FD2867,46 IS 12

C.I.O.S. REF. B.24

German Aviation Research Department
Report No. 1406

Influence of sulphur compounds on the anti-knock value and the residue formation of leaded fuel

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Synopsis: In general the addition of lead tetraethyl to fuels causes some reaction, depending on the type of fuel, increasing the anti-knock value. The so-called lead sensitivity depends on the composition of the base fuel and its state of refinement. For straight-run gasolines the lead sensitivity is very high: for cracked gasolines it is comparatively low. The refining is frequently carried out with sulphuric acid: one therefore suspects that the traces of sulphur that are sometimes left may have unfavorable effects. The deliberate addition of sulphur compounds does in fact have a not unappreciable effect.

In the following, the influence of sulphur compounds on the anti-knock value is shown with the aid of experimental results.

Simultaneously we report the experimental results on the gum formation of sulphur-containing leaded gasolines and on the light stability of these fuels.

Index

I. Statement of the problem:

Nowadays almost all aviation fuels are provided with a small addition of lead tetraethyl (maximum amount 0.125% vol.) in order to increase the anti-knock value. This increase depends on the composition of the base fuel, e.g. it is known that fuels containing large amounts of aromatic substances are not as lead sensitive as pure paraffin gasolines.

Since aviation fuels are subjected to a special refining treatment, one should investigate whether traces of sulphur such as might be left by refining agents containing sulphur would effect the anti-knock value.

S.F. Birch and R. Stansfield (1) have carried out experiments in this direction. They found that the lead sensitivity of fuels depends on their degree of purity.

M.S. Kramsky[2] also found that small amounts of sulphur reduce the lead sensitivity, the lead tetraethyl having a very much weaker effect.

It is particularly important to know the degree to which the various sulphur compounds effect the leaded fuels. The influence of lubricating oil containing sulphur has also to be clarified.

At the same time it is proposed to investigate whether gum formation is increased by sulphur compounds in combination with T.E.L. - tetraethyl lead.

Finally it is proposed to investigate the influence of light on the deposit formation of leaded gasolines containing sulphur compounds; the most favorable storage conditions are to be inferred therefrom.

II. Selection of fuels

Fuels were selected so as to provide large differences in composition and hence in octane numbers. The following fuels were used:

1. Gasoline No.1 with octane number 41.5 (base fuel purely paraffinic).
2. Gasoline No.2 with octane number 74.5 (Leuna-hydropetrol)
3. Gasoline No.3 with octane number 64.0 (base fuel naphthalene - Roumanian gasoline)

Another two commercial aviation fuels - B.4 fuels - were employed in the experiments (gasoline Nos. 3 and 4). The analytical data of the five fuels is tabulated in Table 1.

III. Lead sensitivity of fuels and the effect of sulphur compounds on the anti-knock value.

First, the fuels 1 to 3 were examined with respect to their lead sensitivity. For this purpose, various amounts of lead tetraethyl were added to the fuels in the form of ethyl fluid: the octane number was determined in the I.G. test engine. Furthermore, the effect of the sulphur compounds thiophene, carbon disulphide and ethyl mercaptan, on the fuels 1 to 5, was tested.

1. Effect of lead tetraethyl and thiophene on the anti-knock value of fuels.

The gasolines 1, 2, and 3 were mixed with 0.05, 0.1 and 0.15% vol. of ethyl fluid successively, and the anti-knock value of the various fuel samples was determined.

The composition is thus:-

0.05 vol. % ethyl fluid	0.0326 vol. %	$Pb(C_2H_5)_4$
0.10 " " " "	0.0653 " "	"
0.15 " " " "	0.0979 " "	"

The various values of the anti-knock values can be seen from fig. 1 to 3.

The octane number for the highest lead content, i.e. an addition of 0.15 vol. % ethyl fluid gives an octane number of 73.2 for gasoline 1 (without thiophene addition): for gasoline 2 the octane number becomes 91.5, and for gasoline 3, 74.2. It is immediately striking that gasoline 3 is not as lead sensitive as the gasolines 1 and 2. Gasoline 1 is the most sensitive. This lead sensitivity is dependent solely on the composition of the fuels, in which the sulphur present in the base fuel of course plays a considerable part (table 1).

When 0.05% vol. of thiophene is added the octane numbers fall: for gasoline 1 to 70.0, for gasoline 2 to 88.88, and for gasoline 3, with an addition of 0.1% vol. thiophene, to 73.7. Thus we register a diminution of the octane number of 3.2 units for gasoline 1, 2.7 for gasoline 2 and 0.5 with gasoline 3, with double the amount of thiophene. It is thus found that sulphur and lead have opposite effects on the anti-knock value.

If the addition of thiophene is taken still higher a further lowering of the octane number occurs. When 2% of thiophene is added (which does not, however, occur in practice), the octane number for gasoline 1 falls to 56.0, for gasoline 2 to 80.0, and for gasoline 3 to 76.6. Here it is striking that for gasoline 3 the octane number only falls by 3.6 units in spite of the high addition of 2% thiophene. Thus gasoline 3 reacts least both to lead and to sulphur.

2. Effect of lead tetraethyl and carbon disulphide on the anti-knock value of fuels.

Carbon disulphide was now used in place of thiophene. It can be seen from figs. 4 to 6 that here too the anti-knock value decreases. For example gasoline 1 gives the octane number 63.4 with 0.15 vol. % ethyl fluid and 0.10 vol. % carbon disulphide. Under the same conditions the octane number for gasoline 2 becomes 85.8 and for gasoline 3, 72.6. The octane numbers decrease correspondingly as the additions increase. The lowering of the octane number by carbon disulphide is larger than that due to thiophene.

3. Effect of lead tetraethyl and ethyl mercaptan on the anti-knock value of fuels.

Ethyl mercaptan was used as a further sulphur compound. The ethyl mercaptan was added to the various fuels under identical conditions and the anti-knock value was determined.

When 0.1% vol. of ethyl mercaptan is added to gasoline 1 + 0.15% vol. of ethyl fluid, then the octane number falls from 73.2 to

63.8 (fig.7). Under the same conditions gasoline 2 only has an octane number of 84.8 (fig.8) and gasoline 3, the octane number 72.0 (fig.9).

Keeping the proportion of lead tetraethyl constant the octane number of gasoline 1 falls to 43.8 in the presence of 2% vol. of ethyl mercaptan (fig.7), for gasoline 2 it falls to 73.8 (fig.8), and to 64.0 for gasoline 3 (fig.9). Gasoline 1 thus almost reaches the anti-knock value of the base gasoline; for gasoline 2 the anti-knock value is less than that of the base gasoline, and it remains at about the same value as the base gasoline for gasoline 3.

Compared to thiophene and carbon disulphide, ethyl mercaptan has the largest depressing effect on the octane number.

4. Influence of sulphur compounds on highly leaded aviation fuels

The effects of thiophene, carbon disulphide and ethyl mercaptan were tested for two commercial aviation gasolines of octane numbers 90.0 (gasoline 4) and 87.9 (gasoline 5).

The depression of the octane number is about equal for each gasoline for equal additions of the various sulphur compounds.

Here, too, the effect on the two gasolines is least in the case of thiophene and largest for ethyl mercaptan. The octane number of gasoline 4, for example, is 72.8 for a 2% vol. addition of ethyl mercaptan, whereas with 2% vol. of thiophene one still has a value of 82.0. The behaviour of gasoline 5 is quite similar in the presence of sulphur compounds (fig.11).

5. Comparison of the effects of sulphur compounds

On comparing figs. 1 - 7 it becomes quite evident that the various sulphur compounds tested have different effects. The anti-knock value of all the gasolines examined decreases on addition of sulphur compounds, always in the following order :-

1. Thiophene $\begin{matrix} CH = CH \\ \vdots \\ CH = CH \end{matrix} \rangle S$

2. Carbon disulphide (CS_2)

3. Ethyl mercaptan (C_2H_5SH)

The proportion of sulphur in each of these may easily be calculated from the chemical formulae, thus :-

Thiophene contains	38.1% S	
Carbon disulphide	42.1%	(Translators note: this should be 84.2% and thus affects subsequent arguments)
Ethyl mercaptan	51.6%	

Thus it seems that the main factor in the depression of the octane number is the amount of sulphur occurring in the various compounds. This experimental result is confirmed by the work of L.M. Henderson, W.B. Ross and C.M. Ridgway (3). They show by means of practical experiments that gasolines treated with sodium plumbite and sulphur need more tetraethyl lead before attaining a certain octane number than gasolines treated with sodium hydroxide only. The amount of lead tetraethyl required also falls if one interposes an alkali treatment. The lead sensitivity increases with the amount of mercaptan-sulphur removed by the alkali washing.

The following conclusions may be drawn from detailed consideration of the experimental results:

Gasoline 1 with an octane number of 41.5 has the greatest lead sensitivity: an octane number of 73.2 is reached by an addition of 0.15% vol. of ethyl fluid, which is an increase of 31.7 units. Gasoline 2 with the relatively high octane number 74.5 reaches 91.5 for the same leading, thus having risen by 17.0 units. Gasoline 3 with an octane number of 64.0 is least lead sensitive: with an addition of 0.15% vol. of ethyl fluid it rises by only 10.2 units, reaching 74.2. This increase of the octane number is to be regarded as small, particularly for the reason that the lead sensitivity of fuels is generally larger with decreasing octane number of the base gasoline. Accordingly in gasoline 3 which is from Roumania, there must be components present from the start which strongly depress the lead sensitivity. This is actually the case, for on comparing the elementary analyses of gasolines 1 to 3, it is at once striking that the gasoline 3 as such already contains 0.025% by weight of sulphur.

Like the lead sensitivity, the sulphur sensitivity depends on the base gasoline. It is true that the anti-knock value of the unleaded fuels is affected in a different degree to the anti-knock value of leaded fuels. Nevertheless a distinct depression of the octane number is observed, especially when ethyl mercaptan is added (table 2). The sulphur compounds thiophene and carbon disulphide on the other hand do not noticeably favour knocking. Sulphur sensitivity and lead sensitivity are correlated in such a way that high sulphur sensitivity corresponds to high lead sensitivity and conversely. Gasoline 1, for example, whose octane number is raised very considerably when lead tetraethyl is added, has a lower anti-knock value when sulphur is added to the leaded fuel. Gasoline 3 which is only slightly lead sensitive, is affected only slightly by sulphur, especially if the additions are small. Gasoline 2 takes up a middle position between gasolines 1 and 3. The octane number of all leaded fuels may be reduced to nearly the value of the basic gasoline and sometimes even below it by the addition of larger amounts of ethyl mercaptan.

IV. Gum formation of fuels and the influence of sulphur compounds

The gum formation of fuels has particular significance for the operation of an engine, for on this account the piston rings and valves may stick. For this reason a fuel must not yield more than 10 mg/100 cc. residue (gum content), on evaporation.

In this connection we ask ourselves to what extent sulphur compounds play a part in gum formation.

1. Gum content of the unleaded fuels and the effect of sulphur compounds

The effect of sulphur compounds on the residue formation was tested for the basic fuels 1 to 3. The experiments show that gum contents exceeding 10 mg/100 cc. do not occur even for larger additions of sulphur (table 3). This is probably due to the boiling characteristics of the organic sulphur compounds. Thiophene, for example, has a boiling point of 84°C., ethyl mercaptan boils as low as 37°C and carbon disulphide, with 46°C also has a low boiling point. For this reason the sulphur presumably goes off in the vapour phase from the glass dish. One would have to carry out practical experiments in order to ascertain the behaviour of the sulphur compounds in a closed combustion chamber. There do not thus seem to be any chemical reactions at atmospheric pressure.

2. Gum formation of leaded fuels and the influence of sulphur compounds.

Surprisingly, the addition of lead tetraethyl (maximum amount 0.0979% vol. corresponding to 0.15% vol. ethyl fluid) does not produce an appreciable increase of gum formation (table 4), all the gum values ~~lying below 10 mg~~/100 cc. Later experiments, however, show that by storing the leaded fuels, deposits are formed which consist mainly of lead salts. We shall deal with this phenomenon later.

If the leaded fuels are now mixed with the sulphur compounds thiophene, carbon disulphide, and ethyl mercaptan, then there is no increased gum formation here either, as may be seen from tables 5 to 7. These low gum values may again be due to the favourable boiling characteristics of the organic sulphur compounds used.

The gum values were simply obtained by evaporating the fuel in the glass dish under atmospheric pressure. The effect both of the increased pressure and the metals present must be taken into account for the operation of the engine. Chemical reactions may occur here. An instrument is therefore being developed for the determination of the gum content, which would take into account the engine conditions.

3. Estimation of the gum content of fuels in light-metal dishes

To approach the conditions obtaining in the engine in at least one respect, light-metal alloys were employed in place of glass dishes.

These preliminary experiments were carried out with only one highly-leaded B.4 fuel. The gum values entered in tables 8 to 10 were obtained in this way. The gum values are consistently higher than those found for the glass dishes. The effect of the boiling point of the sulphur compounds also becomes of diminishing importance. Thiophene, which boils at 84°C, sometimes shows lower gum values than the leaded gasoline itself (table 8): carbon disulphide, on the other hand, which boils at 46°, consistently gives higher values (table 10). These values indicate that it is the sulphur content of the various compounds that determines the gum formation.

V. Influence of light on the anti-knock value of leaded gasolines containing sulphur

Already during earlier experiments it had been observed that in daylight deposits are formed in leaded fuels which may sometimes cause a considerable lowering of the anti-knock value. It is true that this deposit formation and the lowering of the octane number connected with it do occur on storing in the dark, but only to a slighter extent. This phenomenon depends on the composition of the fuel.

It is striking that deposit formation for leaded gasolines containing sulphur sets in very quickly in daylight, but comes to an end in a short time. This influence of daylight on the anti-knock value was only tested for gasoline 2. 0.1 to 2% vol. of the sulphur compounds mentioned above were added to the gasoline samples, leaded to various degrees (0.05 to 0.15% vol. ethyl fluid). The anti-knock value was measured before and after exposure to light, the tests being carried out for 8 days in daylight. Fig.12 gives the octane numbers before and after exposure, lowering of the octane number always being represented by an area.

✓ Samples with thiophene and ethyl mercaptan additions showed only a slight diminution of the octane number after daylight exposure; samples with additions of carbon disulphide show a quite considerable diminution of the octane number. When, for example, 2% vol. of carbon disulphide was added to a gasoline sample leaded with 0.15% vol. ethyl fluid the octane number was depressed from 77.0 to 70.9. These experimental results, summarized in fig.12, also confirm that the composition of the leaded gasoline is extremely important for the precipitation of the lead and thus for the decrease of the octane no.

VI. Summary

The lead and sulphur sensitivities of fuels of various compositions with respect to knock-rating and residue-formation were investigated. It was found that the sulphur sensitivity as well as the lead sensitivity increase with the purity of the fuel.

The tested sulphur compounds have a very unfavorable effect on leaded fuels, the anti-knock value being not inconsiderably decreased by even small amounts. Of the sulphur compounds selected, viz., thiophene, carbon disulphide, and ethyl mercaptan, ethyl mercaptan has the largest and thiophene the smallest effect. One may infer that what matters is the proportion of sulphur in the various sulphur compounds.

The gum formation of the examined fuels is not affected by the addition of thiophene, carbon disulphide or ethyl mercaptan when the gum content is determined in the glass-dish at atmospheric pressure. Higher contents are always obtained when light-metal dishes are used.

Leaded fuels are light sensitive. This becomes apparent when precipitation of lead salts occurs on illumination, thus lowering the octane number. This light sensitivity depends on the composition of the leaded gasoline. The light sensitivity is raised strongly by the addition of small amounts of carbon disulphide.

Figures

Fig. 1: Influence of thiophene on the anti-knock value of the leaded gasoline 1.
Fig. 2: Influence of thiophene on the anti-knock value of the leaded gasoline 2.
Fig.3 : Influence of thiophene on the anti-knock value of the leaded gasoline 3.
Fig. 4: Influence of carbon disulphide on the anti-knock value of the leaded gasoline 1.
Fig. 5: Influence of carbon disulphide on the anti-knock value of the leaded gasoline 2.
Fig. 6: Influence of carbon disulphide on the anti-knock value of the leaded gasoline 3.
Fig. 7: Influence of ethyl mercaptan on the anti-knock value of the leaded gasoline 1.
Fig. 8: Influence of ethyl mercaptan on the anti-knock value of the leaded gasoline 2.
Fig. 9: Influence of ethyl mercaptan on the anti-knock value of the leaded gasoline 3.

Figs.10 & 11: Influence of sulphur compounds on the anti-knock values of two commercial aviation fuels.

Fig.12: Influence of light on the anti-knock value of leaded gasoline of added sulphur compounds.
The lowering of the octane number after 8 days exposure to light is represented as an area in each case.

References

(1) S.F. Birch and R. Stansfield: Ind. Eng. Chem. 28, 688 (1926)

(2) M.S. Komsky: Petrol. ind. (7) 3844 (1937)

(3) L.M. Henderson, W.B. Ross and C.M. Ridgway: Ind. Eng. Chem. 31, 27-30 (1939).

TABLE I

Physico-chemical properties of the tested fuels

	Gasoline 1	Gasoline 2	Gasoline 3	Gasoline 4	Gasoline 5
	Colourless	Colourless	Yellowish	Coloured blue with a dye	
Water soluble components	0	0	0	0	0
Density @ 20°C g/cm³	0.7111	0.735	0.726	0.7242	0.734
Refractive Index	1.3996	1.4198	1.4093	----	----
Gum content					
@ 110°C mg/100 cm³	4.4	3.9	3.0	4.1	2.4
@ 220°C mg/100 cm³	3.1	1.1	1.5	1.4	1.2
Dimethylsulphate No. + (aromatics and olefines) Vol. %	6.2	12.0	12.8	10.4	13.6
Aniline Point °C	65	49.3	53.5	55.2	52.5
Naphthene content Vol. %	16	61	48	44	50
Initial Boiling Point °C	67	44	40.5	50.0	48.0
Volume distilled					
5% @ °C	81	56	50	64	64
35%	98	104	88	82.5	86
65%	114	135	120	101	105
95%	142	159	169	135	147
Final Boiling Point °C.	155	160.5	179	150	155
Vol.%	97.6	96.5	97	97.5	97.0
Mean Boiling Point	108	124.6	105	93.9	98.4
Elementary Analysis:					
C wt. %	84.7	85.8	85.2	85.9	86.6
H wt. %	15.3	14.1	14.75	14.05	13.3
S wt. %	0.002	0.007	0.025	0.003	0.005

T A B L E 2

Influence of sulphur compounds
on the antiknock value of gasolines 1 to 3

Octane number of base fuels		Octane number on addition of		
		2 vol. % Thiophene	2 vol. % CS_2	2 vol. % ethyl mercaptan
Gasoline 1	41.5	41.5	41.5	38.0
Gasoline 2	74.5	74.5	73.4	69.0
Gasoline 3	64.0	64.0	62.1	57.8

T A B L E 4

Gum content of three different fuels
~~in mg/100 cc. in the presence of lead tetraethyl~~

	Gasoline 1		Gasoline 2		Gasoline 3	
	110°C	220°C	110°C	220°C	110°C	220°C
+ 0 vol. % ethyl fluid	3.7	1.4	0.6	0.2	3.3	0.5
+ 0.05 vol. % ethyl fluid	4.3	4.2	3.4	2.8	7.4	2.2
+ 0.1 vol. % ethyl fluid	3.2	2.7	5.7	5.0	5.8	1.6
+ 0.15 vol. % ethyl fluid	4.3	2.8	4.9	4.4	6.7	2.0

T A B L E 10

Gum content in light metal discs
under the influence of ethyl mercaptan

Alloy Temperature	ECY 110°C	ECY 220°C	EC 124 110°C	EC 124 220°C	EC 138 110°C	EC 138 220°C
	Gum content in mg/100 cm^3					
Leaded gasoline	55.7	24.2	56.5	10.9	56.2	20.2
+ 0.01 vol. % ethyl mercaptan	120.5	68.3	117.0	45.8	110.8	78.4
+ 0.05 vol. % ethyl mercaptan	118.9	70.4	114.5	42.5	114.2	75.3
+ 0.1 vol. % ethyl mercaptan	124.2	72.5	126.8	69.9	119.5	72.3
+ 1.0 vol. % ethyl mercaptan	110.5	49.4	109.2	45.6	111.2	49.6

TABLE 3

Gum content of three different fuels
in mg/100 cc. in the presence of sulphur compounds

	Gasoline 1		Gasoline 2		Gasoline 3	
	110°C	220°C	110°C	220°C	110°C	220°C
+ 0.1 vol. % Thiophene	1.3	1.0	1.4	0.8	6.0	1.0
+ 0.5 " " "	2.6	1.3	1.9	0.3	6.0	1.0
+ 1.0 " " "	1.9	1.0	1.2	0.6	7.0	1.6
+ 2.0 " " "	3.1	1.4	1.7	0.7	4.7	1.0
+ 0.1 vol. % CS_2	2.7	0.7	1.3	0.6	4.5	1.0
+ 0.5 " " "	5.6	1.5	1.2	0.4	4.4	1.3
+ 1.0 " " "	2.6	0.7	1.1	0.2	4.1	1.2
+ 2.0 " " "	3.0	0.9	1.2	0.4	5.1	1.4
Without additive	3.7	1.4	0.6	0.2	3.3	0.5
+ 0.1 vol. % ethyl mercaptan	3.4	2.0	1.2	0.7	6.0	1.2
+ 0.5 vol. % ethyl mercaptan	2.6	1.2	1.0	0.8	7.0	1.2
+ 1.0 vol. % ethyl mercaptan	1.9	0.9	1.9	1.5	5.6	1.2
+ 2.0 vol. % ethyl mercaptan	1.7	0.9	1.9	1.5	7.0	1.2

TABLE 7

Gum content of leaded gasoline (gasoline 3)
in mg/100 cc. in presence of sulphur compounds

	Gasoline 3 + 0.05 vol. % ethyl fluid		Gasoline 3 + 0.1 vol. % ethyl fluid		Gasoline 3 + 0.15 vol. % ethyl fluid	
Vol. % in sulphur compounds	0.1	2.0	0.1	2.0	0.1	2.0
Type of sulphur compounds	Gum content in mg/100 cm^3					
Thiophene @ 110°C	7.4	7.8	7.7	6.6	8.0	10.0
Thiophene @ 220°C	5.5	6.5	1.4	1.7	6.2	6.7
CS_2 @ 110°C	8.7	8.9	5.3	6.5	8.6	11.1
CS_2 @ 220°C	6.5	4.5	1.4	1.2	5.8	6.7
Ethyl mercaptan @ 110°C	5.9	6.7	7.5	7.6	6.6	7.3
Ethyl mercaptan @ 220°C	1.5	1.9	2.8	1.9	1.4	3.0

T A B L E 5

Gum content of leaded gasoline (gasoline 1)
in mg/100 cc. in the presence of sulphur compounds

	Gasoline 1 + 0.05 vol. % ethyl fluid + sulphur compounds						Gasoline 1 + 0.1 vol. % ethyl fluid + sulphur compounds						Gasoline 1 + 0.15 vol. % ethyl fluid + sulphur compounds					
Vol. % in sulphur compounds	0.01	0.05	0.1	0.5	1.0	2.0	0.01	0.05	0.1	0.5	1.0	2.0	0.01	0.05	0.1	0.5	1.0	2.0
Type of sulphur compounds	Gum content in mg/100 cm^3																	
Thiophene @ 110°C	1.5	1.2	1.4	1.2	1.0	1.4	3.1	2.0	2.8	6.6	1.8	3.4	2.6	4.0	4.9	3.4	3.3	3.0
Thiophene @ 220°C	1.2	1.1	1.1	0.4	0.4	0.4	1.5	1.4	0.8	2.2	1.1	2.8	2.3	3.4	3.4	1.6	1.3	1.4
CS_2 @ 110°C	2.1	1.8	1.7	1.6	2.1	2.1	3.9	9.5	7.5	11.3	6.2	5.7	4.3	2.7	5.2	7.3	4.4	4.2
CS_2 @ 220°C	1.1	1.2	0.6	1.1	1.0	1.0	2.2	4.1	4.4	6.3	4.3	3.0	2.2	0.8	3.2	3.4	2.3	1.4
ethyl mercaptan @ 110°C	3.1	2.7	4.0	2.9	2.6	2.1	2.1	2.5	1.4	5.2	6.1	2.3	11.2	7.4	12.2	11.1	6.1	4.4
ethyl mercaptan @ 220°C	2.9	2.6	2.9	2.6	1.9	1.2	1.1	1.9	0.7	3.3	3.5	1.2	7.2	4.6	8.0	6.0	3.0	2.0

T A B L E 6

Gum content of leaded gasoline (gasoline 2)
in mg/100 ccs. in the presence of sulphur compounds

	Gasoline 2 + 0.05 vol. % ethyl fluid						Gasoline 2 + 0.1 vol. % ethyl fluid						Gasoline 2 + 0.15% ethyl fluid					
Vol. % in sulphur compounds	0.01	0.05	0.1	0.5	1.0	2.0	0.01	0.05	0.1	0.5	1.0	2.0	0.01	0.05	0.1	0.5	1.0	2.0
Type of sulphur compounds	Gum content in mg/100 cm^3																	
Thiophene @ 110°C	2.9	2.1	3.0	2.8	2.5	2.0	2.1	1.9	6.9	3.1	2.2	2.7	2.1	3.6	2.0	2.7	1.6	3.7
Thiophene @ 220°C	2.6	1.8	2.7	2.3	2.1	1.6	1.3	1.2	2.7	0.0	0.0	0.1	0.4	1.6	1.2	1.0	0.7	1.7
CS_2 @ 110°C	6.1	10.4	6.3	3.2	2.0	4.1	2.1	2.2	3.2	3.2	1.8	3.8	1.0	2.2	1.5	1.5	2.2	2.5
CS_2 @ 220°C	1.3	1.6	1.4	1.5	1.1	1.4	0.8	1.3	2.0	1.9	1.1	2.6	0.2	0.2	0.3	1.2	0.4	0.9
Ethyl mercaptan @ 110°C	4.2	5.1	5.5	4.6	4.6	2.9	1.9	1.3	5.0	2.0	6.4	8.7	1.1	1.5	2.9	7.2	2.8	2.2
Ethyl mercaptan @ 220°C	2.5	2.9	3.0	4.1	4.1	2.7	0.9	0.8	3.1	0.6	2.5	4.1	0.1	0.6	1.7	2.2	0.8	1.0

T A B L E 8

Gum content in light metal discs under the influence of thiophene

Alloy Temperature	ECY 110°C	 220°C	EC 124 110°C	 220°C	EC 138 110°C	 220°C
	Gum content in mg/100 cm³					
Leaded gasoline	55.7	24.2	56.5	10.9	56.2	20.2
+ 0.01 vol. % thiophene	58.9	40.1	58.5	23.7	55.9	36.3
+ 0.05 vol. % thiophene	34.7	16.3	32.8	7.8	32.5	14.5
+ 0.1 vol. % thiophene	29.7	14.5	29.7	7.0	27.4	11.4
+ 0.5 vol. % thiophene	30.2	14.7	32.0	4.8	32.4	16.4
+ 1.0 vol. % thiophene	34.5	15.2	29.0	8.3	30.6	13.5

T A B L E 9

Gum content in light metal discs under the influence of carbon disulphide

Alloy Temperature	ECY 110°C	 220°C	EC 124 110°C	 220°C	EC 138 110°C	 220°C
	Gum content in mg/100 cm³					
Leaded gasoline	55.7	24.2	56.5	10.9	56.2	20.2
+ 0.01 vol. % CS_2	115.5	49.7	105.5	21.1	101.0	52.0
+ 0.05 vol. % CS_2	116.5	50.2	105.7	18.7	99.1	52.0
+ 0.1 vol. % CS_2	111.3	39.2	108.3	23.7	100.4	51.4
+ 0.5 vol. % CS_2	102.4	45.8	107.3	19.4	107.9	54.1
+ 1.0 vol. % CS_2	63.0	26.1	64.9	13.4	61.5	21.3