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THERMALLY STABLE JET FUEL COMPOSITIONS

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This invention is directed to improved stabilized jet fuels, particularly to jet fuels containing additives to inhibit the deterioration of the fuel under conditions of thermal stress. According to the present invention, improved jet fuels such as grades JP–4 and JP–5 are produced on incorporating therein a metal deactivator and a selected amine salt of an acid alkyl phosphate.

Specifications governing the formulation of fuels for aircraft turbine engines, ram jet engines and rocket engines are stringent. One of these is the thermal stability requirement, which may be determined in a CFR fuel coker, a laboratory apparatus designed to measure the high temperature stability of jet fuels by subjecting the test fuel to the same level of temperature stress and in a manner similar to that occurring in jet engines. In the operation of a jet engine, before the fuel is combusted it is preheated, for example, by the hot operating engine itself, in which case the fuel, which is pumped through feed lines under pressure, serves as coolant for the engine while on its way to the combustor. Before entering the combustor, the fuel may attain temperatures ranging from 300° to 500° F. Under such thermal stress, because of the inherent instability of many of its hydrocarbon components, the fuel tends to deteriorate. Varnish-like deposits may accumulate in the feed lines, on filter screens, and in feed orifices leading into the combustion chamber, and particles of sludge may become lodged in the orifices and trapped in the filter systems. Such accumulations are harmful, as they may lead to engine malfunctions by restricting the flow of fuel to combustor, impeding heat transfer through the metal of the feed lines, and causing imperfect flame patterns around the orifices when the fuel is ignited.

Tests on commercial JP–4 and JP–5 jet fuels in the CFR fuel coker under standard conditions (as described in CRC Manual Number 3, Instructions for Operation and Maintenance of CFR Fuel Coker, March 1957, of the Coordinating Research Council, Inc.), have shown that all form some, and many form rather heavy preheater and filter deposits, which is indicative of the behavior to be expected in the jet engine under field conditions.

Various additives have been suggested for improving jet fuel with regard to corrosion of metals and to oxidative deterioration in storage and to such deterioration promoted by trace metals. Among these are certain antioxidants of the phenolic and aromatic amine type, corrosion inhibitors, and metal deactivators, which have been approved for military use, as described in MIL–J–5624D, December 24, 1957 (superseding MIL–F–5624C, May 18, 1955). The approved additives may be used singly or in combination in specified amounts. None, however, have been found in our tests to effect significant improvements in the thermal stability of the fuel. Some have been found to be harmful, or incompatible with one another in this respect. For example, the well-known metal deactivator, N,N′ - disalicylidene - 1,2 - propanediamine, while effective in the approved amounts to reduce tube deposits, is usually harmful to the filterability of the fuel through the heated filter system. Also, an approved corrosion inhibitor, which is understood to consist essentially of an oil-soluble n-alkyl primary amine salt of an acid alkyl phosphate, while effective to improve the filterability of the fuel (as well as to inhibit corrosion), is not effective to reduce tube deposits. It might be expected that, in combination, the two would be effective, the one controlling tube deposits, the other providing filterability. However, such combination is practically ineffective to reduce tube deposits.

It is an object of this invention to provide jet fuels having improved thermal stability. In particular, the object of the present invention is to provide significantly improved jet fuels by incorporating into said fuels the hereinafter described soluble additives of the approved classes of metal deactivator and corrosion inhibitor compositions which function compatibly to inhibit the deterioration of the fuel under conditions of thermal stress. These and other objects will become apparent in the following description and claims.

More specifically, the present invention relates to a thermally stabilized jet fuel comprising essentially a jet fuel and, as thermal stabilizers therefor, from about 1 to 10 lbs. per 1000 barrels of an N,N′-disalicylidene-aliphatic polyamine and from 5 to 50 lbs. per 1000 barrels of a jet fuel-soluble salt of (1) a C_6 to C_{24} monoamine taken from the group consisting of (*a*) a tertiary alkyl primary amine, (*b*) a secondary amine whose two organic substituents are monovalent aliphatic or cycloaliphatic hydrocarbon radicals, (*c*) a tertiary amine whose three organic substituents are monovalent aliphatic or cycloaliphatic hydrocarbon radicals and (2) mixed mono- and dialkyl phosphates whose alkyl groups contain from 8 to 18 carbon atoms.

Furthermore, the present invention is directed to the operation of a jet engine in which the jet fuel to be combusted is in heat-exchange relationship with the hot engine, in which method of operation the step of stabilizing the jet fuel against thermal deterioration while in such a heat-exchange relationship is accomplished by introducing into said fuel before the fuel enters into said heat-exchange relationship an N,N′-disalicylidene-aliphatic polyamine compound and an amine salt of an acid alkyl phosphate, said amine salt and alkyl phosphates as above defined.

This invention is based on the discovery that the described additives, in combination in jet fuel, inhibit the thermal deterioration of the fuel while it is under conditions of thermal stress such as those occurring in a jet engine, and thereby provide for substantially clean, deposit-free flow of fuel from fuel tank to combustor.

As demonstrated in the CFR fuel coker test under thermal conditions simulating those pertaining in the operation of a jet engine, the additives of this invention exert an unexpected combined effect to maintain the flow of fuel through the feed lines and filter system and to inhibit the deposition of sludge and varnish-like deposits in these parts. It is also significant that these additives impart, to the fuel, properties of anti-corrosion and metal deactivation, as might be expected, and have no adverse effect on other properties of the fuel such as its water-reaction.

The combined beneficial effect of the subject additives in improving the thermal stability of jet fuel is both unexpected and surprising in view of the observations that (*a*) each of the additives alone is only partially effective and (*b*) amine salts of acid alkyl phosphates in general are incompatible with N,N′-disalicylidene-1,2,-propanediamine metal deactivator compositions for the dual purpose of improving the filterability of the jet fuel and retarding the formation of deposits in the feed and filter systems under conditions of thermal stress. The incompatibilty of these two classes of additives is such that the benefit of reducing tube deposits, normally associated with and to be expected from the presence in the jet fuel of the metal deactivator, is markedly less apparent or is lost altogether.

The amine salts of the acid alkyl phosphates are pre-

pared simply by neutralizing an acid alkyl phosphate or pyrophosphate with the appropriate amine to a pH of about 6–7.

The acid alkyl phosphates and pyrophosphates are obtained by reacting an alcohol with phosphoric anhydride (P_2O_5). From about 2 to 4 moles of a primary alkanol or mixture of such alcohols may be employed per mole of P_2O_5. Preferred for the present purpose are the approximate equimolar mixtures of the mono- and dialkyl phosphates produced on using 3 moles of alcohol per mole of P_2O_5.

For the preparation of the acid alkyl phosphates, the alkanol will be a primary alkanol, and preferably a branched primary alkanol, having 8 to 18 carbon atoms. Examples are the normal alkanols derived from coconut kernel oils. One such fraction, available commercially, consists mainly of the n-octyl and n-decyl alcohols. Another consists largely of n-dodecyl alcohol but contains other n-alkanols containing from 10 to 18 carbon atoms. Still another ranges from n-C_8 to n-C_{16}, with n-C_{12} predominating. Preferably the alcohol will be a mixture of branched chain primary alkanols, such as those produced in the well-known "Oxo" process from CO, H_2 and a branched chain olefin. Examples of these are the "Oxo" octyl, decyl, tridecyl and octadecyl alcohols, all of which are mixtures consisting predominantly of branched chain primary alkanols obtained from propylene-butylene dimer, tri-propylene, tetra-propylene and penta-propylene, respectively.

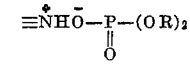
The amine salts of the subject compositions will be fuel-soluble substituted ammonium alkyl phosphates prepared by neutralizing an acid alkyl phosphate with a C_6 to C_{24} non-aromatic monoamine which broadly may be a primary amine containing a tert-alkyl substituent on nitrogen, or a secondary or tertiary amine containing monovalent aliphatic or cycloaliphatic hydrocarbyl substituents on nitrogen.

Preferably the amine will be a C_8 to C_{21} tert-alkyl primary amine, and preferably the amine salt will be the salt of such an amine and the acid phosphate derived from the mixed octyl alcohols made by the "Oxo" process. Examples of the tert-alkyl amines used to prepare these preferred additives are: 1,1,3,3-tetramethylbutyl amine (tert. octyl amine); the mixed tert. alkyl amine fractions having from 12 to 14 carbon atoms and from 18 to 21 carbon atoms, respectively, such as those marketed commercially under the trade names "Primene 81–R" and "Primene JM–T"; and "tert. nonyl amine," also available commercially, consisting mainly of the C_9 with small amounts of C_8 and C_{10} amines and having a molecular weight range of 143 to 157.

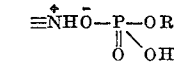
Representative of the secondary amines and tertiary amines are diisopropylamine, di-2-ethylhexylamine, N-octenyl-cyclohexylamine, tributylamine, triisooctylamine, and N,N-diethylcyclohexylamine.

Representative substituted ammonium acid alkyl phosphates are described in the examples. In the preferred embodiment of the invention, there will be employed the C_8–C_{21} tert. alkyl primary amine salts of the mixed mono- and dioctyl phosphates whose octyl groups are derived from the C_8 branched primary alkanol mixture produced in the "Oxo" process.

Produced by neutralization of the mixed mono- and dialkyl phosphates to pH 6–7, the amine salts consist of two main species which may be schematically represented as follows:



and



The metal deactivator component of the subject compositions may be prepared by reacting the appropriate o-hydroxy aromatic carbonyl compound with a polyamine having two NH_2 groups, e.g., 1,2-propane diamine and ethylene diamine, as described in U.S. 2,181,121, 2,255,597 and 2,813,080. Metal deactivators comprised essentially of the reaction products obtained from salicylaldehyde and 1,2-propane diamine are preferred, e.g., N,N'-disalicylidene-1,2-propanediamine. Others which may be used are derived from mixtures of salicylaldehyde and o-hydroxyacetophenone and 1,2-propane diamine or mixtures of this diamine with diethylenetriamine, as described by Bartlett in U.S. 2,813,080. As the preferred metal deactivators are derived from o-hydroxy aromatic aldehydes whose major component is salicyladehyde, they may be regarded as consisting essentially of N,N'-disalicylidene compounds. These metal deactivator compositions, in addition to containing the N,N'-disalicylidene compound as the active ingredient, will ordinarily also contain, particularly in their commercial forms, diluents such as xylene or a combination of such a liquid aromatic hydrocarbon with a phenol such as xylenol, as described by Bartlett in U.S. 2,813,080.

Normally from about 5 to 50 lbs. of an amine salt as defined, and from about 1 to 10 lbs. of a metal deactivator as defined will be employed per 1000 barrels of jet fuel. The actual quantities employed in a given fuel will depend largely on the susceptibility of that fuel to thermal deterioration in use. In general, however, about 7.5 to 30 lbs. of an amine salt such as the "Primene 81–R" salt of the mixed "Oxo" octyl phosphate, and not more than about 2 lbs. of a metal deactivator such as N,N'-disalicylidene-1,2-propane diamine, per 1000 barrels of jet fuel, will be preferred.

The fuel-soluble amine salt and metal deactivator compositions are homogeneously incorporated into the jet fuel simply by agitating. Preferably these two essential additives are separately added to and blended into the jet fuel to be stabilized. The additives are conveniently handled in liquid form, i.e., as concentrates in hydrocarbon solvents such as kerosene for the amine salt and xylene or xylene-xylenol combination for the metal deactivator.

In addition to containing the metal deactivator and amine salt compositions described above, the jet fuel may also contain an antioxidant of the alkyl phenolic or aromatic amine type such as 2,6-ditertiary butyl-p-cresol or N,N'-disecondary butyl-p-phenylenediamine.

Representative examples illustrating the present invention are as follows:

PREPARATION OF AMINE SALTS

The mixed acidic mono- and dialkyl phosphates, and their amine salts described in the examples, were prepared by the following general procedures:

Anhydrous phosphoric pentoxide (P_2O_5), is added gradually under anhydrous conditions to 3 molar equivalents of the alcohol under agitation. The addition of P_2O_5 is regulated so as to maintain the reaction temperature in the range 40 to 90° C. (Good results are ordinarily obtained either at 50±10° C. or at 80±10° C.) When the addition of P_2O_5 is complete, the reaction mass is held at 60–70° C. for about 12 to 24 hours to complete the reaction (the course of which may be followed by conventional methods of analysis for reactants and products). In most instances, the acid alkyl phosphate is a viscous oil.

The amine salt is obtained by neutralizing the above-produced acid alkyl phosphate to a pH of about 7 by the addition thereto of approximately 2 moles of amine per mole of P_2O_5 originally employed. Conveniently, the amine, together with sufficient kerosene to produce a final solution containing about 80% of the neutralized salt as the active ingredient, is added gradually to the acid phosphate under agitation, and the reaction mass held at 70±10° C. until it becomes completely homogeneous.

The neutralized salt-kerosene compositions are relatively mobile liquids at ambient temperatures.

A barrel of jet fuel in the following examples represents 42 U.S. gallons and a specific gravity within the range of 0.739 to 0.845.

TEST METHOD

Jet fuels with and without additives, as described below, were tested for thermal stability in the CFR fuel coker in accordance with the CRC Manual No. 3 referred to earlier. The fuel coker is a laboratory apparatus designed to measure the fuel's high temperature stability. In principle, it subjects the test fuel to the same level of temperature stress and in a manner similar to that occurring in jet engines. The unit consists essentially of a fuel system, a preheater and a heated filter section. The preheater, which simulates the hot fuel line sections of the engine, consists essentially of two concentric aluminum tubes, the inner tube housing an electric heater. The heated filter section, which is heated electrically and which represents the nozzle area of the engine where fuel degradation particles may become trapped, contains a sintered stainless steel filter that serves to trap such degradation particles forced in the fuel during the test. The extent of this build up of trapped particles is transmitted as a pressure drop across the filter.

In the test, the fuel, at a pressure of 150 p.s.i. and at a fixed flow rate of 6 pounds/hr., enters the preheater through a fuel inlet body and passes between the inner and outer tubes where it is heated to the required temperature by the heater contained in the inner tube. The heated fuel leaves the preheater through an outlet body where its temperature is measured by means of a thermocouple. The hot fuel then enters the heated filter section which also contains a thermocouple for measuring its temperature. Pressure taps before and after the filter section lead to a manometer where the pressure drops across the filter is measured.

In the test runs described below, the fuel presure was 150 pounds and the fuel flow rate 6 pounds/hr. For JP–4 fuels the preheater temperature was 300° or 350° F. and the filter temperature 400° F. For JP–5 fuels the preheater temperature was 400° F., the filter temperature 500° F. The fuel was passed through the unit for 300 minutes or to a pressure drop of 25 inches of mercury across the filter. If a pressure drop of 25 inches occurred before 300 minutes had elapsed, the run was stopped to remove the filter and then continued to 300 minutes.

The pressure drop across the filter and the condition of the preheater after 300 minutes with respect to tube deposits is taken as a measure of the fuel's high temperature stability.

It is standard, in reporting the condition of the preheater tube, to rate each inch of its 13 inches of length according to the following code:

Tube Deposit Code

0—no visible deposits
1—haze or dulling, no color
2—barely visible discoloration
3—light tan
4—heavier than 3

As the 3-and 4-ratings are apparently the most significant, an abbreviated notation is employed in reporting the present results. The tube deposit ratings are expressed as follows: the sum of the 13 individual ratings, followed by the total number of 4-ratings, followed by the total number of 3-ratings. (The difference between the sum total of the 13 ratings and the sum of all the 4- and 3-ratings is the sum of the 0-, 1- and 2-ratings.)

EXAMPLE 1

The results tabulated below were obtained in the CFR fuel coker test described above, on employing a commercial JP–5 jet fuel designated as lot 1 below, with and without the following fuel-soluble additives:

A=the 1,1,3,3-tetramethylbutylamine salt of mixed 1:1 mono- and di-"Oxo" octyl phosphate; concentration=15 lbs./1000 bbls. of fuel.

DMD=N,N'-disalicylidene-1,2-propane diamine; concentration=2 lbs./1000 bbls. of fuel.

Test Conditions

Preheater temp. ---------- 400° F.
Filter tem. ---------- 500° F.
Fuel pressure ---------- 150 lbs./sq. in.
Fuel flow rate ---------- 6 lbs./hr.

[Fuel=JP-5, lot 1]

Test	Additives	Deposits		Minutes to press. drop, in inches of Hg
		Tube	Filter	
1	None	42, 5, 7	Light bronze	40 to 25
2	A	33, 0, 10	None	300 to 0.0
3	DMD	14, 0, 0	Light bronze	29 to 25
4	A+DMD	21, 0, 4	None	300 to 0.0

The data show the instability of the fuel itself, the adverse effect of DMD on filterability, and the marked effect of the combined additives A and DMD in maintaining fuel flow and inhibiting tube and filter deposits.

EXAMPLE 2

A commercial JP–5 jet fuel designated as lot 2 below was treated to contain 2 lbs./1000 bbl. of N,N'-disalicylidene-1,2-propane diamine (DMD) and 15 lbs./1000 bbl. of each of the following tert. alkylammonium salts of the mixed 1:1 mono- and di-"Oxo" octyl phosphate:

B=the "Primene 81–R" salt
C=the "Primene JM-T" salt
D=the tert. butylamine salt

The results obtained in the CFR fuel coker, under the conditions described in Example 1 are tabulated below:

[Fuel=JP-5, lot 2]

Test	Additives	Deposits		Minutes to press. drop, in inches of Hg
		Tube	Filter	
5	None	29, 3, 2	Brown	112 to 25
6	DMD	21, 0, 3	Bronze	300 to 6.6
7	B	23, 0, 3	None	300 to 0.08
8	B+DMD	5, 0, 0	do	300 to 0.1
9	C+DMD	25, 0, 1	do	300 to 0.2
10	D+DMD	27, 0, 2	Light bronze	152 to 25

Apparently lot 2 fuel is itself more stable than the lot 1 fuel of Example 1. While either DMD or B substantially inhibit thermal deterioration of this fuel, it will be noted that the combination of DMD with B in particular, or with C, provides superior results. Test 10 is for comparison only. The tertiary butyl amine salt, which is excluded from the present invention, is actually harmful to filterability in the presence of DMD. This is surprising for in general amine salts of acid alkyl phosphates can be relied on to improve filterability.

EXAMPLE 3

Example 2 was repeated, using the fuel of Example 2, 2 lbs./1000 bbls. of DMD and 15 lbs./1000 bbls. of each of the following fuel-soluble secondary amine salts of mixed mono- and dialkyl phosphates:

E=diisopropylammonium "Oxo" tridecyl phosphate
F=di-2-ethylhexylammonium "C_8–C_{16}" n-alkyl phosphate
G=di-2-ethylhexylammonium "Oxo" octyl phosphate
H=piperidinium "Oxo" octyl phosphate
I=di-2-ethylhexylammonium n-butyl and isoamyl phos-

phate prepared from a 1:1 molar mixture of butyl and isoamyl alcohols

J=N-(octenyl)-cyclohexylammonium "Oxo" octyl phosphate

The results of the CRF fuel coker test are tabulated below:

[Fuel=JP-5, lot 2]

Test	Additives	Deposits		Minutes to press. drop, in inches of Hg
		Tube	Filter	
Control	None	29, 3, 2	Brown	112 to 25
11	E+DMD	16, 0, 0	None	300 to 0.1
12	F+DMD	32, 0, 9	do	300 to 0.5
13	G+DMD	21, 0, 3	do	300 to 0.0
14	H+DMD	31, 2, 3	Dark bronze	190 to 25
15	I+DMD	29, 0, 2	None	214 to 25
16	J+DMD	5, 0, 0	Light bronze	300 to 0.13

Tests 14 and 15 are for comparison only, amine salts H and I being outside the scope of the invention for reasons of inoperability. Amine salt F appears to be marginally effective in reducing tube deposits, though it greatly aids filterability. Comparison of test 12 with test 13 (and with tests 11 and 16) explains the preference for the branched primary alkyl groups in the phosphate; test 14, however, shows that this feature alone is not enough to provide the desired results.

EXAMPLE 4

The following results were obtained, using the fuel of Example 2, 2 lbs./1000 bbls. of DMD and 15 lbs./1000 bbls. of each of the following fuel-soluble tertiary amine salts of mixed 1:1 "Oxo" octyl phosphate:

K=tributylamine salt
L=N-diethylcyclohexylamine salt
M=triisooctylamine salt

[Fuel=JP-5, lot 2]

Test	Additives	Deposits		Minutes to press. drop, in inches of Hg
		Tube	Filter	
17	K+DMD	31, 0, 6	Very light bronze	300 to 0.15
18	L+DMD	9, 0, 0	None	300 to 1.57
19	M+DMD	12, 0, 3	do	300 to 0.06

For the control run see Example 2.

EXAMPLE 5

The JP-5 jet fuel of Example 1 was treated to contain 2 lbs./1000 bbls. of DMD and 15 lbs./1000 bbls. of each of the following amine salts of the mixed 1:1 "Oxo" octyl phosphate, or of commercial additive Q:

B=the "Primene 81-R" salt
K=tributylamine salt
M=triisooctylamine salt
N=2-ethylhexylamine
Q=a commercial corrosion inhibitor, believed to be the "cocoamine" salt of acid C_5–C_8 alkyl phosphates

[Fuel=JP-5, lot 1]

Test	Additives	Deposits		Minutes to press. drop, in inches of Hg
		Tube	Filter	
Control 1	None	42, 5, 7	Light bronze	40 to 25
Control 2	DMD	14, 0, 0	do	29 to 25
20	B+DMD	21, 0, 3	None	300 to 0.1
21	K+DMD	20, 0, 0	do	300 to 0.05
22	M+DMD	25, 0, 5	do	300 to 0.0
23	N+DMD	32, 2, 2	Bronze	300 to 0.0
24	Q	41, 5, 6	Brown	300 to 0.0
25	Q+DMD	32, 4, 2	Light brown	300 to 0.0

The over-all effectiveness of the subject additives of tests 20–22 is surprising in view of the relative ineffectiveness of the excluded additives of tests 23 and 25 to inhibit deposit formation.

EXAMPLE 6

The JP-5 of Example 1 was treated to contain DMD and fuel-soluble additives A of Example 1, K of Example 5, N of example 5, and P, the tert. nonlyamine salt of the mixed 1:1 mono- and di-"Oxo" octyl phosphate, in the quantities given below.

Each of the fuel samples was then aged in the dark for 6 weeks at 110° F. in 5 gallon metal cans before it was run in the CFR fuel coker test. The fuel coker test results for the aged fuels follow:

Test	Additives	Conc. lbs./1000 bbls.	Deposits		Minutes to press. drop, in inches of Hg
			Tube	Filter	
26	None		42, 6, 4	Light bronze	29.5 to 25
27	A+DMD	7.5+2	17, 0, 0	None	300 to 0.0
28	A+DMD	15+1	8, 0, 0	do	300 to 0.0
29	K+DMD	30+2	31, 0, 6	do	300 to 0.08
30	P+DMD	7.5+2	13, 0, 0	do	300 to 0.08
31	P+DMD	15+2	11, 0, 0	do	300 to 0.1
32	P+DMD	30+2	27, 0, 3	do	300 to 0.0
33	N+DMD	7.5+2	37, 3, 7	Light brown	300 to 0.1
34	N+DMD	15+2	32, 2, 3	None	300 to 0.0

Tests 33 and 34 are for comparison. Additive N, the 2-ethylhexylamine salt, is excluded from the scope of the invention. The compatibility of the subject additives with DMD in fuel under accelerated storage conditions is noteworthy.

EXAMPLE 7

Example 6 was repeated on the JP-5 fuel of Example 1, with and without the combined additives DMD and A of Example 1. The following results were obtained in the fuel coker test after the treated fuel samples were aged in the dark for 12 weeks at 110° F. in 5 gallon metal cans.

Additives	Conc. lbs./1000 bbls.	Deposits		Minutes to press. drop, in inches of Hg
		Tube	Filter	
None		40, 7, 4	Light bronze	33.5 to 25
A+DMD	15+2	8, 0, 0	do	300 to 0.06
A+DMD	30+2	27, 3, 1	do	300 to 0.05

Substantially the same relative order of results are obtained in the CFR fuel coker test with commercial JP-4 jet fuels, as described in the above examples for the JP-5 fuels. The combined effect of the amine salt as defined and a metal deactivator such as N.N'-disalicylidene-1,2-propane diamine, is to improve the filterability of the fuel and lessen tube and filter deposits.

None of the additives, in any of the fuel compositions described above, promoted the emulsification of water in the fuel. All fuel compositions passed the standard water tolerance test, involving the use of water buffered with phosphates to pH 7, as described in Method 3251 of Federal Specification VV-L-791e.

As many apparently widely different embodiments of this invention may be made without departing from the spirit and scope thereof, it is to be understood that this invention is not limited to the specific embodiments thereof except as defined in the appended claims.

The embodiments of the invention in which an exclusive property or privilege is claimed are defined as follows:

1. A thermally stabilized jet fuel, consisting essentially of a liquid hydrocarbon jet fuel, and, as thermal stabilizers thereof, from about 1 to 10 lbs. per 100 bbls. of said fuel of an N,N'-disalicylidene aliphatic polyamine and from about 5 to 50 lbs. per 1000 bbls. of a jet fuel-soluble salt of (1) a C_6–C_{24} monoamine taken from the group consisting of (*a*) a tertiary alkyl primary amine, (*b*) a secondary amine whose two organic substituents are monovalent saturated hydrocarbon radicals, (*c*) a tertiary amine whose three organic substituents are monovalent saturated hydrocarbon radicals, and, (2) mixed mono-

and dialkyl phosphates whose alkyl groups contain from 8 to 18 carbon atoms.

2. The thermally stabilized jet fuel of claim 1 wherein the amine salt additive is a C_8–C_{21} tertiary alkyl primary amine salt of an acid alkyl phosphate, the alkyl groups being branched chain alkyl groups having from 8 to 18 carbon atoms.

3. An improved method of operating a jet engine wherein the jet fuel to be combusted is in heat-exchange relationship with the hot engine which comprises the step of combusting a liquid hydrocarbon jet fuel stabilized against thermal deterioration by introducing into said fuel, before the fuel enters into said heat-exchange relationship, an N.N'-disalicylidene aliphatic polyamine, and, a jet fuel-soluble salt of (1) a C_6–C_{24} monoamine taken from the group consisting of (*a*) a tertiary alkyl primary amine, (*b*) a secondary amine whose two organic substituents are monovalent saturated hydrocarbon radicals, (*c*) a tertiary amine whose three organic substituents are monovalent saturated hydrocarbon radicals, and, (2) mixed mono- and dialkyl phosphates whose alkyl groups contain from 8 to 18 carbon atoms.

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