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ENCLOSURE (B) 24

STUDIES ON THE STANDARDIZATION OF AVIATION GASOLINE IN WAR TIME

(In Two Parts)

by

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PART I

STUDIES ON STANDARIZATION OF AVIATION GASOLINE IN WAR TIME

by

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Research Period: 1943-1944

SUMMARY

To supply a large quantity of aviation gasoline the changing of the specifications of the gasoline was attempted. Various samples from Sumatra and Borneo crude oils with various distillation curves were tested in full size aircraft engines. The engine performance showed that the temperature of 50% and 90% distilled point could be raised to 115-125°C and 180-200°C from 105°C and 150°C respectively, and thus the production of aviation fuel greatly increased, but the octane number of the gasoline was lowered about 0.2-0.8 with every one percent increase of gasoline from the crude oil, due to the low octane number of the high boiling fractions.

To prevent the lowering of antiknock property it is necessary to use aniline, tetraethyl lead and oxy- and oxo-compounds.

I. INTRODUCTION

It is obvious that there was a great demand for aviation gasoline in war time. However, it was difficult with the transport capacity and materials available to increase the aviation fuel supply by increasing plant facilities.

Therefore the author tried to increase the production by means of changing fuel specifications.

A. Present specifications of volatility for navy aviation gasoline follow:

Vapour pressure .... below 0.6 kg/cm^2

Distillation Characteristics

Initial Pt.	below 60°C
10%	below 80°C
50%	below 105°C
90%	below 150°C
97%	below 170°C
Sum of 10%, 50%, 90%	over 260°C

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B. Relation between vapour pressure and yield: When the vapour pressure is higher than a certain limit, the fuel pipe is choked due to vaporization in the fuel pump or carburator by influence of temperature and pressure. On the other hand, higher vapour pressure gasoline has higher anti-knock and better starting quality. Therefore, it is necessary to attempt the cooling of fuel, pressurizing of fuel tank and the use of a submerged fuel pump, electrically driven. The relationship of vapour pressure, octane number and yield of gasoline is shown in Table I(B)24, for, as an example, isobutane and isopentane.

TABLE I(B)24

Blended Isobutane	Vap. Press. (kg/cm^2)	Octane No.	Blended Isopentane	Vap. Press. (kg/cm^2)	Octane No.
0.0%	0.26	83.5	0%	0.48	90.0
2.5%	0.39	86.0	5%	0.49	90.5
5.0%	0.53	88.0	10%	0.53	91.0
7.5%	0.75	90.5	20%	0.69	92.0
10.0%	0.87	91.0	30%	0.79	93.4

C. Relationship between distillation characteristics and yield of aviation fuel: Distillation characteristics of aviation gasoline affect engine starting, distribution of fuel, acceleration, etc. It is well known that the lower the distillation characteristics, the better, but this defeats the purpose of increasing the yield of aviation gasoline.

The possible increase of quantity of aviation gasoline from the four-point method and the proposed change in specifications of aviation gasoline were computed. The yields of aviation gasoline fractions calculated by the four-point computation method on 38 crude oils of Sumatra and Borneo are shown in Table II (B)24.

As shown in Table II(B)24, the yield of aviation gasoline is limited by the following percentages at the four control points:

10% Point 2.6%
50% Point 97.4%
90% Point 0
97% Point 0

Therefore, the 50% point, 105°C, was the controlling one. Since 1937, the following specifications had been used in summer as non-vapor lock fuel and no accidents occurred.

	Special 92 gasoline (1940 average value)	Specification (ordinary)
Initial point	70.6°C	60° max.
10%	101.6°C	80° max.
50%	115.5°C	105° max.
90%	137.1°C	150° max.
97%	148.8°C	170° max.
Vapour pressure	0.16 kg/cm^2	0.60 kg/cm^2

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TABLE II(B)24

Crude oil	Number	Yield of four point method 10%	50%	90%	97%	Yield of Aviation Gasoline	Octane number 0.15 $Pb(C_2H_5)_4$ added
North Sumatra	1	153.8	52.26	55.42	58.94	52.26	(87.0)
	2	124.9	50.22	52.90	57.43	50.22	(87.5)
	3	132.0	51.50	54.41	57.71	51.50	(88.1)
	4	160.0	55.00	56.50	59.40	55.00	(89.0)
	5	92.8	44.60	50.70	57.60	44.60	
Abab	11	37.4	17.3	19.80	21.80	17.30	(86.5)
	12	52.8	20.66	22.81	25.22	20.66	(87.0)
	13	50.1	20.70	22.40	24.30	20.70	(87.5)
	14	42.7	17.80	20.50	23.00	17.80	(90.5)
	15	48.4	18.70	21.80	23.60	18.70	(89.5)
	16	44.8	18.50	23.20	26.50	18.50	(88.0)
	17	40.2	16.00	18.40	21.50	16.60	(88.0)
	18	53.5	23.40	25.00	27.00	23.40	(87.5)
	20	58.63	16.34	19.06	21.59	16.34	(87.5)
Talangimar	21	21.5	11.00	14.50	16.50	11.00	(90.0)
	22	28.7	12.60	16.30	18.50	12.00	(90.0)
	23	17.9	8.60	12.04	14.54	8.60	(89.5)
	24	16.0	8.74	12.84	15.23	8.74	(88.5)
Jambi	25	79.7	32.90	42.00	32.90	32.90	(90.4)
Mangunjye	26	3.5	2.70	4.50	2.70	2.70	(88.0)
	27	3.4	2.04	3.21	2.04	2.04	(91.1)
	28	5.9	3.00	4.40	3.00	3.00	(90.0)
Ceria (heavy)	30	4.8	3.06	4.50	3.06	3.06	(90.6)
	31	5.5	3.60	5.98	3.60	3.60	(91.0)
	32	5.6	3.30	4.70	3.30	3.30	(92.0)
	33	3.5	3.00	4.60	3.00	3.00	(90.0)
	34	4.5	2.70	4.60	2.70	2.70	(91.5)
	35	4.0	3.00	4.20	3.00	3.00	92.6
	36	4.8	3.22	4.52	3.22	3.22	92.0
	37	2.9	2.20	3.97	2.20	2.20	89.8
Ceria (light)	38	32.8	21.02	26.24	21.02	21.02	
	45	27.2	19.10	25.90	19.10	19.10	92.4
	39	24.0	17.60	24.50	26.80	17.60	92.4
Klli	40	5.3	8.46	15.55	17.50	5.30	91.8
	41	4.66	3.34	7.09	8.59	3.54	91.5
Sangasanga	42	13.07	10.47	19.16	23.39	10.47	91.9
	43	9.50	9.14	19.35	21.71	9.14	92.8

Therefore, when the 50% point was elevated to 115°C the author expected such a fuel would be used only for specially built engines, particularly for solid injection type engines. So the author tried to calculate the increase of y[illegible] when specifications were modified as shown in Table II (B)24.

The specifications are given in Table III(B)24.

TABLE III(B)24

	I	II	III (Present specifications)
Initial Pt.	60°C max.	60°C max.	60°C max.
10%	80°C max.	90°C max.	80°C max.
50%	115°C max.	125°C max.	105°C max.
90%	150°C max.	180°C max.	150°C max.
97%	170°C max.	200°C max.	170°C max.

Limiting Distillation Factor:

10%	30.5%	0
50%	27.8%	94.5%
90%	41.7%	0
97%	0	5.5%

Average yield of aviation gasoline from each oil field is shown in Table IV(B)24.

By the above proposed modification of specifications, the yield of aviation gasoline increased 25% by the first modification and 80% by the second modified specification. This represented increased production of gasoline of ca. 300,000 kl and 1,000,000 kl per year from the East Indies oil (8,450,000 kl/y), regarding total crude oil.

D. Degradation of antiknock properties by proposed modifications of specifications is shown in Table V(B)24. Octane numbers would be lowered by 1.5-7.4.

E. Method of regaining loss of octane number:

1. Increasing the amout of tetraethyl lead.
2. Blending of isooctane.
3. Blending of aniline.
4. Blending of ethanol, acetone, butyrone, diisopropyl ether etc.

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TABLE IV(B)24

Crude Oil	Number of Samples	% Present Yield	First % Yield	% Increase	Second % Yield	% Increase
North Sumatra	5	50.71	54.00	6.5	69.1	36.5
Talangimar	4	10.15	13.92	27.3	16.75	65.0
Ababu	9	18.88	21.31	12.9	28.1	48.0
Mangunjya	3	2.58	3.57	38.1	4.7	82.0
Jambi	1	32.40	42.00	27.6	52.0	58.0
Mili	2	4.40	4.98	13.1	12.4	72.0
Ceria (light)	3	19.24	25.80	34.5	31.3	63.5
Ceria (heavy)	8	3.01	4.15	38.0	5.49	83.0
Sangasanga	2	10.40	13.07	25.6	20.9	101.0
TOTAL	37	16.92		24.65		78.66

TABLE V(B)24

Crude Oil	Present Yield (%)	Octane No.	First Modification		Second Modification	
			Increased Yield (%)	Octane No.	Increased Yield (%)	Octane No.
North Sumatra	50.71	87.5	54.0	85.5	69.1	81.5
Talangimar	10.15	89.0	13.92	87.0	16.75	85.5
Ababu	18.88	88.2	21.31	86.5	28.1	84.0
Mangunjya	2.58	91.1	3.57	90.0	4.7	89.5
Jambi	32.90	90.4	42.0	86.0	52.0	83.0
Mili	4.40	91.5	4.98	91.0	12.4	87.0
Ceria (light)	19.24	91.1	25.80	88.5	31.3	86.5
Ceria (heavy)	3.01	91.5	4.15	90.5	5.49	90.0
Sangasanga	10.40	94.0	13.07	93.0	20.9	89.5

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II. CONCLUSIONS

First modified specification is good for combat planes even in winter.

Second modification is satisfactory for use in summer for combat planes by practical aeroplane test. Therefore Japanese naval specifications of aviation gasoline were changed by the first and second modifications (Table VI(B)24.

The two heavier aviation fuels, modifications 1 and 2, were successfully used during the war.

TABLE VI(B)24

A 87 G and A 91 G			
Properties	1939 - 3	1944 - 7	1945 - 5
Fractional Distillation		Modification 1	Modification 2
Initial Pt.	60°C max.	60°C max.	70°C max.
10% Pt.	80°C max.	90°C max.	90°C max.
50% Pt.	105°C max.	115°C max.	125°C max.
90% Pt.	150°C max.	160°C max.	180°C max.
97% Pt.	170°C max.	170°C max.	200°C max.
Sum of 10%, 50%, 90%	260°C min.	260°C min.	260°C min.
Leaded	0.1% max.	0.15% max.	0.15% max.
Vapour Pressure	0.53 kg/cm^2	0.6 kg/cm^2	0.6 kg/cm^2

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PART II

ENGINE TESTS OF AVIATION GASOLINE WITH INCREASED TETRAETHYL LEAD CONTENT

by

Chem. Eng. Lieut.
K. TSUNODA

Research Period: 1944

SUMMARY

Objectives of Project: The objective of this engine test is to find the influence of the increased tetraethyl lead content in aviation gasoline upon the engine performance and ignition plugs, and to decide the utility of such gasoline as high octane aviation fuel.

Significant Results: The author tested the aviation fuels with the contents of:

tetraethyl lead .... 0.3 vol%
ethylene dibromide .... 1.0, 1.3 and 1.5 equivalent

The significant results were as follows:

1. The aviation gasoline containing 0.3 vol.% tetraethyl lead did not show the same engine performance compared with the gasoline of same octane number of ordinary tetraethyl lead content (i.e. 0.15%).

2. Ethylene dibromide acted as an inhibitor of the contamination of the spark plugs with lead deposits, but an excess of ethylene dibromide caused the plugs to burn.

INTRODUCTION

A. History of Project: In order to obtain more aviation fuel from a definite quantity of the base oil, we have no other way than to degrade the specification, that is, to enlarge the distillation range. As the result of the elevation of the final cutting temperature its octane number inevitably decreases. Then it is necessary to increase the tetraethyl lead content of the gasoline to maintain the same octane number, but this is supposed to give more contamination upon the spark plug. The author, therefore, increased the ethylene dibromide content as an inhibitor of the contamination due to lead and examined the influence of both additives by long running engine tests. These engine tests were done from May to November 1944, in relation to the revision of the specification of aviation fuel during the war time.

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B. Key research personnel working on project:

Chem. Eng. Lieut. K. TSUNODA.

.II. DETAILED DESCRIPTION

A. Description of the test apparatus:

Engine: Kinsei 4 type single cylinder testing machine made by Ishikawajima Aircraft Company, Ltd.
Cylinder: diameter 140mm
stroke 150mm
Compression ratio 6.6
(Other details: presented blue prints)

B. Test procedures and conditions: The author chose the long-running (30 hours) engine tests to find various influences of the new fuel upon the engine performance and the spark plug. Details of the condition are shown in Table VIII(B)24.

C. Experimental results

1. Physical and chemical properties of fuel samples

TABLE VII(B)24

Sample	Content of tetraethyl lead	Content of ethylene dibromide	Octane No.	Distillation Character				
				F. drop	10%	50%	90%	95%
A	0.3 vol.%	1.0 equiv.	Ca. 92	50	80	115	160	180
B	0.3 vol.%	1.3 equiv.	Ca. 91	50	90	130	170	190
C	0.3 vol.%	1.3 equiv.	Ca. 97	35	70	115	150	160
D	0.3 vol.%	1.5 equiv.	Ca. 96	50	80	115	155	170

2. Performance test

a. At first the author tested the fuel sample "A" at lower and higher power to decide which condition gives the worst influence upon the ignition plug.

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TABLE VIII(B)24

Experiment No.	Sample No.	Brake Horsepower	Revolution (RPM)	Boost (mmHg)	Situation of test Front plug	Rear plug
1	A	10	1500	250	Began to misfire after 10 hours and then changed to new plug.	In good condition throughout the test.
2	A	50	2500	150	Began to misfire after 15 hours but did not change plug during the test.	Misfired after 10 hours.
3	B	50	2500	150	Power began to fall after 6 hours and it was necessary to stop the test after 13 hours.	
4	C	50	2500	150	In good condition throughout the test.	
5	D	50	2500	150	Same as Experment No. 4.	

As shown in Table VIII(B)24, in the case of lower power (Experiment No. 1: 250mm boost and 1500 RPM) the front plug which was supposed to be kept at lower temperature than the rear one began to misfire after 10 hours by the contamination with lead deposits but the rear plug which was supposed to be in moderate temperature was in good conditions during the test.

In the case of higher power (Experiment No. 2: 150mm boost and 2500 RPM) both front and rear plug began to misfire after 10-15 hours. From these facts the author supposed that in the former condition the misfiring was not due to the increased contents of tetraethyl lead but perhaps to the lubricating oil as the cylinder was kept at relatively lower temperature, and if the cylinder temperature were kept moderately high it should be free from any contamination throughout the test. Therefore the author decided to examine following fuel samples under conditions of higher power output.

b. The author tested sample "B" in which the content of ethylene dibromide was 1.3 equivalent in order to prevent misfiring of the plug. In this case the engine power began to fall after 6 hours and the test was stopped after 13 hours due to low horsepower. As shown in Table 7, Enclosure B-24, this fuel sample had lower octane number compared with another sample. This was perhaps due to the character of the base gasoline, so that the author used samples "C" and "D" which were prepared to have nearly same octane number.

c. In the test of the sample "C" which contained 1.3 equivalent ethylene dibromide both plugs were in good conditions throughout the test that is, the contamination was small and the center pole of the spark plug was only a little burnt.

d. Then we increased the content of ethylene dibromide to 1.5 equivalent. In sample "D" both plugs were in good condition. that is, there was no perceptible contamination, but the center pole of the plug was considerably burned.

III. CONCLUSION

Although only a few experiments were made and definite conclusions could not be drawn, it could be said at least as follows:

A. Aviation gasoline which contains 0.3% tetraethyl lead does not show the correspondent engine performance with its octane number. For example sample "B" has 91 octane number but it cannot pass the engine endurance test. Our original purpose was to gain such fuels that have 91 octane number and corresponding engine performance with their octane number. Therefore the effort to get new specification by means of enlarging the distillation range of gasoline was negative from the standpoint of the engine performance.

B. Then the first purpose of the test program was changed and only the indluence of ethylene dibromide as an inhibitor was examined by using high octane number fuels which were endurable for long-running engine tests, and having regular specification boiling points, for example, sample "C" and "D". From these results of test, it could be concluded as follows, when tetraethyl lead content was increased from 0.15 vol.% to 0.30%, the suitable equivalent of ethylene dibromide was 1.3.