants are certain alkylphenols, primarily those with symmetrical structure, such as 4-methyl-2, 6-di-tert-butylphenol (4M26B, Ionol, Topanol O), which is widely used to aviation fuels. Such additives at concentrations of 0.002-0.005% by weight are effective at the normal storage and service temperatures for commercial aviation fuels intended primarily for subsonic aircraft. However, such additives do not prevent metal corrosion when aggressive fuel components are present, such as acids, mercaptans, elemental sulfur, etc.; and they do not improve the antiwear properties of hydrotreated or hydrogenated fuels, since they are not surface-active substances. They are not sufficiently effective as stabilizing additives at high fuel temperatures (about $150^\circ C$), especially when unstable fuel components are present.

A major advantage of this additive is its lyophobicity and its near-insolubility in water and in caustic solutions.

American and British military specifications, which permit the use of 4M26B type antioxidants in aviation fuels, consider such additives as gum inhibitors.
Metal Deactivators. Treatment with copper-salt solutions is often used to remove excess mercaptans from straight-run fuels. After such treatment, the fuel may contain traces of residual copper, which is catalytically active and accelerates the oxidation of fuel constituents. This undesirable phenomenon can sometimes be avoided by adding to fuel (along with a phenol-type antioxidant) a metal deactivator that forms inactive complexes with the copper ions. Salicylidenes are used as metal deactivators; these are condensation products of salicylaldehyde and amines or aminophenols—e.g., disalicylidene-1,2-propanediamine. Such additives are not readily soluble in fuels, so they are generally supplied for blending in toluene or xylene solution, and typical use concentrations are 0.0006-0.0010% by weight.

Corrosion Inhibitors. The corrosion inhibitor "Santolene" is widely used at concentrations of 0.0010-0.0012% by weight; this additive consists primarily of linoleic acid dimer and trimer with a small amount of bis(diamyl-phenyl) orthophosphate [1]. According to [2], corrosion inhibitors also improve the antiwear properties of fuels.

Antiwear Additives. Many surface-active substances improve the antiwear (lubricity) properties of fuel, which are very much in need of improvement if the fuel has been hydrogenated or hydrotreated. Let us note that the nonhydrocarbon fuel constituents that are removed during treatment with hydrogen include substances that give significant improvements in fuel lubricity at extremely low concentrations [2-4]. It is precisely this situation that brings up the question of establishing an optimum severity for hydrotreating.

It has already been mentioned that the corrosion inhibitor "Santolene," since it contains linoleic acid polymers, improves fuel lubricity.

Unless a hydrogenated stock is used by itself as fuel, there is generally no serious problem in the lubricity of fuels for subsonic aircraft. Sufficient lubricity is given to the fuel by naturally occurring nonhydrocarbon compounds (sulfur, oxygen, and nitrogen). For supersonic aircraft fuels intended for use at flight speeds above Mach 2.5, blended from severely treated hydrocarbons of specific structure, the necessary lubricity apparently must be achieved by the use of suitable additives.

Anti-icing Additives. Additives in this class include the monomethyl or monoethyl ether of ethylene glycol, added to fuels at relatively high concentrations of 0.10-0.30% by weight [5, 6]. In some cases, U.S. military specifications have called for the addition of 0.4% by weight of glycerin to the monomethyl ether of ethylene glycol (additive FA-4) [7].

Additives that prevent the formation of ice crystals in fuel (anti-icing additives) are effective not for some arbitrary water content, but only with respect to the dissolved water that comes out of solution in the fuel when the temperature drops rapidly. Under these conditions, a low-freezing mixture of additive and water is formed in the fuel, thus preventing any ice-crystal blockage of filters or connecting lines in the aircraft fuel system.

Antistatic Additives. As aircraft loads and flight ranges have been increased, so has the fuel load. The natural tendency is to speed up the refueling operation, especially for large aircraft. However, high-rate refueling may cause dangerous charges of static electricity to accumulate in the fuel system, capable of causing fire or explosion. This is the reason why certain countries, Canada for example, require the use of an additive to increase the fuel conductivity. Although it is undesirable to increase the ash content of fuels, thus far it has been necessary to use antistatic additives consisting of fuel-soluble organometallic compounds. The additive in current use, Shell ASA-3, consists of three components: 1) chromium salts of mono- and dialkylosaliclyc acids (14-18 carbon alkyl chains), 2) calcium salts of 2-ethylhexylsulfosuccinic acid, and 3) an ashless organic polymer acting as a stabilizer of the system. The ASA-3 is used in the fuel at a concentration of 0.001% by weight. Such amounts will increase the fuel conductivity to such an extent that the static charge formed during fuel pumping will not accumulate [8]. Antistatic additives of different structures have been proposed [9]. However, all such formulations include organometallic compounds, and the required effective concentrations may be even higher than 0.001% by weight.

In order to avoid fires caused by spark discharges when using modern refueling equipment and methods, the conductivity of the fuel should be at least $50 \times 10^{-14}$ ohm$^{-1}$ cm$^{-1}$. This will provide sufficiently rapid relaxation of static charges. If the conductivity is lower, charge dissipation is too slow to prevent charge accumulation, possibly to dangerous levels. The ASA-3 additive at a concentration of 0.0001% by weight will give jet fuel conductivities of approximately $50 \times 10^{-14}$ ohm$^{-1}$ cm$^{-1}$ [10].

Coagulant Additives. Requirements on jet fuel cleanliness are becoming more stringent. In modern aircraft fuel-system mechanisms, the clearances are such that the fuel must not contain any contaminant particles larger