UNIVERSITY OF IDAHO
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Alcohol-Gasoline Engine Fuels

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ALCOHOL is the name applied to a class of substances comprised of several types; each type, in turn, is made up of many members. The type of alcohol to which methyl and ethyl alcohol belong is of chief agricultural importance and is known as "monohydroxy saturated alcohol." This type is closely related to the paraffin hydrocarbons which are contained in natural gas and gasoline. The general chemical formulas of a few of these alcohols and the corresponding hydrocarbons with their boiling points are listed in Table I.

TABLE I

Alcohol General Formula $C_nH_{2n+1}OH$			Corresponding Hydrocarbon C_nH_{2n+2}		
Name	Formula	Boiling Point	Name	Formula	Boiling Point
Methyl or Wood Alcohol	CH_3OH	66.0° C.	Methane	CH_4	-164.7° C.
Ethyl or Grain Alcohol	C_2H_5OH	78.4° C.	Ethane	C_2H_6	-86.0° C.
Propyl Alcohol	C_3H_7OH	97.4° C.	Propane	C_3H_8	-38.0° C.
Butyl Alcohol	C_4H_9OH	117.0° C.	Butane	C_4H_{10}	+1.0° C.
Amyl Alcohol	$C_5H_{11}OH$	137.8° C.	Pentane	C_5H_{12}	+37.0° C.

Ethyl or grain alcohol is the easiest alcohol to produce from agricultural products. It may be produced from sugar or substances that may be converted into sugar through the action of yeast in water solution. It is produced from starch by treating the latter with diastase which occurs in sprouted grains or in certain fungus growths and which converts the starch into sugar. Separation of the alcohol from the water is effected by distillation, by means of which it may be purified 95 per cent. Chemical processes must be used in order to completely purify the product. It is then known as absolute alcohol.* The three latter alcohols mentioned above are produced from agricultural products in a similar manner, but the process is more difficult to control and the cost therefore somewhat higher.

Uses of Alcohol

Ethyl alcohol has many uses. In general these may be classified under three headings.

* For a detailed description on the production of alcohol the reader is referred to "Industrial Alcohol" by Herrick, John Wiley & Sons.

1. Fuel.
2. Raw material for the production of other materials.
3. Solvent for manufacturing processes.

Alcohol may be used as a fuel for internal combustion engines, lamps, and heaters of various kinds. It burns with an absolutely smokeless and odorless flame and therefore is prized as a fuel for mantle lamps, since no blackening of the mantle will occur. According to authorities on the subject of illumination, 1 gallon of alcohol when burned in a Welbach mantle will generate as much light as 3½ gallons of kerosene.* It may also be used to advantage in kitchen stoves where the smoke and odor from kerosene is objectionable. The use of alcohol for fuel purposes therefore need not be limited to internal combustion engines.

Alcohol is also an important raw material. The production of many commodities begins with ethyl alcohol. Some of these materials and their uses are as follows:

Substance	*Use*
Ether	Anaesthetic, solvent, fuel.
Ethylene Glycol	Solvent, antifreeze.
Ethyl Bromide	Refrigerant, raw material for production of other materials.
Butyl Acetate	Solvent for nitrocellulose, flavors.
Cellulose Acetate	Rayon, non-flammable photographic films and motion picture films, lacquers, varnishes, non-shatterable glass.
Chloral Hydrate	Raw material for the production of other materials, medicine.
Chloracetic Acid	Raw material, manufacture of indigo, medicine.
Dichloraethyl Ether	Solvent, degreasing textiles, raw material.
Diethyl Sulphate	Raw material, ethylating agent.
Ethyl Acetate	Solvent, flavors, lacquers.
Ethyl Acetoacetate	Solvent, flavors, pyrazolone dye, synthesis.
Ethyl Bromide	Raw material, refrigerant.
Ethyl Butyrate	Solvent, flavors.
Ethyl Chloride	Anaesthetic, refrigeration, organic synthesis, lead tetraethyl.
Ethyl Dichloride	Solvent, fumigant.
Ethylene Dinitrate	Low freezing dynamite.
Butyl Cellosolve	Solvent for nitrocellulose gums and resins.
Cellosolve	Solvent, dye, penetrant.
Cellosolve Acetate	Lacquers, nitrocellulose solvent.
Ethylene Oxide	Raw material, fumigant.
Ethyl Lactate	Solvent.
Ceresin	Fungicide.
Ethyl Nitrate	Medicine, solvent, raw material.
Potassium Xanthate	Flotation of ores.

Alcohol is used as a solvent in the production of over 90 materials. This number could, no doubt, be increased by mak-

* Manual of Industrial Chemistry by Rogers, Page 1144, D. Van Nostrand & Company.

ing it available at lower cost through efficient methods of production at our disposal. Ethyl alcohol may be produced from sugar or from substances that may be converted into sugar, such as starch. Potatoes, sugar beets, fruits, cereals, and sugar cane molasses may be used for this purpose.

Relative to the question of raw materials Dr. Henry Arnstein, consulting chemist of Philadelphia, says in part:

"The purest alcohol obtained from any raw material is that obtained out of potatoes, and a large number of distilleries (over 35,000 of which are now in actual operation in Germany) are primarily using potatoes as a raw material.

"Alcohol produced out of grain is always purer and commands higher prices than alcohol obtained out of molasses. Furthermore, by the use of cereals or potatoes one recovers about 20 per cent of the raw material in the form of a valuable cattle feed, and if one is to go into the recovery of by-products, we shall find that bakers' yeast obtained from potatoes is incomparably superior to a yeast obtained from molasses."

Use of Alcohol With Gasoline As Engine Fuel

The blending of alcohol with gasoline was brought to the attention of the American public by the low prices prevailing for agricultural products. The use of alcohol as engine fuel and for other purposes would be an important factor in increasing the demand for agricultural products, thereby increasing the price.

Owing to the large number of units of production in agriculture, it has been very difficult to concentrate on the development of new outlets. The profitable utilization of the apparent surplus and waste agricultural products is the concern of the research workers in the Idaho Agricultural and Engineering Experiment Stations.

The work on the use of alcohol at the Idaho Agricultural Experiment Station was begun early in 1932. The purpose was to find a market for waste and inferior agricultural products other than the food market, with the idea in view that if these were removed the better grade of products would command a higher price. The use of alcohol as engine fuel offered an immediate outlet. The Purnell project approved early in 1933 had as its objective the comparison of gasoline and gasoline-alcohol mixtures and the determination of changes that would be necessary in the present engine to give best performance on the mixture of the two fuels. That the present internal combustion engine offered to the American public, as designed for gasoline, should give the best possible performance with an alcohol mixture was more than could be expected. The study also included a survey of practices in foreign countries relative to the use and production of alcohol and its by-products.

Alcohol may be used as fuel in internal combustion engines either in the pure state or in conjunction with petroleum fuels, such as gasoline.

Anhydrous or absolute ethyl alcohol will mix with gasoline in all proportions. Commercial alcohol (alcohol of 95 per cent purity) will not mix with gasoline unless it constitutes at least 50 per cent of the mixture. It can be made to blend with gasoline in any proportion by adding blending agents. The higher alcohols mentioned above are excellent blending agents, but rather large amounts are required if the stability of the mixture at low temperatures is to be maintained. At the present time these are rather expensive. It is also possible to combine commercial alcohol with gasoline by using a double bowl carburetor with the bowls connected to separate fuel tanks. The three methods of using alcohol with gasoline as engine fuel are:

1. By blending absolute ethyl alcohol with gasoline.

2. By blending commercial ethyl alcohol with gasoline through the use of blending agents, such as propyl, butyl, and amyl alcohols, benzol, or acetone.

3. By using a double bowl carburetor and mixing the two fuels in the vapor phase.

The first of these is used extensively in Europe, especially in Germany, Sweden, and Czechoslavakia. It is the type of blend which has been advocated in the United States and has been subjected to wide discussion. Among other objections, opponents of its use in that way have contended that the alcohol will separate from gasoline when small amounts of water are added and that the mixture does not perform very well.

It is not generally pointed out by opponents of the idea that the design of the engine has a great deal to do with its performance when a given fuel is used. Usually the higher the compression ratio, the greater is the efficiency. On the other hand, if the compression ratio is too high, detonation (knocking) will occur which will cause the engine to overheat and even stop, and will also be very harmful to the engine. The maximum permissible compression ratio is determined by the character of the fuel. Gasoline may be treated with various materials to suppress the detonating tendency. This treatment makes possible its use with higher compression engines and consequently with greater efficiency.

The detonating tendency of any fuel is designated in terms of octane number. The fuel offered to the public as ethyl gasoline is treated with tetraethyl lead, which raises the octane rating of the fuel and therefore permits its use with higher compression engines. Ethyl gasoline can be used in higher compression engines to advantage, but is not advantageous in low compression engines. When added to gasoline, alcohol will raise the octane rating of the fuel. Its use with higher compression ratios shows a corresponding improvement in efficiency. A mixture containing 10 per cent absolute alcohol and 90 per cent gasoline has an octane value between that of ordinary gasoline and the standard ethyl gasoline.

Commercial ethyl alcohol will not mix with gasoline in proportions less than 50 per cent due to the 5 per cent water it contains. This water, however, is an advantage after the blending difficulty is surmounted. The presence of moisture in the fuel charge suppresses the detonating tendency of the fuel, thereby bringing about superior performance. This probably accounts for the popular belief that an engine runs smoother at night than during the day. This is due to the higher relative humidity of the atmosphere. Fuels that detonate violently in a very dry atmosphere do not detonate in a moist atmosphere. For that reason the water in the commercial alcohol has a tremendous effect in raising the octane number of a fuel.

The three methods of using ethyl alcohol referred to above have been tested by the Department of Agricultural Engineering at the University of Idaho, on the road and in the laboratory.

The laboratory equipment consisted of a 30-horsepower direct current generator, control panel, direct reading wattmeter, and a bank of resistances. The generator was connected with the engine through the transmission. The efficiency curve of the generator was not available; consequently the results are given on a comparative basis. The test unit is shown in Figure 1.

A 1931 Model A engine and a 1934 Model V-8 Ford engine were used with the above dynamometer. The Model A engine was tested with cylinder heads giving compression ratios of 5.1:1 and 5.5:1. The V-8 engine was tested with aluminum heads giving a compression ratio of 6.35:1 and with cast-iron heads giving compression ratios of 5.5:1. Tests were also made with the 1933 carburetor in addition to the 1934 carburetor and intake manifold.

The results of the laboratory tests with the Model A Ford engine are given in Table II.

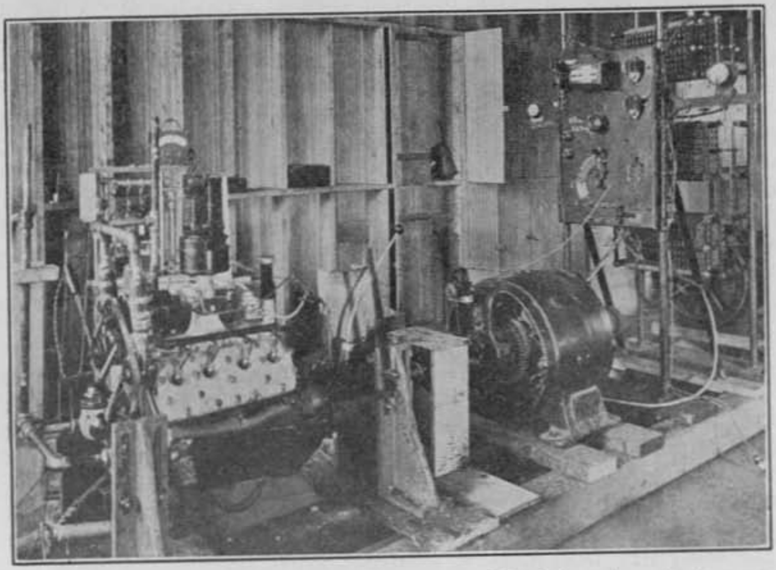


Fig. 1.—Engine and dynamometer used in laboratory tests.

A blend of 10 per cent absolute alcohol and 90 per cent gasoline gave performance practically identical with gasoline. It did not, however, knock at the heavier loads as did gasoline. The performance of gasoline is given in several of the tests that follow. The data for the gasoline for the 5.5:1 compression ratio are given in Table II under Tests 12, 13, and 14, and that for the 5.1:1 compression ratio under Tests 44, 45, 46, and 47. The data for the blend referred to above are given under Tests 18, 19, and 20.

In the blend containing 20 per cent commercial alcohol the performance of the gasoline was superior at the loads less than five horsepower, while at the higher loads the reverse was true.* The performance of the two fuels at the two compression ratios is shown graphically in Figure 2. The data for the blend are given in the table under Tests 15, 16, and 17 for the 5.5:1 compression ratio and under Tests 48, 49, and 50 for the 5.1:1 compression ratio.

The carburetor on the same engine was modified, as is shown in Figure 3, in order to burn a lower purity of alcohol

* The blend used in these tests was developed in cooperation with Professor R. S. Snyder of the Department of Agricultural Chemistry, and Mr. Otto Turinsky of the Department of Organic Chemistry.

by drawing it from a separate tank. Carburetors of this type are in use in Germany. Such an arrangement permits the engine to idle and run on light loads with gasoline, and as the load increases, alcohol is fed with the gasoline.

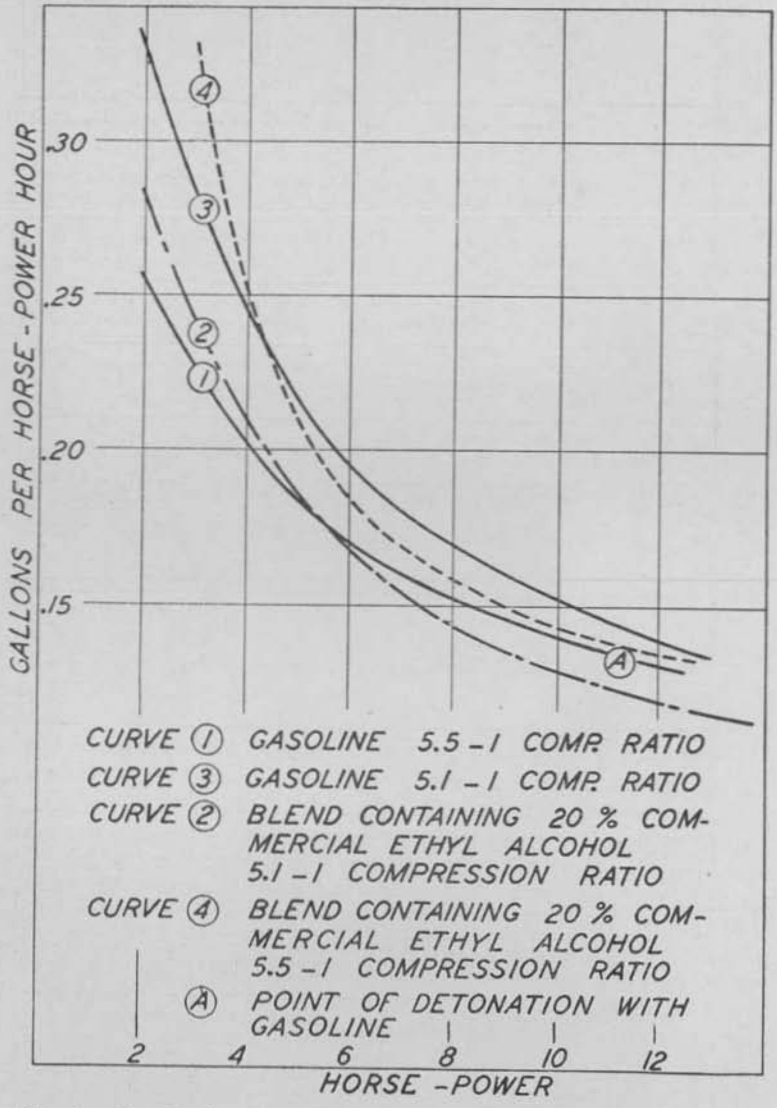


Fig. 2.—Graph showing relationship between load and fuel consumption in gallons per horsepower hour.

TABLE II

Test No.	Load In Horse-power	Engine Speed	Radiator Temperature In Degrees Fahrenheit	Gallons Per Horse-power Hour	Alcohol Per Cent	Purity of Alcohol Per Cent	Type of Fuel	CO_2 Per Cent	O_2 Per Cent	CO Per Cent	Compression Ratio	Remarks
3	3.300	805	187.0	0.2475	18.10	95	Dual	8.0	6.4	......	5.5 to 1	Auxiliary jet open one-half turn
4	7.600	820	188.8	0.1720	13.20	95	Dual	9.4	3.1	......	5.5 to 1	
5	7.400	820	188.8	0.1570	18.10	95	Dual	10.9	3.5	......	5.5 to 1	
6	3.900	807	192.5	0.2010	31.40	95	Dual	8.5	7.5	......	5.5 to 1	
7	2.350	790	181.3	0.2740	3.85	95	Dual	8.0	6.9	......	5.5 to 1	
8	8.150	840	181.3	0.1490	4.53	95	Dual	11.2	4.1	......	5.5 to 1	
9	4.250	840	185.0	0.1910	10.50	95	Dual	9.3	7.0	......	5.5 to 1	
10	7.950	815	185.0	0.1400	11.90	95	Dual	10.9	3.8	......	5.5 to 1	
11	13.400	1000	165.2	0.1270	9.90	95	Dual	11.3	3.9	......	5.5 to 1	
12	4.350	803	185.0	0.1965	....	......	Gasoline	7.6	6.4	......	5.5 to 1	
13	7.800	820	188.8	0.1535	....	......	Gasoline	10.5	3.6	......	5.5 to 1	
14	10.920	800	181.3	0.1340	....	......	Gasoline	11.6	3.1	......	5.5 to 1	
15	3.900	795	174.5	0.2100	2.00	95	*Blend No. 1	8.4	8.5	......	5.5 to 1	
16	6.700	820	192.5	0.1620	20.00	95	Blend No. 1	10.4	4.6	......	5.5 to 1	Incipient knocking
17	12.330	900	170.5	0.1180	20.00	95	Blend No. 1	11.5	4.6	......	5.5 to 1	Violent knocking
18	4.025	803	176.0	0.2130	10.00	Absolute	†Blend No. 2	8.2	7.8	......	5.5 to 1	
19	10.550	1000	176.0	0.1355	10.00	Absolute	Blend No. 2	10.8	4.8	......	5.5 to 1	
20	8.000	825	176.0	0.1550	10.00	Absolute	Blend No. 2	....	......	......	5.5 to 1	
21	3.500	840	177.8	0.2220	6.10	90	Dual	8.0	7.6	1.0	5.5 to 1	
22	6.350	950	177.8	0.1800	6.10	90	Dual	9.4	4.6	1.2	5.5 to 1	
23	9.200	....	189.6	0.1570	7.80	90	Dual	10.5	4.5	1.2	5.5 to 1	
24	6.520	840	194.0	0.1790	9.10	85	Dual	9.4	4.8	1.8	5.5 to 1	
25	2.960	810	194.0	0.2580	11.30	85	Dual	8.0	7.3	1.3	5.5 to 1	
26	10.100	900	179.6	0.1755	6.80	85	Dual	10.8	3.9	1.1	5.5 to 1	
27	4.275	840	185.0	0.1900	9.10	90	Dual	8.7	7.8	0.0	5.5 to 1	

TABLE II (Continued)

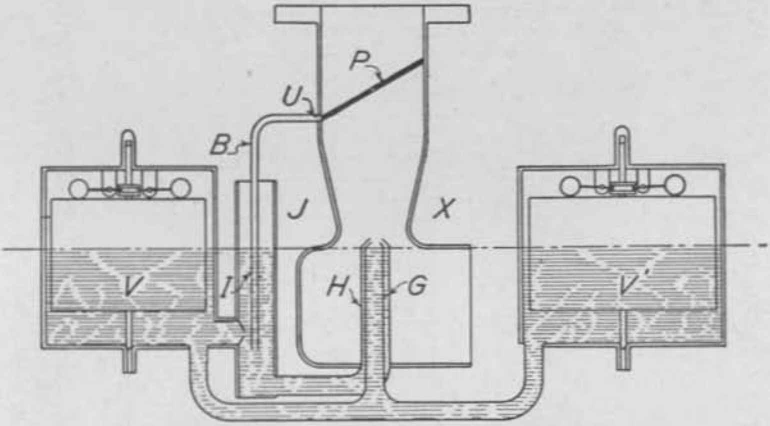
Test No.	Load In Horse-power	Engine Speed	Radiator Temperature In Degrees Fahrenheit	Gallons Per Horse-power Hour	Alcohol Per Cent	Purity of Alcohol Per Cent	Type of Fuel	CO_2 Per Cent	O_2 Per Cent	CO Per Cent	Compression Ratio	Remarks
28	6.330	840	177.8	0.1725	9.90	90	Dual	10.4	4.0	0.6	5.5 to 1	
29	9.872	950	163.5	0.1330	8.70	90	Dual	11.0	4.2	0.8	5.5 to 1	
30	3.000	815	179.6	0.2270	10.10	85	Dual	8.3	7.7	0.0	5.5 to 1	
31	5.200	825	187.0	0.1770	9.80	85	Dual	9.3	7.7	0.5	5.5 to 1	
32	11.120	950	179.6	0.1325	10.10	85	Dual	11.2	3.8	0.0	5.5 to 1	
44	4.300	810	177.8	0.2140	......	......	Gasoline	9.9	8.3	0.0	5.1 to 1	
45	2.900	800	185.0	0.2860	......	......	Gasoline	6.3	7.7	1.8	5.1 to 1	
46	5.650	825	189.6	0.2200	......	......	Gasoline	9.7	5.3	0.6	5.1 to 1	
47	10.270	840	185.0	0.1465	......	......	Gasoline	11.4	3.0	0.4	5.5 to 1	
48	9.700	835	179.6	0.1460	20.00	95	Blend No. 1	11.2	1.8	0.5	5.1 to 1	
49	5.800	825	181.3	0.1930	20.00	95	Blend No. 1	......	......	......	5.1 to 1	
50	3.300	800	177.8	0.291	20.00	95	Blend No. 1	......	......	......	5.1 to 1	
51	3.450	805	187.0	0.288	7.20	95	Dual	4.5	7.0	0.0	5.1 to 1	
52	5.500	825	177.8	0.218	8.10	95	Dual	7.2	4.3	......	5.1 to 1	
53	9.850	900	177.8	0.159	8.30	95	Dual	8.6	4.6	......	5.1 to 1	

* Blend No. 1 was made up as follows:
20% Commercial alcohol.
5% Higher alcohol.
5% Benzol.
4% Ethyl Ether.
66% Gasoline.

† Blend No. 2 consisted of the following:
10% Absolute alcohol.
90% Gasoline.

Alcohol used in Tests No. 21 to 26 was denatured according to the United States Formula No. 5. This denaturant polymerized during carburetion and gave unsatisfactory performance.

The results obtained in using 10 per cent alcohol of 95 per cent purity are shown graphically in Figure 4. The performance of the mixture at the lower compression ratio was inferior to that of gasoline at all loads. At the higher compression ratio the performance of the mixture was superior at loads greater than four horsepower. The gasoline detonated at point A which made it impractical at the higher compression ratio. The curves for the mixture were based on Tests 9, 10, and 11 for the higher compression ratio, and on Tests 51, 52, and 53 for the lower compression ratio.



B IDLE TUBE
G MAIN FUEL JET
I COMPENSATING JET
H COMPENSATING JET TUBE
J COMPENSATING ARRANGEMENT
P THROTTLE
U IDLE JET
V GASOLINE BOWL
V' ALCOHOL BOWL
X MAIN AIR JET

Fig. 3.—Carburetor used for concurrent use of alcohol and gasoline.

Similar tests were conducted with the 5.5:1 compression ratio for similar proportions of alcohol of 90 and 85 per cent purity. The performance is shown graphically in Figures 5 and 6 with that of gasoline for comparison. The increased amount of water in the alcohol did not affect the performance materially. The curves are based on Tests 27, 28, and 29; and 30, 31, and 32 respectively. The alcohol used in the above tests was denatured with butanol, which is a legal denaturant. However, crotonic aldehyde is used more extensively.

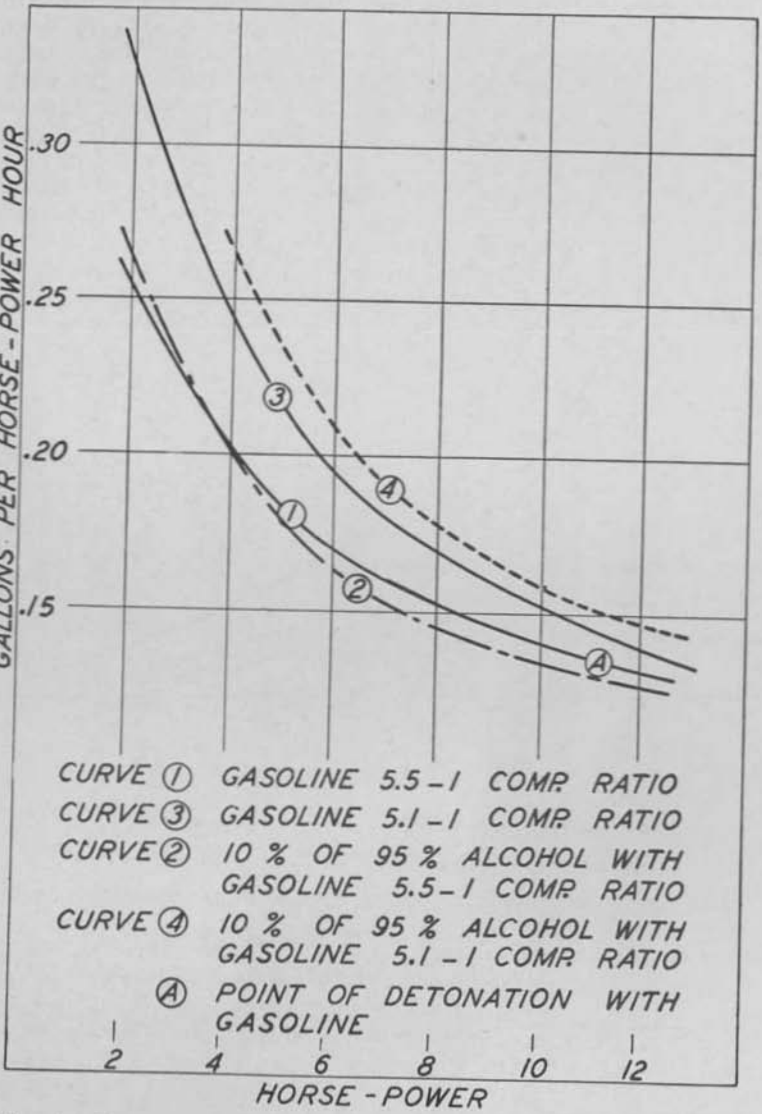


Fig. 4.—Curves showing relation between load and fuel consumption in gallons per horsepower hour.

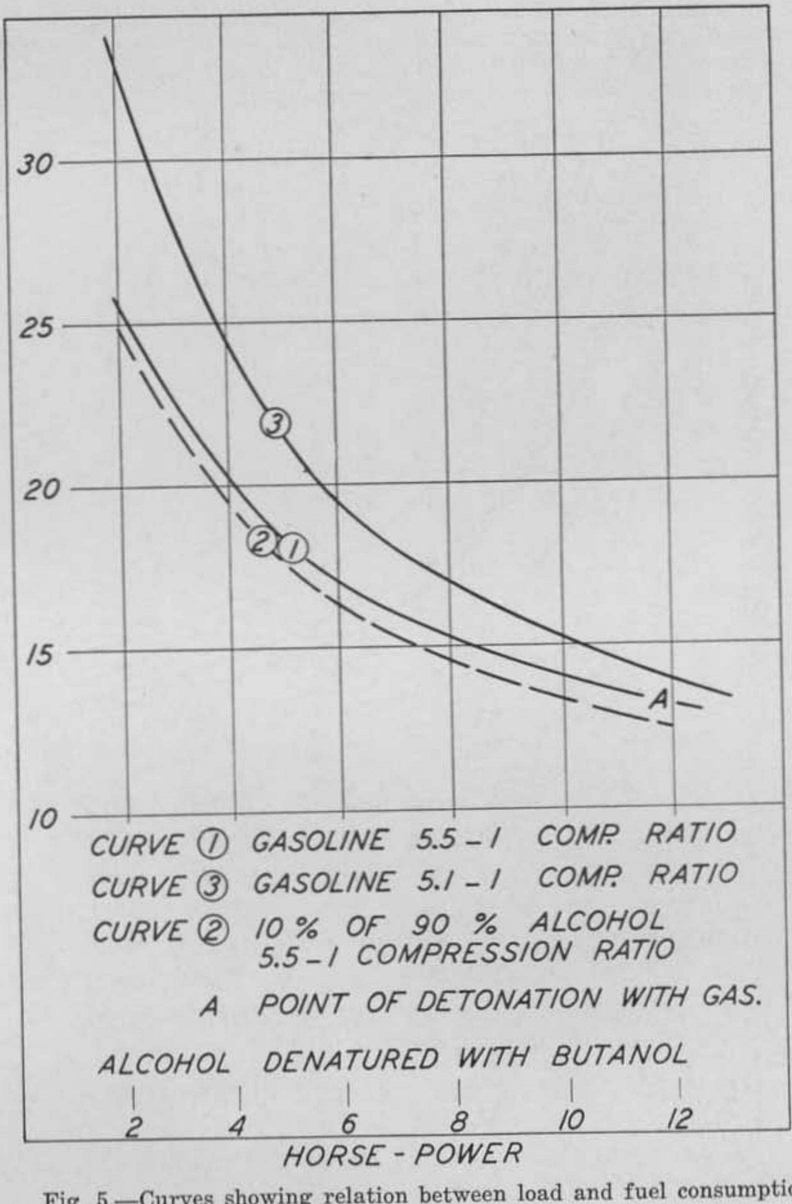


Fig. 5.—Curves showing relation between load and fuel consumption in gallons per horsepower hour.

Tests were conducted using 10 per cent of alcohol of 90 and 85 per cent purity, both denatured with crotonic aldehyde. The results are set forth graphically in Figures 7 and 8 with the performance of gasoline for comparison. The curves are

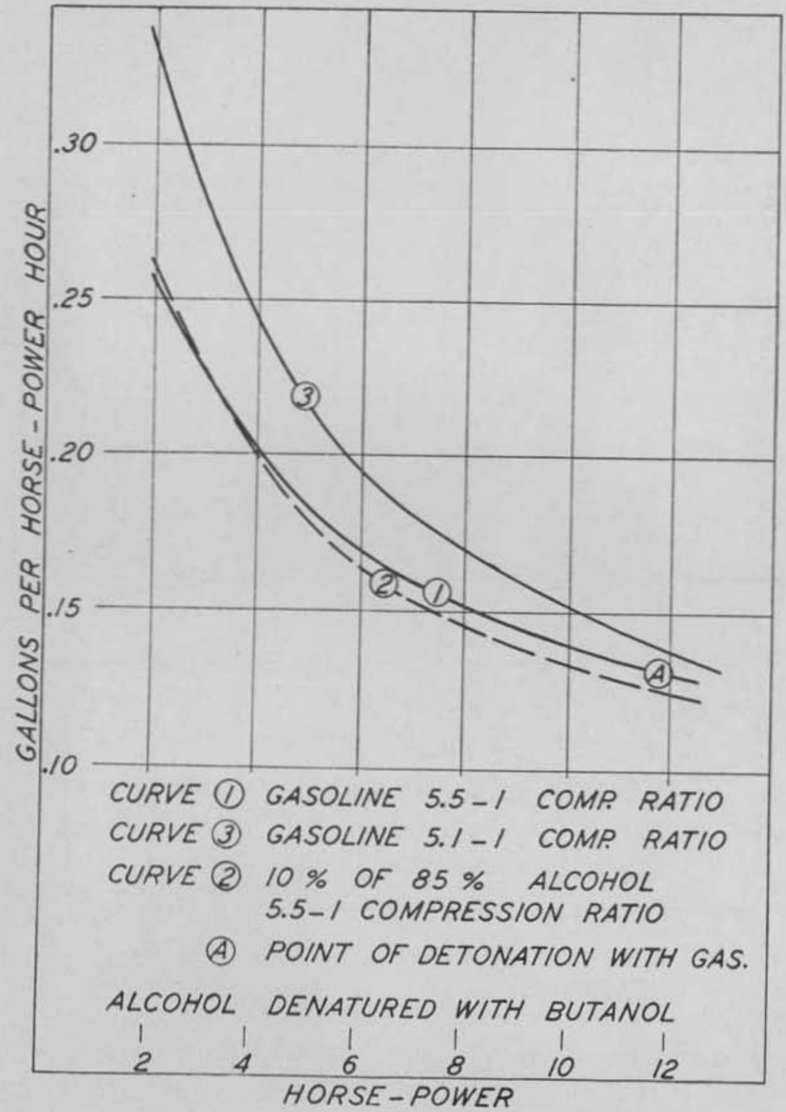


Fig. 6.—Curves showing relation between load and fuel consumption in gallons per horsepower hour.

based on Tests 21, 22, and 23; and 24, 25, and 26 respectively. In these cases the performance of the alcohol mixtures was very poor. This probably was due to the polymerization of

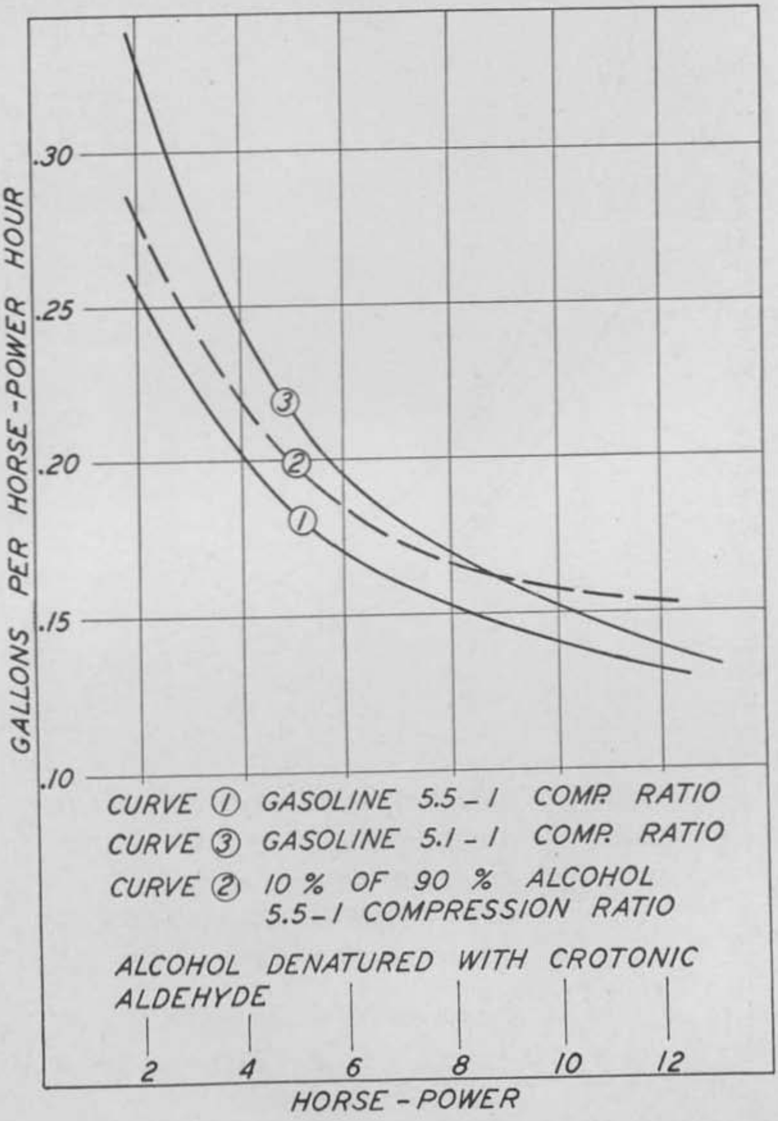


Fig. 7.—Curves showing relation between load and fuel consumption in gallons per horsepower hour.

the crotonic aldehyde which results in a soft resinous material that interferes with the passage of the fuel through the nozzles. This material also causes the engine inlet valves to stick.

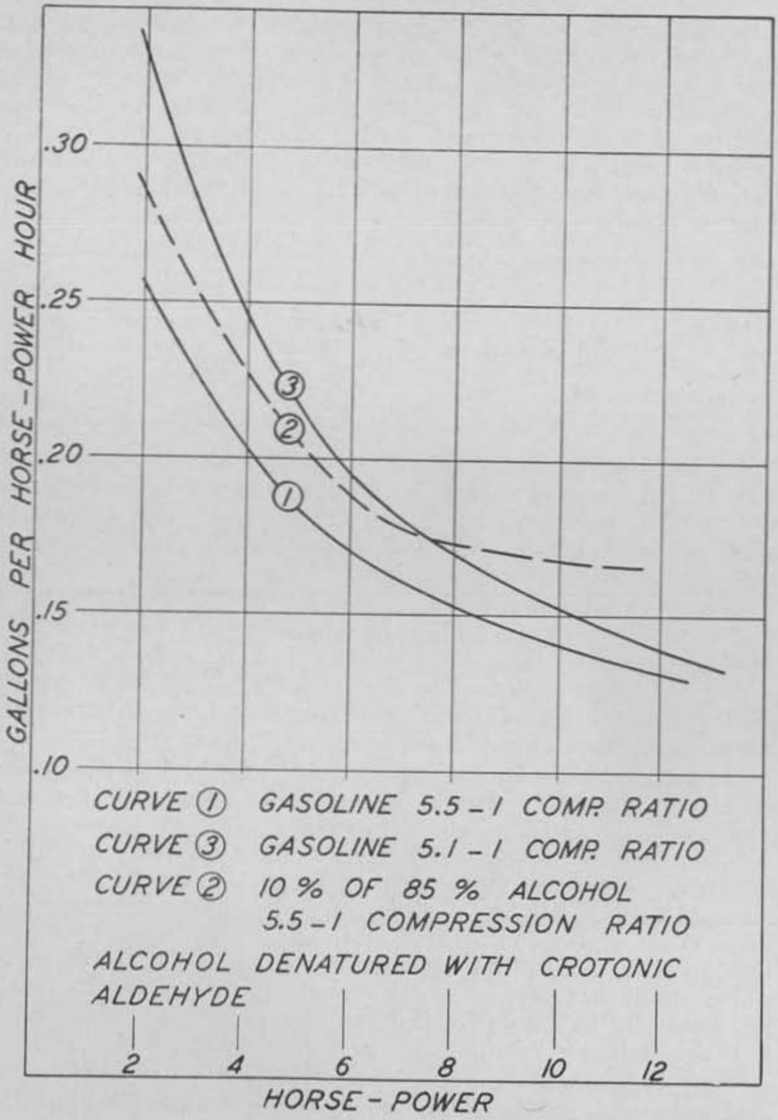


Fig. 8.—Curves showing relation between load and fuel consumption in gallons per horsepower hour.

Its use as a denaturant for ethyl alcohol should be discontinued, not only for the trouble it causes in internal combustion engines, but because its odor is so objectionable that the alcohol is unfit for lamps and stoves.

Road tests were also conducted with the same engine that was used in obtaining the above data. The car was driven over a distance of 300 miles for each test to eliminate as far as possible the error due to normal variations in the road conditions. Tests were made with the standard cylinder head giving a compression ratio of 4.22:1 and with the "police head" giving a compression ratio of 5.5:1. The following data were obtained:

Fuel	Mileage	Distance Traveled	Compression Ratio
"A" gasoline	19.31	300	4.22:1
(third structure blend made up of "A" gasoline and 20 per cent commercial ethyl alcohol	19.25	300	4.22:1
	24.50	300	5.50:1
"B" premium gasoline	23.00	300	5.50:1

It is interesting to note that at the lower compression ratio on the road, as well as in the laboratory, the performance of gasoline was superior to the mixture. The grade of gasoline used in the first test could not be used with the higher compression ratio due to detonation.

At the higher compression the performance of the blend was superior to the premium gasoline by 6.15 per cent. The premium gasoline "knocked" readily during moderate acceleration; the blend could not be forced to "knock." Consequently the compression ratio could have been raised considerably and the mileage increased still further.

Results of tests conducted on a 1934 Ford V-8 engine are given in Table III. Gasoline and a blend using 20 per cent of commercial alcohol were used in these tests.

Cast iron cylinder heads giving a compression ratio of 5.5 to 1 were compared with aluminum heads giving a compression ratio of 6.35 to 1. The gasoline gave superior performance at the lower compression ratio at all loads. At the higher compression ratio the gasoline knocked violently at 13 horsepower which made it impractical to use at that compression ratio. The blend in that case was the more superior fuel. The results of these tests are set forth graphically in Figure 9.

A road test was conducted on a 1933 Ford V-8 car between Moscow and Lewiston, Idaho, a trip of 80 miles. The gasoline gave a mileage of 16.68 miles per gallon as compared with 18.11 miles per gallon with the blend. The gasoline knocked

TABLE III

Test No.	Load	Engine Speed	Cooling Water Temperature In Degrees Fahrenheit	Fuel	Gallons Consumption Per Horsepower	Cylinder Head Material	Heat Lost In BTA Cooling System Per H. P. Hour	Compression Ratio	Exhaust Gas Temperature	Exhaust Gas Analysis		
										CO_2	O_2	CO
205	5.20	845	154.4	Gasoline	0.186	Cast Iron	16,120	5.5 to 1	570	13.0	2.6	0.0
206	8.80	860	154.4	Gasoline	0.1505	Cast Iron	10,920	5.5 to 1	670	13.4	1.6	0.0
207	11.20	880	158.0	Gasoline	0.1382	Cast Iron	10,720	5.5 to 1	750	13.0	1.8	0.0
208	14.90	910	158.0	Gasoline	0.1290	Cast Iron	8,020	5.5 to 1	835	13.4	1.6	0.0
209	5.40	840	152.6	20% Commercial alcohol blend	0.1965	Cast Iron	14,920	5.5 to 1	580	11.6	4.4	0.0
210	9.80	870	154.4	20% Commercial alcohol blend	0.1535	Cast Iron	9,750	5.5 to 1	670	11.9	4.1	0.0
211	11.15	880	154.4	20% Commercial alcohol blend	0.1468	Cast Iron	9,620	5.5 to 1	720	12.0	3.5	0.0
212	15.50	900	158.0	20% Commercial alcohol blend	0.1334	Cast Iron	8,030	5.5 to 1	810	11.7	3.4	0.0
213	5.30	840	147.2	Gasoline	0.1800	Aluminum	14,300	6.35 to 1	530	12.3	3.1	0.0
214	9.20	......	158.0	Gasoline	0.1440	Aluminum	10,700	6.35 to 1	615	13.0	1.5	0.0
215	11.75	880	155.3	Gasoline	0.1380	Aluminum	10,120	6.35 to 1	690	13.0	1.3	0.0
216*	13.00	870	156.2	Gasoline	0.1344	Aluminum	9,080	6.35 to 1	720	13.0	1.5	0.0
217	3.20	800	147.2	20% Commercial alcohol blend	0.2640	Aluminum	21,100	6.35 to 1	520	11.0	11.0	0.0
218	7.40	850	158.0	20% Commercial alcohol blend	0.1640	Aluminum	11,700	6.35 to 1	590	12.0	12.0	0.0
219	10.80	870	156.2	20% Commercial alcohol blend	0.1425	Aluminum	11,420	6.35 to 1	670	12.3	12.3	0.0
220	14.90	900	154.4	20% Commercial alcohol blend	0.1290	Aluminum	8,150	6.35 to 1	740	12.3	12.3	0.0

* Violent detonation set in.

readily during acceleration while no knock could be produced with the blend.

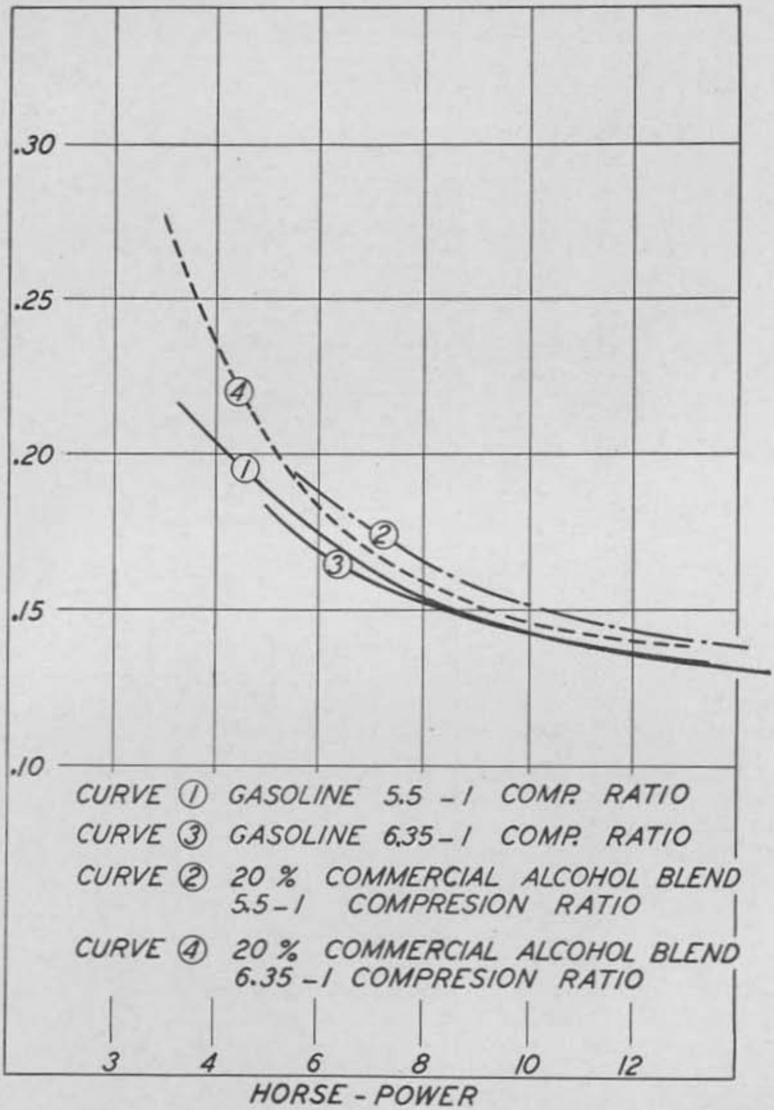


Fig. 9.—Curves showing relation between load and fuel consumption in gallons per horsepower hour.

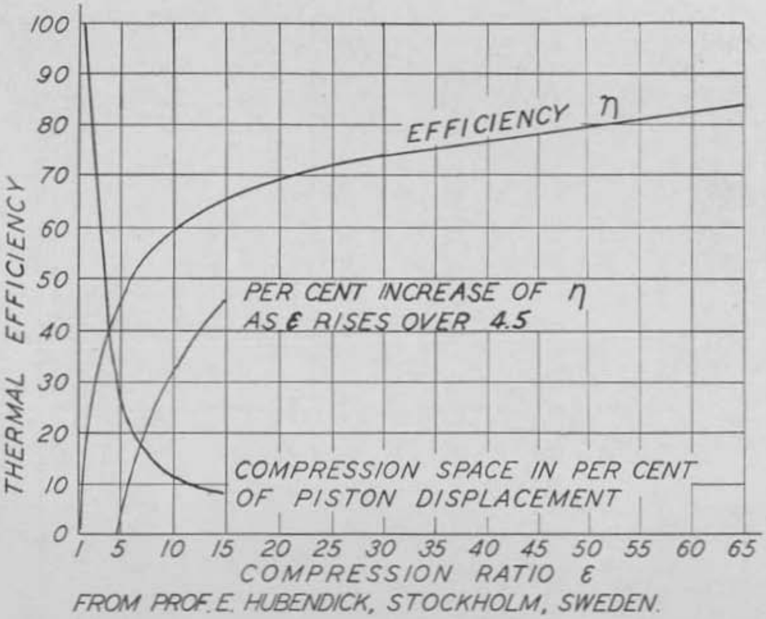


Fig. 10.—Curves showing relationship between thermal efficiency and compression ratio in motors of comparable construction.

The relationship between compression ratio and efficiency for an ideal engine is shown in Figure 10. In practice the efficiency is lower but is in proportion. The rapid rise of the efficiency up to a compression ratio of 7.5:1 is very noticeable.

The limiting factors with respect to compression ratios are the character of the fuel, the diameter of the cylinder, and the material in the cylinder head. The smaller the bore, the higher is the permissible compression ratio with a given fuel. Aluminum cylinder heads also permit higher compression ratios than heads made of cast-iron. On the other hand, the smaller the cylinder the greater is the loss of heat which offsets some of the advantages of the higher ratios. Aluminum is more conductive than cast-iron; consequently, it may be expected that more heat will be dissipated in the cooling system, which will tend to offset some of the effect of the higher compression ratios. Manufacturers have chosen the best combination for the available fuel.

In cases such as are shown in Figures 5 and 6 it is evident that the higher water content of the alcohol did not hamper the performance, in fact, the presence of the additional water

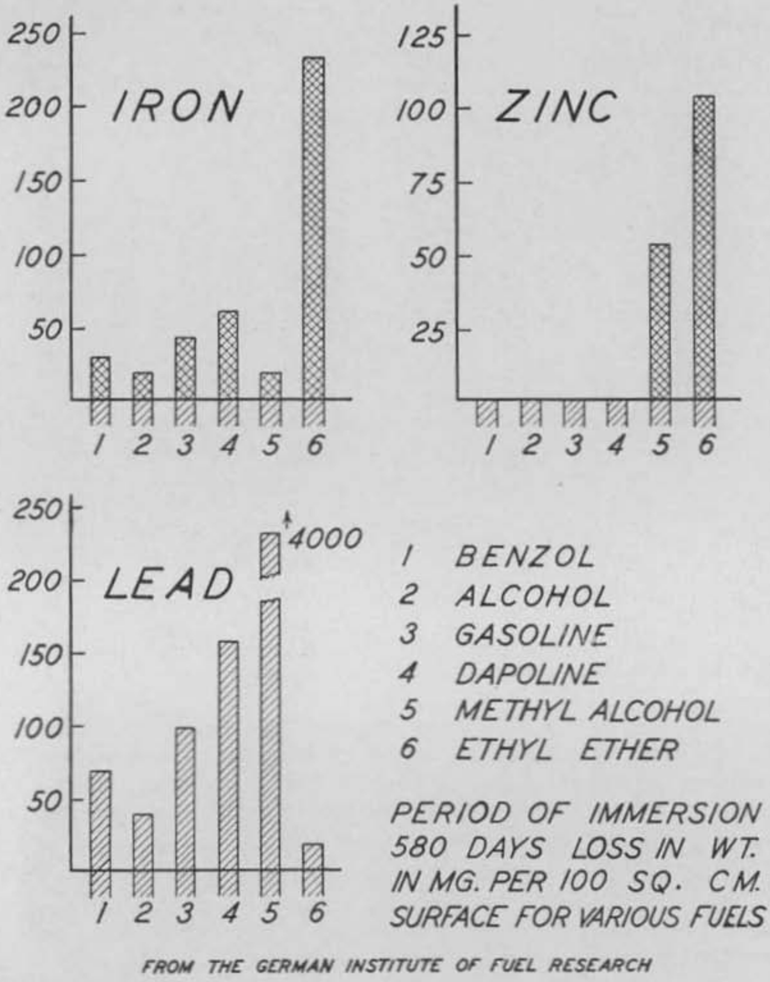


Fig. 11.—Graphs showing corrosive action of various fuels on different metals.

is an advantage because it further suppresses the detonating tendency of the gasoline. Furthermore, the cost of the production of the alcohol is lowered considerably by the lower purity required. Ten per cent of alcohol of 90 per cent purity fed along with gasoline can be used with compression ratios as high as 8:1 in designs that knock with gasoline at compression ratios of 5:1. Reference to Figure 9 shows that an increase of 23 per cent in efficiency may be expected after

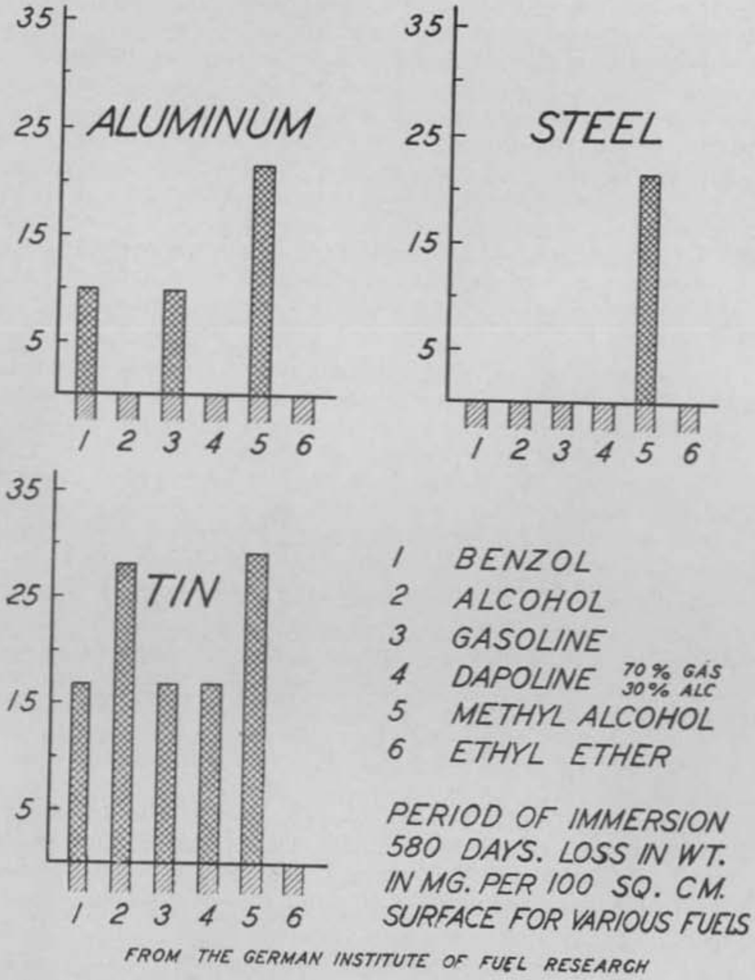


Fig. 12.—Graphs showing corrosive action of various fuel on different metals.

increasing the compression ratio from 5:1 to 8:1. This is supported by experimental evidence given in Figures 4, 5, 6, 7, and 8. Based on the above facts, alcohol of either 90 or 85 per cent purity could sell at a price 200 per cent higher than gasoline. This price is well within the cost of producing and marketing the alcohol.

Using ethyl alcohol as engine fuel with gasoline either as a blend or in a dual carburetor has several advantages. The carbon monoxide content of the average smooth-running engine burning gasoline is about 4 per cent. By using alcohol along with gasoline this can easily be reduced to less than 1 per cent. One pound of carbon oxidized to carbon monoxide releases 4,360 B.t.u. compared with 14,600 B.t.u. when oxidized to carbon dioxide, a difference of 10,340 B.t.u. A mixture of 80 per cent gasoline and 20 per cent alcohol has 91.5 per cent as much heat as an equivalent volume of gasoline. However, when alcohol is used more heat is made available. On the basis of the above figures on carbon monoxide the above mixture would liberate 99.4 per cent as much heat as an equivalent volume of gasoline, even with the lower calorific valve.

The elimination of carbon monoxide is highly desirable because it is a deadly poison. Six hundred and three fatalities occurred in the United States in 1932 due to carbon monoxide poisoning from automobile engines. When alcohol is used, there is very little deposition of carbon in the engine. Severely carbonized engines have been thoroughly cleaned by the use of ethyl alcohol with gasoline after 20 hours of operation under load. Alcohol containing water is the most effective.

The successful use of ethyl alcohol as an engine fuel and anti-detonant depends on the compression ratio of the engine. Compression ratios as high as 6.5:1 are standard equipment of a few cars sold in the United States. Most truck and tractor manufacturers of the United States have available engines with compression ratios as high as 7:1 for countries using alcohol. The higher compression ratio is obtained in case of L-head engines by replacing the regular heads with heads having smaller combustion spaces. In case of I-head engines, regular pistons are replaced with longer pistons that extend further up in the cylinder, thus increasing the compression ratio. These are available to the American consumer.

There is also a new development in internal combustion engines known as the Hesselman engine. This is a spark ignition engine, but injects the fuel similar to a Diesel. Like a Diesel it always operates at full compression pressures and is available with compression ratios ranging from 6:1 to 8:1. The performance of the Hesselman engine compares favorably with a Diesel type of engine. This engine gives promise of being able to use alcohol with petroleum very successfully.*

Alcohol may be used economically in engines having compression ratios as low as 5.5:1, provided the valves and intake

* "Tests of Multiple Fuel in an Injection Motor," (translation of title) M. Clerget, Compt. Rend. Acad. Sci., Paris. Volume 196, Number 22, Pages 1645-1647. 1933.

manifolds are not so restricted that the volumetric efficiency will be reduced.

General Observations On the Properties of Alcohol

Corrosion

Professor Wawrziniok of Dresden, Germany, conducted a series of tests on the corrosive effects of various fuels, including alcohol and alcohol blends, on various metals. The method used was to immerse the samples over a period of 580 days in the fuel. The samples were weighed before and after immersion, and the loss in weight charged to corrosion. Some of the results are shown graphically in Figures 11 and 12.

It is interesting to note that only tin is corroded more by alcohol than by gasoline. Iron, lead, and aluminum are affected less by alcohol than by gasoline. Zinc and steel are affected by neither.

Products of incomplete combustion

When gasoline is burned in a deficiency of air, the well-known carbon monoxide is produced. In case of alcohol under the same conditions and in the presence of copper, acetic acid is produced. Professor Hubendick of Stockholm, Sweden, conducted an experiment on the products of incomplete combustion of alcohol under operating conditions in internal combustion engines. He found that in the presence of benzol or gasoline, ethane formed rather than acetic acid. Ethane is a hydrocarbon of the gasoline family, and is not corrosive. He further reports no abnormal wear on engines using blends containing 25 per cent alcohol.

Separation of alcohol from gasoline

Alcohol may be separated from gasoline with which it is blended by agitating the mixture with water. However, there is no danger of separation due to such amounts of water as are liable to get into the fuel tank by condensation or filling during a rain. Nor is a mixture of alcohol and gasoline hygroscopic enough to absorb sufficient moisture to cause separation. A blend of alcohol and gasoline was placed in an open beaker and set in a closed jar containing water in the Agricultural Engineering laboratory. The temperature varied between 50° and 90° Fahrenheit. There was no separation after two months. Should separation be effected by agitation with large amounts of water, the alcohol could still be rendered unfit for beverage purposes by the selection of a proper denaturant.

Cost of manufacturing alcohol

In determining the cost of producing alcohol due consideration should be given to the by-products. A ton of potatoes will yield 30 gallons of 190 proof alcohol, 198 pounds of carbon dioxide, and about 400 pounds of residue. Due to recent developments in the production of "dry ice" from carbon dioxide a tremendous potential market has been opened for this material. The cost of processing the alcohol by the malt process is about 12½ cents per gallon, and by the Amylo process about 7 cents per gallon. The cost of processing the carbon dioxide into dry ice is about one-half cent per pound.

Non-agricultural sources of ethyl alcohol

Ethyl alcohol can be produced from ethylene gas which is formed in the cracking of petroleum. According to Dr. Gustav Egloff of the Research Laboratories of the Universal Oil Products Company, Chicago, in the "Manual of Industrial Chemistry," by Rogers a maximum of 300,000,000 gallons of ethyl alcohol could be made available from this source per year. This amount represents 1.7 per cent of the engine fuel requirements for the United States. This figure would also be reduced by virtue of other well established uses for ethylene, such as welding, production of ethylene glycol, and artificial ripening of fruits.

Ease of starting

No starting difficulty has been experienced by the Experiment Station workers at the University of Idaho. German and Swedish investigators report absolutely normal starting.

Use of alcohol in foreign countries

Alcohol is being used as engine fuel in most of the European countries. The Department of Agricultural Engineering communicated with Dr. C. H. Dencker, Director of Der Landwirtschaftlichen Hochschule, Berlin, Germany, regarding the practice in that country. Dr. Dencker reports that in Germany 98 per cent of the engine fuel contains the legally required percentage (10 per cent) of alcohol. He also reports that a fuel sold under the name of "monopolin" containing from 20 to 25 per cent of alcohol is gladly used by motorists and constitutes from 7 to 8 per cent of the total engine fuel consumption of Germany.

Alcohol as a means of conserving petroleum resources

It is generally conceded that irreplaceable natural resources should be carefully conserved. America should indeed be thankful for its extensive petroleum resources. Relative to this question, it is interesting to note the following from the October, 1932, report of the Federal Oil Conservation Board:

> "The public must not lose sight of the fact that our reserves are exhaustible and should not be exploited heedlessly. The public interest demands that these reserves should be properly and carefully developed to assure recovery of the maximum amount of oil and gas and their economic utilization.
>
> "There is every reason to believe that new supplies of petroleum will be found, but the fact remains that the number, productivity, and the time when such new fields will be discovered are matters of conjecture. Therefore, unknown reserves are not determinable and may or may not be available when needed.
>
> "Although in this fourth report this Board discussed some of the factors causing revision of estimates of oil supply and pointed out that during the last decade every estimate had required revision upward in the light of increased production factors; nevertheless it is timely to realize the significance which should be attached to well founded figures showing that at the current rates of production the equivalent of our present known oil reserves will have been withdrawn from their underground reservoirs in 10 to 12 years."

In view of this report, alcohol should be used as a possible means of conserving our oil resources. The market for alcohol is at the scene of the production of raw materials on the farm. This gives alcohol the advantage of eliminating the high freight rates charged to petroleum fuels.

Lubrication

The efficiency of an alcohol blend is somewhat improved when one-half per cent of oleic acid is added to the lubricating oil. One of the major oil companies operating in the United States treats its oil in that way for use with gasoline. Oleic acid is not corrosive, is produced from corn oil, and is therefore an agricultural product.

General Effect on Agriculture

Should the use of alcohol as engine fuel be commercialized, the outlet created for agricultural products would be tremendous. The annual engine fuel consumption of the United States is about 17,000,000,000 gallons. If 20 per cent of this amount were alcohol, an outlet would be created for the starch content of 2,200,000,000 bushels of corn or 113,000,000 tons of potatoes. Our national production of these crops in 1928 was 2,500,000,000 bushels and 14,000,000 tons respectively. While it can not be expected that all engine fuel will contain the above amount of alcohol, other uses for it would develop, as mentioned early in the discussion. The requirements would be much in excess of what could be produced from our waste and surplus agricultural products.

Probably some of the best sources of alcohol in the state of Idaho are potatoes and sugar beets. Idaho produces annually at the present time about 8,000,000 bushels of cull and second-grade potatoes. These tend to lower the price obtained for the first-grade product and should be diverted to other uses. These lower grades of potatoes are as good as first-grade potatoes for the production of alcohol and its by-products. One ton of potatoes will yield about 30 gallons of 95 per cent alcohol, 198 pounds of carbon dioxide, and about 400 pounds of residue. Thus 7,200,000 gallons of alcohol, 23,760 tons of carbon dioxide, and 47,520 tons of residue would be available from this source annually. Idaho uses 60,000,000 gallons of gasoline annually, with a possibility of displacing 20 per cent of this amount with alcohol. Again, as has been pointed out early in this discussion, alcohol has other extensive uses, and these, together with the engine fuel outlet, would make possible the ready disposal of the quantity of alcohol mentioned above.

Carbon dioxide can be converted into the so-called dry ice at a cost of one-half to three-fourths cent per pound when obtained in the pure state, such as is the case when produced as a by-product of fermentation. The solid has a temperature of —109.3° Fahrenheit. One pound of dry ice has a refrigerating capacity of two pounds of water ice and in terms of refrigerating capacity occupies only 32½ per cent as much space as water ice. The solid goes directly into a gas, and therefore the mess that accompanies the use of water ice is absolutely eliminated. The gas checks the rotting and softening of fruits and vegetables. Although the temperature of the solid is very low, the refrigerated compartment may be maintained at any desired higher temperature by varying the degree of insulation surrounding the dry ice. These properties make carbon dioxide a highly desirable refrigerant in the transportation of agricultural products, such as fruits, eggs, meats, and dairy products. The frozen fruit industry has been held in check for want of an economical and effective refrigerant during transportation. Dry ice may be used in that industry to advantage as soon as it becomes available in large quantities. The transportation of fresh fruits and vegetables can be tremendously improved by using dry ice in place of water ice. Likewise the transportation of meats can be improved. In localities where dry ice is available the animals are slaughtered near the scene of production, thus saving the high freight rates on the live animals to central slaughter houses and on the tankage back to the farm.

The use of dry ice in the ice cream industry for the lowering of handling and transportation costs has long been recognized. The use of dry ice in domestic refrigeration also would provide a large outlet for this product as soon as its merits were generally known. The above outlets all taken together would require a tremendous quantity of dry ice which would contribute to the profits of the producers of perishable products as well as those that furnish the raw material.

The residue referred to is in proteins, in carbohydrates, and in vitamins B and G. It is a valuable feed for dairy cattle and for the finishing of cattle coming in from the range. It would, no doubt, find a ready market in areas where alcohol is produced.

Acknowledgments

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LITERATURE CITED

1929 Mitteilungen Des Instituts Für Kraftfahrwesen an Der Sächsischen Technischen Hochschule, Dresden, Germany.
Klasing and Company G.m.b.h., Linkstrasse 38, Berlin, Germany.

1929 Studien über die Verwendung von Spiritus and Spiritus Kohlen-wasserstoff-Gemischen für den Betreib von Vergasermotoren von E. Hubendick, Professor an der Koenigl. Technischen Hochschule in Stockholm.

1933 The New Detergents, R. A. Duncan. Industrial and Engineering Chemistry, Volume 26, Number 1, Pages 24-26.

1933 Production of Industrial Alcohol, W. L. Owen, Industrial and Engineering Chemistry, Volume 25, Number 1, Page 87.

1933 Foth G. Handbuch der Spiritusfabrikation, Paul Parey. Berlin, Germany. 1929.

1933 Bonnefoy Fabrication de L'Alcool par les Procedes, H. Boulard, Pages 169-181. Supplement tech aux cahiers coloniaux de l'inst. Marseille. 1931.

1933 Solid Carbon Dioxide from Flue Gas by Application of Joule Thomson Effect, F. E. E. Germann. Industrial and Engineering Chemistry, Volume 25, Number 2, Pages 150-152.

1933 United States Department of Agriculture Technical Bulletin Number 318.

1934 Fuels for Spark-Ignition and Compression-Ignition Engines, J. B. Fisher. A. S. A. E. Volume 15, Number 4, Page 133.