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AVIATION GASOLINE

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This invention relates to improved fuels for internal combustion engines. In one of its more specific aspects, it relates to an aviation fuel conforming to rigid specifications of anti-knock rating, vapor pressure, and distillation characteristics, and having in addition, characteristics which result in providing substantially even distribution of high anti-knock portions of the finished fuel to all of the cylinders of a multicylinder, aviation-type, spark ignition, internal combustion engine. In another specific aspect, it relates to a improved operation of an aviation engine.

This is a continuation of our U. S. application, Serial No. 750,174, filed May 23, 1947, and now abandoned.

Among other requisites which must be met in a superior aviation gasoline blend is that of high anti-knock properties. This requirement resulted from the discovery that engine knock is a function of fuel composition as well as engine conditions. Many approaches have been made to the problem of raising anti-knock characteristics of fuels. One of the first such approaches was made with the use of additives or anti-knock agents, e. g. tetraethyl lead, aniline, carbonyls of iron or nickel, etc., whose sole purpose, when added to gasoline was to act as knock inhibitors and increase the anti-knock rating. Thereafter emphasis was placed on blending of specific fuels according to rigid specifications and in conjunction with the use of knock inhibitors.

It has generally been believed heretofore that efficiency of an aviation fuel can be pretty well predicted from the ASTM octane number. We have, however, now discovered that such is not always the case. Two fuels having essentially the same octane number may, when used in actual flight, vary quite radically in actual performance. The knock limited horsepower derived from one fuel may be substantially greater than that gained from another fuel having the same octane number and the same anti-knock rating, when used in the same engine. Aircraft engines, which have been designed to operate on fuels falling within a specific octane number range, can now be operated by means of our invention on fuels which fall substantially below the design octane range of the engine.

"Knock limited horsepower," as used herein is the maximum horsepower output obtainable with a given fuel in an aviation-type, spark ignition, internal combustion engine under specific operating conditions that will not result in knocking. This is to be distinguished from "knock limited horsepower" as used in the automotive industry, wherein it means the horsepower reached at a point where power falls off due to knocking. Our invention provides an aviation fuel which yields an increased knock limited horsepower, under conditions of sustained flight, over that provided by ordinary fuels. This improved performance is obtained without increasing the laboratory octane rating of the fuel as measured by ASTM Aviation Method Designation D-614-44T.

The fact that multicylinder internal combustion aircraft engines do not distribute the charge of gasoline equally to all cylinders, is common knowledge to the aircraft and petroleum industries. Those cylinders which receive the leanest fuel-air ratio have an increased tendency to detonate. The more volatile fuel fraction, in most engines, travels to the cylinders farthest from the carburetion point while the heavier fractions are burned in the nearest cylinders. Since those cylinders which receive the leanest mixture of gasoline and air tend to receive the more volatile constituents of the original gasoline charge, i. e., those constituents which are vaporized first under given conditions, we have discovered that it is very desirable that these more volatile constitutents be as high in anti-detonation characteristics as possible to permit operation in all cylinders at the highest possible knock limited horsepower under all engine conditions.

An object of our invention is to provide fuel of high anti-knock quality.

A still further object of our invention is to provide an aviation fuel which will result in improved engine performance, insofar as maximum obtainable knock limited horsepower is concerned, under all operating conditions.

A still further object of our invention is to provide an improved method for operating an aviation engine.

Another object of our invention is to provide a fuel which will give better comparable performance in all comparable engines, regardless of the engine fuel distribution characteristics, than can be obtained with ordinary aviation gasolines.

A further object is to provide a means and method of more effectively utilizing the B. t. u. potential of an aviation gasoline.

Other objects of the invention will be apparent from the discussion and description contained herein.

Although different aviation gasolines may have substantially identical laboratory anti-knock ratings, no attempt has been made, heretofore, to substantially concentrate the highest quality anti-knock components of an aviation fuel in the low boiling blend portion where they will allow the engine to give the greatest overall knock limited horsepower and make the best utilization of the B. t. u. potential of the fuel. As pointed out above, we have discovered that by concentrating high anti-knock properties in substantially the lowest boiling 45–55 volume per cent fuel blend we increase the knock limited horsepower which will be produced by an aviation engine using such fuel under lean fuel-air ratio conditions. By thus increasing the knock limited horsepower we more efficiently make use of the B. t. u. potential of the fuel.

Fuels having high anti-knock components in the higher boiling portions require even distribution of the unvaporized fractions, if any exist, under all operating conditions to give maximum anti-knock performance. This type fuel depreciates in flight anti-knock value as conditions develop that result in uneven distribution of the unvaporized fractions, while the fuels of our invention, having high anti-knock components in the low boiling fraction, give comparatively better flight knock limited horsepower performance under such conditions.

The special aviation fuel of our invention has shown a superior performance on actual flight tests because it compensates for the lack of perfect fuel distribution in the engine. It is known that the lean mixture cylinders receive a disproportionately high proportion of the lighter fractions of the fuel and limit the knock free performance of the engine. Thus it will be seen that those cylinders receiving a lean mixture require a higher anti-knock fuel, to provide knock free performance, than do those cylinders which receive the richest mixtures. We have also found that special knock inhibitors or anti-knock agents, such as tetraethyl lead, have a tendency to follow the heavier fraction of any internal combustion engine fuel

in an engine having imperfect fuel distribution characteristics. By the practice of our invention one tends to correct the premature knock limit by blending an aviation gasoline so that the lighter fractions comprise the highest octane quality ingredients and thus the knock free power output of the engine is increased.

The present invention may be employed in a great variety of blending operations involving all suitable blending agents and base stocks. One such procedure is outlined in the following operations. A fuel may be prepared according to a blending formula which requires definite proportions of normal hexane, iso-hexane, HF heavy alkylate and a heavy naphtha comprising hydrocarbons containing 11 to 12 carbon atoms per molecule in order to produce a composition having an octane number between 83 and 85, determined by the ASTM Aviation Method Designation D–614–44T, with a given concentration of tetraethyl lead. Said blending formula is devised so that the composite fuel will have a Reid vapor pressure of approximately 4 pounds.

An illustration of the improved performance characteristics obtained by use of a high anti-knock low boiling fraction to furnish overall high anti-knock performance under lean mixture conditions is shown in the following data.

Example

An aviation fuel blend (1) was prepared by mixing two fuels shown as formulas A and B together with approximately 4 ml. tetraethyl lead per gallon. Aviation fuel blend (2) was prepared by mixing two fuels shown as formulas C and D together with approximately 4 ml. tetraethyl lead per gallon.

Blend Formula	Boiling Range, ° F.	Reid vapor pressure	Composite, volume percent				ml. TEL per Gallon	ASTM Aviation Method Designation D614–44T
			n-hexane	i-hexane	HF Heavy Alkylate	Heavy Naphtha		
A	132–155	6.85	24.4	75.6			4	93.8
B	356–409	0			55	45	4	72.5
C	357–391	.15			100		4	92.6
D	138–157	6.3	100				4	75.6
(1)	136–395	4.3	12.7	39.3	26.4	21.6	3.93	83.3
(2)	145–387	4.0	49		51		4.13	83.6

While it will be noted that blend (2) has a slightly better ASTM Aviation Method Octane Number than blend (1), the higher boiling fraction of blend (2) has a concentration of higher anti-knock properties, and in blend (1) the lower boiling fraction has the concentration of higher anti-knock properties. In each case all components are saturated and primarily paraffinic. Blends (1) and (2) were tested in actual flight using a C–49K airplane equipped with Wright R–1820–87 engines. The following data on knock limited horsepower were obtained while operating the engines at 1750 R. P. M. and at 33° F. carburetor air temperature.

Knock limited horsepower

Fuel-Air Ratio	.060	.065	.070	.075	.080
Blend (1)	540	570	594	612	621
Blend (2)	531	560	584	606	620

There are times when a plane must of necessity have a greatly increased power output from its engines over that required under ordinary cruising conditions. In instances where for one reason or another an engine of a multi-motored plane should stop, it then becomes necessary for the remaining operable engine or engines to furnish a substantial portion of the power which was formerly furnished by the defective engine. It will thus be noted that a considerable safety factor is necessary in a fuel or engine in order to furnish the additional power when required. Aircraft engines as now constructed and designed fall within the fuel requirement classes of 91 or 100 minimum octane number or 115 minimum performance number, and engines are now contemplated in fuel requirement classification considerably above 115 minimum performance number, such as in the vicinity of 130 minimum performance number and above. Octane number may be defined as the per cent by volume of iso-octane (2-2-4, trimethylpentane) that must be mixed with normal heptane in order to match the knock intensity of the unknown fuel and may be determined by ASTM Aviation Method Designation D–614–44T. Performance number is an average value indicating the per cent of knock limited power output developed with a fuel based on the knock limited power output of iso-octane (2-2-4, trimethylpentane) as 100. Performance numbers bear a relation to ratings of iso-octane plus TEL and are usually determined from conversion charts or tables of iso-octane plus TEL, vs. performance numbers. For the purpose of simplicity we will use hereinafter the term anti-knock rating rather than octane number or performance number but which term will include both. It will be understood that when the anti-knock rating is 100 or below we mean octane number as above defined and when the anti-knock rating is above 100 we mean performance number which is converted as shown in the following conversion table.

Performance Number	Knock Value [1]	Performance Number	Knock Value [1]
100	0.00	131	1.36
101	0.02	132	1.43
102	0.05	133	1.51
103	0.07	134	1.59
104	0.10	135	1.68
105	0.13	136	1.77
106	0.16	137	1.86
107	0.19	138	1.96
108	0.22	139	2.06
109	0.25	140	2.17
110	0.28	141	2.28
111	0.32	142	2.40
112	0.35	143	2.52
113	0.39	144	2.65
114	0.43	145	2.78
115	0.47	146	2.92
116	0.51	147	3.06
117	0.55	148	3.22
118	0.59	149	3.37
119	0.64	150	3.54
120	0.69	151	3.72
121	0.74	152	3.90
122	0.79	153	4.09
123	0.84	154	4.29
124	0.90	155	4.50
125	0.96	156	4.72
126	1.02	157	4.95
127	1.08	158	5.19
128	1.14	159	5.45
129	1.21	160	5.71
130	1.28	161	5.99

[1] Knock value = ml. TEL/US gal. in iso-octane

$$\text{ml. lead} = \frac{(\text{P. N.}-100)}{42.42-0.736\,(\text{P. N.}-100)+0.003\,(\text{P. N.}-100)^2}$$

The above classes are based on the minimum recommended lean anti-knock rating for the fuel, believed to be necessary for absolutely knock free performance. An advance in flying operation which is now coming into use is the utilization of instruments to indicate the point when knocking of each engine begins, thus obviating the necessity of trial and error method. Operation of aircraft engines with fuels of our present invention, will, with such knock indicating instruments, give from 2 to 25 per cent more knock limited horsepower than will ordinary fuels under lean mixture conditions. A lean mixture is considered by many within the motor fuel and aviation industries to be a fuel-air ratio smaller than 0.09 but not lower than .05. Those greater than 0.09 are considered to be rich mixtures. A fuel which gives the necessary power and high knock limited performance under lean mixture conditions is highly desirable as the main fuel due to the increased economy of operation obtained.

It is common knowledge that aircraft engines, as classified in the 91, 100, 115 and higher minimum anti-knock classifications, have safety factors and will ordinarily operate commercially on ordinary fuels with anti-knock ratings below the minimum anti-knock rating of the design classifications but still within the safety factors of said engines. It would be extremely difficult to say that any one engine has a specific safety factor of a certain span of anti-knock units. In fact that would not be true for, under ideal flying conditions, an engine would operate satisfactorily on ordinary fuels having an anti-knock rating considerably below the minimum anti-knock rating classification of the engine. Under more severe flying conditions it will be noted that the safety factor has been caused to shrink and will take a higher anti-knock rated fuel to give absolutely knock free performance under commercial flying conditions. By operating the same engine on a fuel blended according to our invention we in effect increase the safety factor of the engine. A fuel blended according to our invention will commercially operate that engine and give knock free performance when the fuel has an anti-knock rating between 2 and 10 anti-knock units below that of an ordinary fuel which will operate the engine at the lower limit of its fluctuating safety factor. Of course as a matter of common practice engines are not actually operated commercially with fuels which will barely give knock free performance within the lower margin of the safety factor. The purpose of this discussion is, however, to point out the fact that additional safety as well as power is derived in operation with a fuel blended according to this invention.

The results of the preceding test indicate that a fuel having high anti-knock components substantially concentrated in a low boiling blend comprising in the neighborhood of 50 such as 45 to 55 volume per cent of the composite blend will give substantially greater horsepower in actual flight under lean fuel conditions than will a fuel of nearly the same anti-knock rating but having the high anti-knock components substantially concentrated in the high boiling fraction.

One other point of interest is the fact that many engines have even smaller safety factors under their class rating than the specific test engines used in this test. The difference in knock limited horsepower developed with the two fuels in use with these test engines is indicative of the greated difference in results which are obtained with engines having carburetion distribution characteristics comparably less efficient than these test engines. The Wright R–1820 engine, as is well known in the aviation industry, is among the most efficient of aviation gasoline engines in the respect of carburetion distribution characteristics. With an engine having poorer carburetion distribution characteristics, the results from the use of a fuel of our invention are even more outstanding.

While the foregoing specific example provides an illustration of the improvement obtained through practice of the present invention, it will be apparent that the variations which can be produced by changing the volume-ratio, quality and hydrocarbon type of the blending components, are numerous.

The blending stock or fuel blend which is to comprise the light end of the finished fuel should fall within a distillation range, as determined by ASTM Method Designation D–86 of from about 75 to 100° F. to about 225° F., have an anti-knock rating of between 1 and 20 anti-knock units more than that desired in the finished blend when containing an amount of anti-knock agent equal or equivalent to the amount contained in the finished fuel. The blending fuel comprising the heavy end of the finished fuel should fall within a distillation range, as determined by ASTM Method Designation D–86 of from about 175° F. to about 410° F., have an anti-knock rating of between 1 and 20 anti-knock units less than that desired in the finished fuel when containing an amount of anti-knock agent the same as the amount contained in the finished fuel, which if containing tetraethyl lead fluid should contain between 0 and 6 ml. per gallon. As the anti-knock rating requirement is increased the variance of the light and heavy blend anti-knock ratings from that desired in the finished blend will diminish proportionally from 7 to 20 anti-knock units for a 91 minimum anti-knock rating engine to 1 to 6 anti-knock units for a 135 minimum anti-knock rating classification engine. The variance of the light and heavy blend anti-knock ratings from that desired in the finished blend may fall within a difference of from 1 to 12 anti-knock units for a 115 or above minimum class engine. The finished fuel of such a blend should have distillation characteristics of gasoline as determined by ASTM Method Designation D–86 and have a Reid vapor pressure of from about 2 to 9 pounds with a pressure between 4 and 7 pounds being preferred.

We have disclosed in our specific example a finished aviation fuel with an anti-knock rating in the vicinity of 80 which is nearly at the bottom of the anti-knock rating range desirable for aviation gasolines. In preparation of higher anti-knock rating gasoline it will be necessary to remove substantially all normal paraffins from the light end blending fuel and use mixtures of isomeric hexanes comprising diisopropyl and neohexane, and mixtures of naphthenic hydrocarbons or naphthenic concentrates which may comprise cyclopentane, methylcyclopentane, methylcyclohexane and cyclohexane. In the higher boiling end aliphatic paraffins, cycloparaffins and nephthenes may be used with aromatics. As the anti-knock rating requirement increases normal-paraffins will be more completely decreased.

We claim:

1. A hydrocarbon fuel composition consisting essentially of a first hydrocarbon fraction comprising 45 to 55 per cent by volume of the finished fuel and consisting essentially of about 25 volume per cent of normal hexane and about 75 volume per cent of iso-hexane; a second hydrocarbon fraction comprising 45 to 55 per cent by volume of the finished fuel and consisting essentially of about 55 volume per cent of HF heavy alkylate boiling within the range of 357° F. to 391° F. and about 45 volume per cent heavy naphtha comprising essentially hydrocarbons containing 11 to 12 carbon atoms per molecule; and about 4 ml. tetraethyl lead, said fuel having distillation range characteristics of gasoline as determined by ASTM Motor Designation D–86, and a Reid vapor pressure of about 4 pounds.

2. A hydrocarbon fuel composition consisting essentially of a first hydrocarbon fraction comprising 45 to 55 per cent by volume of the finished fuel consisting essentially of hexanes, at least 75 volume per cent being at least one iso-hexane; a second hydrocarbon fraction comprising 45 to 55 per cent by volume of the finished fuel

and consisting essentially of HF heavy alkylate boiling within the range of 357° F. to 391° F. and heavy naphtha comprising essentially hydrocarbons containing 11 to 12 carbon atoms per molecule, said second fraction having a lower anti-knock rating than said first fraction; and up to 6 ml. tetraethyl lead per gallon, said fuel having distillation range characteristics of gasoline as determined by ASTM Motor Designation D–86 and a Reid vapor pressure of between 2 and 9 pounds.

3. A hydrocarbon fuel composition consisting essentially of a first hydrocarbon fraction comprising 45 to 55 per cent by volume of the finished fuel consisting essentially of hexanes, at least 75 volume per cent being at least one iso-hexane; a second hydrocarbon fraction comprising 45 to 55 per cent by volume of the finished fuel and consisting essentially of about 55 volume per cent of HF heavy alkylate boiling within the range of 357° F. to 391° F. and about 45 volume per cent heavy naphtha comprising essentially hydrocarbons containing 11 to 12 carbon atoms per molecule; and up to 6 ml. tetraethyl lead per gallon, said fuel having distillation range characteristics of gasoline as determined by ASTM Motor Designation D–86, and a Reid vapor pressure of between 2 and 9 pounds.

4. The fuel composition of claim 3, wherein said isohexane comprises diisopropyl.

5. The fuel composition of claim 3, wherein said isohexane comprises neohexane.

6. The fuel composition of claim 3, wherein said isohexane comprises a mixture of diisopropyl and neohexane.

7. The fuel composition of claim 3, wherein the fuel has a Reid vapor pressure of between 4 and 7 pounds.

8. A hydrocarbon fuel composition consisting essentially of a first hydrocarbon fraction comprising 45 to 55 per cent by volume of the finished fuel consisting essentially of C_6 paraffins, at least 75 volume per cent being at least one C_6 iso-paraffin; a second hydrocarbon fraction comprising 45 to 55 per cent by volume of the finished fuel and consisting of a mixture of hydrocarbons selected from the group consisting of paraffins, cycloparaffins, naphthenes and aromatics boiling within the range of 175° F. to 410° F., said second fraction having a lower anti-knock rating than said first fraction; and up to 6 ml. tetraethyl lead per gallon, said fuel having distillation range characteristics of gasoline as determined by ASTM Motor Designation D–86 and a Reid vapor pressure of between 2 and 9 pounds.

9. A hydrocarbon fuel composition consisting essentially of a first hydrocarbon fraction comprising 45 to 55 per cent by volume of the finished fuel consisting essentially of C_6 paraffins, C_5 and C_6 cycloparaffins and at least 75 volume per cent being at least one hydrocarbon selected from the group consisting of iso-paraffins and cycloparaffins; a second hydrocarbon fraction comprising 45 to 55 per cent by volume of the finished fuel and consisting of a mixture of hydrocarbons selected from the group consisting of paraffins, cycloparaffins, naphthenes and aromatics boiling within the range of 175° F. to 410° F., said second fraction having a lower anti-knock rating than said first fraction; and up to 6 ml. tetraethyl lead per gallon, said fuel having distillation range characteristics of gasoline as determined by ASTM Motor Designation D–86 and a Reid vapor pressure of between 2 and 9 pounds.

10. The hydrocarbon fuel of claim 2, wherein said HF heavy alkylate is at least 55 per cent of said second hydrocarbon fraction.

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