Serial No. 2908,
January, 1929.

REPORTS OF INVESTIGATIONS

DEPARTMENT OF COMMERCE--BUREAU OF MINES

CARBON MONOXIDE FROM AUTOMOBILES USING ETHYL GASOLINE [1]

By W. P. Yant[2] and L. B. Berger[3]

PURPOSE OF INVESTIGATION

Public interest in atmospheric pollution by automobile exhaust gas and in the ventilation of vehicular tunnels makes it desirable to ascertain whether the use of modern automobile fuels is tending to change the amount and composition of the products of combustion. The Bureau of Mines, in cooperation with the Ethyl Gasoline Corporation[4], has completed a series of tests to determine whether any significant difference exists in the carbon monoxide content of the exhaust gas produced by an internal-combustion engine when its fuel is changed from straight gasoline to the same gasoline containing Ethyl fluid whose active ingredient is tetraethyl lead.

In the tests data was sought relative to the composition and amount of the gas produced by ordinary comparatively low-compression motors as well as by higher-compression motors in which distinct detonation occurred with straight gasoline, but which operated without detonation when using the same gasoline containing tetraethyl lead.

DESCRIPTION OF TEST EQUIPMENT

The engine used was a four-cylinder Lycoming, model DXU, of the L-head type, having a 3 1/2-inch bore and 5-inch stroke. A Schebler carburetor was used on all tests; the needle-valve arrangement was altered somewhat to prevent changes in adjustment during tests. The engine was direct-connected to a Sprague electric dynamometer equipped with a tachometer. A revolution counter was used in conjunction with the latter to obtain the average number of revolutions per minute.

1 The Bureau of Mines will welcome reprinting of this article, but requests that the following footnote acknowledgment be used: "Printed by permission of the Director, U. S. Bureau of Mines. (Not subject to copyright.)"
2 Supervising chemist, health laboratory section, Pittsburgh Experiment Station.
3 Laboratory assistant, health laboratory section, Pittsburgh Experiment Station.
4 For an investigation of Ethyl gasoline, see "Experimental Studies on the Effect of Ethyl Gasoline and its Combustion Products," a report of the U. S. Bureau of Mines to the General Motors Research Corporation and Ethyl Gasoline Corporation, by R. R. Sayers, A. C. Fieldner, W. P. Yand, and B. G. H. Thomas, 1927, 447 pp.

For the first series of tests the standard engine head was planed down three thirty-seconds of an inch to increase compression and promote detonation. With this head in place a gauge attached to one of the priming cocks showed a pressure of approximately 95 pounds per square inch when the engine was turned over at 600 revolutions per minute, at normal operating temperature and with the throttle fully opened.

The gasoline used for these tests was all taken from the same refinery run to insure similar composition and characteristics. One portion was used as received from the refinery; to a second portion, Ethyl fluid in the proportion of 2 1/4 c.c. of tetraethyl lead per gallon was added (this represented the antiknock value of standard Ethyl gasoline as marketed); to a third portion was added Ethyl fluid in the proportion of 3 c. c. of tetraethyl lead per gallon.

The gasoline was fed to the carburetor from two large glass flasks mounted on a platform balance so arranged that the amount consumed in each test was determined by difference in weight. One of the flasks contained straight gasoline and the other Ethyl gasoline, either of which could be supplied to the carburetor through an arrangement of valves.

Samples of the exhaust gas were taken through a copper tube inserted in the wall of the exhaust pipe at a point about 2 1/2 feet from the engine; the entering end of the tube bent forward toward the flow of exhaust gas, to give a positive pressure equivalent to 2 or 3 inches of water in the sampling tube.

METHOD OF CONDUCTING TESTS

In conducting the tests the engine was first warmed up to the operating temperature (usually 150°F.). Then, while running on straight gasoline, the carburetor was adjusted to give the desired air-fuel mixture, which was controlled by determining the carbon dioxide content of the exhaust gas. All tests and preliminary carburetor adjustments were made with the engine running at a speed of 1,000 revolutions per minute. Two pounds of each type of gasoline was used on each test, and during the time required to consume that weight of gasoline an average sample of the exhaust gas was taken for complete analysis.

Tests, run in the manner described, were made first on straight gasoline, then on gasoline containing the 3 c. c. of tetraethyl lead per gallon, then on the standard Ethyl gasoline, and again on straight gasoline as a check on the carburetor adjustment during the series of tests. The change from one type of gasoline to another was made without stopping the engine or in any other way altering the conditions of operation. Sufficient time elapsed after a change of gasoline supply to allow the gasoline line and carburetor to become clear of fuel from the preceding test.

Such a series of tests was made with the engine operating at full load, at a rich carburetor adjustment (6.5 per cent CO_2; air-fuel ratio approximately 9.5 to 1), a medium adjustment (9.5 per cent CO_2; air-fuel ratio approximately 11.7 to 1), and a fairly lean adjustment (12.5 per cent CO_2; air-fuel ratio approximately 13.1 to 1). A similar series of tests was made at three-quarter load.

The gas samples collected for complete analysis were analyzed on the mercury type of Orsat gas-analysis apparatus. The carbon monoxide was determined by absorption in cuprous chloride, two pipettes of this solution being used in series, and the solution was renewed at frequent intervals to assure complete absorption.

No attempt was made in this work to measure or differentiate between degrees of detonation. It was noted merely whether detonation was audible or not while the engine was operating on the straight gasoline.

RESULTS OF FIRST SERIES OF TESTS

Table 1 gives details of the results obtained with the engine operating under the aforementioned conditions. It will be noted that upon changing from one type of gasoline to another during any particular test, the maximum variation in carbon monoxide content of the exhaust gas did not exceed 0.2 (which is the possible error of the analytical method used); neither did the content of any other constituent of the exhaust gas show significant variation according to the type of fuel used. In some instances there was a small difference in the gasoline consumed per unit of time as well as in the brake horsepower developed. However, the amount of carbon monoxide per horsepower hour, as given in the last column of the table, bears out the same statement as given for variations in composition of exhaust gas--namely, that with few exceptions the relatively small differences found were independent of the type of fuel.

CHANGES IN METHOD OF ENGINE OPERATION FOR SECOND SERIES OF TESTS

At the completion of this first series of tests the engine head was planed down an additional sixteenth of an inch - in all five thirty-seconds of an inch, was removed from the standard head. With a gauge attached to this head, as previously described, a pressure of 105 to 110 pounds per square inch was indicated. An electric heater was attached to the secondary air inlet of the carburetor, and the air admitted was heated to approximately 195°F. The engine was operated on succeeding tests with a cooling water temperature of 170°F. as compared to 150°F. on the previous tests. These temperature alterations in the test conditions for the second series of tests were made with a view to increasing detonation.

Table 1.- Results of first series of tests, with Nos. 1 to 3, inclusive, at full load; and Nos. 4 to 6, inclusive, at three-quarters load; 2 pounds of gasoline used for each test.

1	2	3	4	5	6	7						8	9	10
Test No.	Type of gasoline used	Period of test, min.	Aver. rev. per min.	Brake horsepower	Aver. temp. cooling water, °F.	Analysis of exhaust gas (per cent by volume)						Lb. of air per lb. of fuel	Cu. ft. of CO per hp.-hr.	Remarks
						CO_2	O_2	CO	H_2	CH_4	N_2			
1	Straight	5.93	1016	19.8	149	6.7	0.2	12.8	7.3	0.3	72.7	9.4-1	17.7	No detonation audible.
	Extra Ethyl[1]	6.00	1014	19.8	150	6.7	.3	12.7	7.3	.4	72.6	9.4-1	17.3	Do.
	Std. Ethyl [2]	5.90	1015	19.8	149	6.7	.2	12.8	7.3	.4	72.6	9.4-1	17.6	Do.
	Straight	5.87	1019	19.8	148	6.7	.2	12.9	7.3	.4	72.5	9.3-1	17.8	Do.
2	Straight	7.28	1007	20.7	148	9.8	.2	6.8	3.7	.3	79.2	12.0-1	8.6	Detonation audible.
	Extra Ethyl[1]	7.30	1010	20.8	149	9.8	.2	7.0	3.8	.4	78.8	11.8-1	8.6	No detonation audible.
	Std. Ethyl [2]	7.32	1010	20.8	147	9.8	.2	7.0	3.9	.3	78.8	11.8-1	8.5	Do.
	Straight	7.45	995	20.5	148	9.7	.2	7.2	3.9	.4	78.6	11.7-1	8.7	Detonation audible.
3	Straight	8.75	984	19.8	153	12.6	.2	3.1	1.4	.2	82.5	13.1-1	3.6	Do.
	Extra Ethyl[1]	8.73	987	20.2	150	12.6	.2	3.2	1.5	.3	82.2	13.1-1	3.6	No detonation audible.
	Std. Ethyl [2]	8.73	990	20.3	148	12.6	.1	3.3	1.3	.3	82.4	12.9-1	3.7	Do.
	Straight	8.82	998	19.9	151	12.7	.1	3.0	1.5	.3	82.4	13.2-1	3.4	Detonation audible.
4	Straight	7.68	981	15.3	147	6.7	.2	12.9	7.3	.4	72.5	9.3-1	17.6	No detonation audible.
	Extra Ethyl[1]	7.62	992	15.4	149	6.8	.2	12.8	7.5	.3	72.4	9.3-1	17.6	Do.
	Std. Ethyl [2]	8.00	989	15.4	149	6.7	.2	12.7	7.4	.4	72.6	9.4-1	16.7	Do.
	Straight	7.75	998	15.4	149	6.8	.3	12.5	7.3	.4	72.6	9.4-1	17.1	Do.
5	Straight	9.02	1000	15.9	150	9.5	.3	7.1	3.7	.3	79.1	12.0-1	9.4	Do.
	Extra Ethyl[1]	9.03	999	15.9	147	9.7	.3	6.9	3.8	.3	79.0	12.0-1	9.1	Do.
	Std. Ethyl [2]	9.00	1001	16.0	148	9.6	.1	7.0	3.9	.4	79.0	11.9-1	9.2	Do.
	Straight	9.00	1006	16.0	149	9.5	.2	7.1	3.9	.4	78.9	11.9-1	9.3	Do.
6	Straight	10.90	997	16.2	151	12.8	.2	3.1	1.0	.3	82.6	13.1-1	3.5	Do.
	Extra Ethyl[1]	10.78	1005	16.3	150	12.9	.2	3.0	.8	.4	82.7	13.0-1	3.4	Do.
	Std. Ethyl [2]	10.92	999	16.2	148	12.9	.2	3.1	1.0	.2	82.6	13.1-1	3.5	Do.
	Straight	10.90	998	16.3	150	13.0	.2	3.2	.8	.3	82.5	12.9-1	3.5	Do.

1 Contained 3.0 c.c. tetraethyl lead per gallon of gasoline.
2 Contained 2.25 c.c. tetraethyl lead per gallon of gasoline.

RESULTS OF SECOND SERIES OF TESTS

Table 2 gives details of the results obtained when operating the engine under the conditions described. They are in accordance with those obtained in the first series of tests. No significant variation in the composition of the exhaust gas nor in the amount of carbon monoxide per horsepower hour was found upon changing from straight gasoline to Ethyl gasoline.

Tests were made at full load only, as audible detonation did not occur at three-quarters load with any carburetor adjustment.

THIRD SERIES OF TESTS

While ascending grades, automobile drivers generally retard the spark to decrease the detonation caused by the use of straight gasoline; as this practice is unnecessary when Ethyl gasoline is used, a third series of tests was conducted with a view to simulating these conditions. In other words, tests were made at full load, using straight gasoline, with the spark retarded to a degree which caused audible detonation to cease; then, as in previous tests, the fuel was changed to Ethyl gasoline and the spark advanced to the point where maximum power was developed. With the exception of the changes in spark timing, these tests were conducted in the same manner as those previously described. The engine head used was that which gave the highest compression pressure (105 to 110 pounds gauge pressure per square inch), the intake air was not preheated, and the cooling water temperature was maintained at 150°F. Table 3 gives the results of these tests.

Table 3 shows that, as in the previous tests, no significant change occurred in the composition of the exhaust gas upon changing the fuel from straight gasoline to Ethyl gasoline. However, the amount of carbon monoxide produced per horsepower hour was approximately 5 to 7 per cent less when operating on Ethyl gasoline than when using straight gasoline.

Table 2.- Results of second series of tests, all at full load and using 2 pounds of gasoline per test

1	2	3	4	5	6	7						8	9	10
Test No.	Type of gasoline used	Period of test min.	Aver. rev. per min.	Brake horse power	Aver. temp. cooling water, °F.	Analysis of exhaust gas (per cent by volume)						Lb. of air per lb. of fuel	Cu. ft. of CO per hp.-hr.	Remarks
						CO_2	O_2	CO	H_2	CH_4	N_2			
7	Straight	6.20	1017	19.7	166	6.6	0.1	12.5	7.4	0.4	73.0	9.6-1	16.8	No detonation audible
	Extra Ethyl[1]	6.10	1009	19.5	165	6.5	.1	12.4	7.8	.4	72.8	9.7-1	17.3	Do.
	Std. Ethyl [2]	6.05	1010	19.6	169	6.5	.1	12.5	7.8	.4	72.7	9.6-1	17.4	Do.
	Straight	6.10	1010	19.6	167	6.5	.1	12.6	7.8	.4	72.6	9.6-1	17.1	Do.
8	Straight	7.28	1020	20.3	170	9.2	.1	8.3	3.4	.4	78.6	11.3-1	10.1	Detonation audible.
	Extra Ethyl[1]	7.28	1019	20.8	169	9.4	.1	8.1	3.6	.3	78.5	11.3-1	9.7	No detonation audible.
	Std. Ethyl [2]	7.32	1011	20.7	167	9.4	.1	8.4	3.3	.4	78.4	11.1-1	9.8	Do.
	Straight	7.35	1013	20.2	167	9.4	.1	8.2	3.3	.4	78.6	11.2-1	9.9	Detonation audible.
9	Straight	9.33	1023	19.7	167	13.0	.1	3.0	0.9	.2	82.8	13.1-1	3.2	Detonation audible
	Extra Ethyl[1]	9.05	1008	20.4	167	12.8	.1	2.8	1.0	.1	83.2	13.6-1	3.1	No detonation audible.
	Std. Ethyl [2]	9.05	1007	20.4	167	12.9	.1	3.1	0.8	.2	82.9	13.1-1	3.3	Do.
	Straight	9.13	1004	19.3	169	12.7	.1	3.4	1.2	.2	82.4	13.0-1	3.8	Detonation audible.

1 Contained 3.0 c.c. tetraethyl lead per gallon of gasoline.
2 Contained 2.25 c.c. tetraethyl lead per gallon of gasoline.

Table 3.- Results of third series of tests, all at full load and using 2 pounds of gasoline per test

1	2	3	4	5	6	7						8	9	10
Test No.	Type of gasoline used	Period of test, min.	Aver. rev. per min.	Brake horse power	Aver. temp. cooling water °F.	Analysis of exhaust gas (per cent by volume)						Lb. of air per lb. of fuel	Cu. ft. of CO per hp-hr.	Remarks
						CO_2	O_2	CO	H_2	CH_4	N_2			
10	Straight	5.85	1022	20.1	153	7.0	0.1	12.3	7.0	0.5	73.1	9.5-1	17.0	Spark retarded until audible detonation ceased.
	Extra Ethyl [1]	5.92	1012	21.4	153	6.9	.0	12.4	7.5	.5	72.7	9.4-1	15.9	Spark advanced until maximum power was developed. No detonation audible.
	Std. Ethyl [2]	5.88	1020	21.5	154	6.7	.1	12.4	7.6	.5	72.7	9.5-1	15.9	Do.
	Straight	5.90	1015	20.3	150	6.9	.0	12.3	7.5	.5	72.8	9.5-1	16.7	Spark retarded until audible detonation ceased.
11	Straight	7.03	1022	21.1	149	9.3	.0	7.2	4.2	.3	79.0	12.1-1	9.3	Do.
	Extra Ethyl [1]	7.07	1025	21.5	153	9.4	.0	7.0	4.0	.3	79.3	12.2-1	8.9	Spark advanced until maximum power was developed. No detonation audible.
	Std. Ethyl [2]	7.07	1022	21.5	151	9.3	.0	7.0	4.2	.4	79.1	12.2-1	8.8	Do.
	Straight	7.03	1024	21.1	153	9.4	.0	7.2	4.2	.3	78.9	12.0-1	9.2	Spark retarded until audible detonation ceased.
12	Straight	8.87	991	20.0	154	12.6	.0	3.7	1.2	.3	82.2	12.7-1	4.0	Do.
	Extra Ethyl [1]	8.67	985	21.0	153	12.2	.1	3.4	1.5	.3	82.5	13.3-1	3.8	Spark advanced until maximum power was developed. No detonation audible.
	Std. Ethyl [2]	8.68	988	21.1	154	12.3	.0	3.6	1.5	.2	82.4	13.2-1	3.9	Do.
	Straight	8.72	984	19.9	153	12.3	.1	3.4	1.5	.2	82.5	13.3-1	4.0	Spark retarded until audible detonation ceased.

1 Contained 3.0 c.c. tetraethyl lead per gallon of gasoline.
2 Contained 2.25 c.c. tetraethyl lead per gallon of gasoline.

SUMMARY OF INVESTIGATION

When the engine was operated at a fixed adjustment and under the conditions described in this report, no significant change was found in the carbon monoxide content, nor in the content of any other constituent of the exhaust gas, upon changing the fuel supply of the engine from straight gasoline to gasoline containing tetraethyl lead (Ethyl gasoline). This was true of both the tests in which a detonation was evident and those in which no detonation was audible. Also, no significant difference in the amount of carbon monoxide per horsepower hour was noted.

However, if the spark was retarded to alleviate detonation during operation on straight gasoline the amount of carbon monoxide per horsepower hour was approximately 5 to 7 per cent less for ethyl gasoline than for straight gasoline.

As to the effect of Ethyl gasoline on health and safety the amounts of carbon monoxide produced by the engine, under any comparable operating condition, were the same for Ethyl gasoline and straight gasoline.

* * * * * * *