



---

MANIFOLD VAPORIZATION AND EXHAUST-GAS TEMPERATURES

Author(s): O C Berry and C S Kegerreis

Source: *SAE Transactions*, Vol. 17, PART I (1922), pp. 160-184

Published by: SAE International

Stable URL: <https://www.jstor.org/stable/44729543>

Accessed: 28-03-2020 14:41 UTC

---

JSTOR is a not-for-profit service that helps scholars, researchers, and students discover, use, and build upon a wide range of content in a trusted digital archive. We use information technology and tools to increase productivity and facilitate new forms of scholarship. For more information about JSTOR, please contact [support@jstor.org](mailto:support@jstor.org).

Your use of the JSTOR archive indicates your acceptance of the Terms & Conditions of Use, available at <https://about.jstor.org/terms>



JSTOR

*SAE International* is collaborating with JSTOR to digitize, preserve and extend access to *SAE Transactions*

# MANIFOLD VAPORIZATION AND EXHAUST-GAS TEMPERATURES<sup>1</sup>

BY O C BERRY<sup>2</sup> AND C S KEGERREIS<sup>3</sup>

Stating that present internal-combustion engine fuel is too low in volatility for economical use and that this is the cause of engine-maintenance troubles, the authors believe that, since it is not possible to obtain the more volatile grades in sufficient quantity, the only hope of remedying this condition is to learn how to use the heavy fuel, and that the most promising method of doing this lies in the effective use of heat.

As the experimental data regarding the best temperature at which to maintain the metal in a hot-spot manifold and the range of temperatures available in the exhaust gases are meager, the authors experimented in the Purdue University laboratory to secure additional data. They present a summary of the results. They feel that the exhaust-gas temperatures are high enough so that properly designed manifolds, together with thermostatically controlled carburetor temperatures, should make possible the satisfactory carburetion of fuels considerably heavier than the present "power" gasoline, without seriously limiting the power, efficiency or flexibility of passenger-car engines or causing any engine-maintenance troubles.

The present fuel situation is one calling for serious thought. Internal-combustion-engine fuel is so low in volatility that it is not being utilized economically. A large number of maintenance difficulties can be attributed to the low volatility of the fuel. The petroleum reserves cannot be increased and, even granting a liberal use of substitute fuels, we can scarcely expect the time to arrive when the refiner will be willing to return to a fuel of higher volatility. Therefore, our only hope of progress is to learn how to use the heavy fuel. A first-class solution of this problem might go so far as to make possible the use of still more of the heavy ends, enable us to get more out of each gallon of fuel and decrease the operating difficulties, thus constituting a real step in progress.

<sup>1</sup> Annual Meeting paper.

<sup>2</sup> M.S.A.E.—Chief engineer, Wheeler-Schebler Carburetor Co., Indianapolis.

<sup>3</sup> Jun. S.A.E.—Assistant in carburetion research, Purdue University Engineering Experiment Station, Lafayette, Ind.

A considerable portion of engine fuel of our present grade passes through the intake-manifolds of automobile engines in liquid form. It is difficult to design a manifold that will distribute uniformly to all of the cylinders this liquid portion of the mixture furnished by the carbureter. No matter what condition the fuel is in when it reaches the cylinder, it must be vaporized before it can be burned. The most effective way yet found of improving distribution and combustion is to apply heat in some form or other. This makes it valuable to know how much heat to introduce and how to introduce it to get the best results.

One of the commonly used methods of heating the mixture is to have portions of the metal in the intake-manifold heated by the exhaust gases. The liquid fuel in the manifold tends to flow along the walls; therefore, it will come into contact with these hot portions and be flashed into a vapor. A considerable portion of the liquid is thrown out of the mixture at the carbureter throttle-valve and onto the walls immediately above the throttle. This liquid tends to cling to the walls. At very low air-velocities, as when the engine is idling very slowly, it will often collect in a puddle immediately above the throttle, especially when the manifold has a long vertical section at that point. At higher air-velocities this liquid will rise through the vertical section of the manifold and collect at the bottom of the horizontal sections. The manifold is swept clean continuously of these liquid-fuel puddles only at comparatively high air-velocities. Still other portions of the liquid fuel tend to collect wherever the direction of the flow changes, or wherever there are eddy currents due to any other cause. Therefore, the ideal condition for drying the mixture would be to have the metal heated at these points, especially on the outside walls at the bends and at the vertical section just above the throttle. These heated portions of the intake-manifold are called "hot-spots."

It is claimed for this hot-spot method that it produces a mixture sufficiently dry without heating it as much as is necessary in the "heated-air" method. The ideal hot-spot manifold would accordingly be one that produces a mixture dry enough to distribute evenly and burn well in the cylinders, with the least possible heating of the mixture itself. Some hot-spot arrangements allow the whole mixture to come into contact with the hot metal, and consequently operate by heating the whole mixture.

Others are arranged to keep the gases away from the hot metal as much as possible, while the liquid portions of the fuel are brought into contact with it and are vaporized. Such manifolds operate principally by heating the fuel itself after it has been metered.

The Society of Automotive Engineers appointed a special committee in 1919 to study the problems involved in the use of present internal-combustion-engine fuels. H. L. Horning served as chairman of this committee, and a careful study was made of the whole situation under his direction. The committee felt that the hot-spot manifold offered the most promising means of alleviating the difficulties encountered in carbureting the present engine fuels. Therefore, it made an exhaustive report on the present state of the art of designing hot-spot manifolds. This was presented to the Society and published in *THE JOURNAL*.<sup>4</sup>

In this report, however, as in the other literature on the subject, there is a lack of experimental data showing the optimum temperature at which to maintain the metal in the hot-spot, and the range of temperatures available in the exhaust gases of an engine under different running conditions. This information is fundamental in designing and perfecting any particular hot-spot manifold. Tests have therefore been carried out in the laboratories of Purdue University to obtain this information. These tests were divided into two groups. The first deals with the optimum temperatures in the metal in the hot-spot; the second, with temperatures available in the exhaust gases, together with the factors influencing these temperatures. A complete report of these tests is contained in a bulletin published by the Purdue Engineering Experiment Station, entitled *The Hot-Spot and Factors Affecting the Exhaust-Gas Temperatures*. The present paper is presented through the courtesy of the Purdue Engineering Experiment Station and gives the general conclusions of the bulletin in an abbreviated form.

#### HOT-PLATE TESTS

Before a hot-spot manifold is designed for any fuel, it is well to determine the following three points:

- (1) The rate of vaporization per unit of area for different temperatures

---

<sup>4</sup> See *THE JOURNAL*, July, 1920, p. 25.

- (2) The best temperature of the hot-spot for the vaporization of the fuel
- (3) The cracking point of the fuel and the deposition of solid matter

This information will provide a foundation on which practical designs can be based for any hydrocarbon fuel.

Fig. 1 gives a general view of the apparatus used in the tests mentioned. An iron plate  $\frac{5}{8}$  in. thick, 4 in. wide and 8 in. long was placed over an electrical heating element and packed in a box filled with asbestos, at *A* in Fig. 1. A well *B*, 1.015 in. in diameter and 0.128 in. deep, was located at the top center of the plate. Two thermometer wells were drilled on each side of the plate, one of each pair being as close as possible to the vaporizing well and the others farther away to give the plate temperature at a point where there was little or no flow of heat. The heat was regulated by a salt-water rheostat, *C*, in series with the heating coil, ammeter and switch. The vaporized fuel was carried away through a hood over the plate connecting with an 8-in. vertical pipe. The gasoline was weighed on a small chemists' balance, the fuel being siphoned from a beaker on the scale through a small copper tube to a point  $\frac{1}{2}$  in. above the top of the well. This prevented any portion from touching the liquid or interfering with the vaporization. The flow of fuel was regulated by a needle-valve, placed in the line just outside of the hood. The temperatures were measured by 950-deg. fahr. nitrogen-filled mercury thermometers, accurate to within 5 deg. at the extreme conditions. The time of each test was taken with a manually operated stop-watch.

A portion of the fuel was thrown out over the edge when the first well, which was shallow, was used; consequently, too high a rate of vaporization per unit area was indicated. Therefore, in the later tests the vaporizing well was made deeper by welding additional metal around the top. When machined, this gave a well of 1.051-in. diameter and 0.610-in. depth. In this well too low a rate of vaporization was indicated. The reason for this is that the iron forming the upper part of the well was considerably farther away from the heating element than the thermometers and was consequently considerably below them in temperature. This resulted in a decreased vaporization from these upper portions. The entire wetted area was measured as the vaporizing surface; so the average rate of vaporization was lower

than it would have been had the entire surface been at the temperature indicated by the thermometers. Since the results obtained from the first well tended to be too high, and those from the deeper well too low, an average between the two will represent nearly the real truth. In plotting the curves and reporting the results of these tests, the average figures are used.

The apparatus is liable to a few errors that can be eliminated by calibration. They are errors due to siphoning and the evaporation from the surface of the fuel in the beaker. The siphoning error is small and equal to the weight of gasoline displaced by the fuel-pipe between the initial and final levels of the fuel in the beaker, the pipe being considered as a solid. The error is 0.88 per cent for the individual beaker and pipe, and was cor-

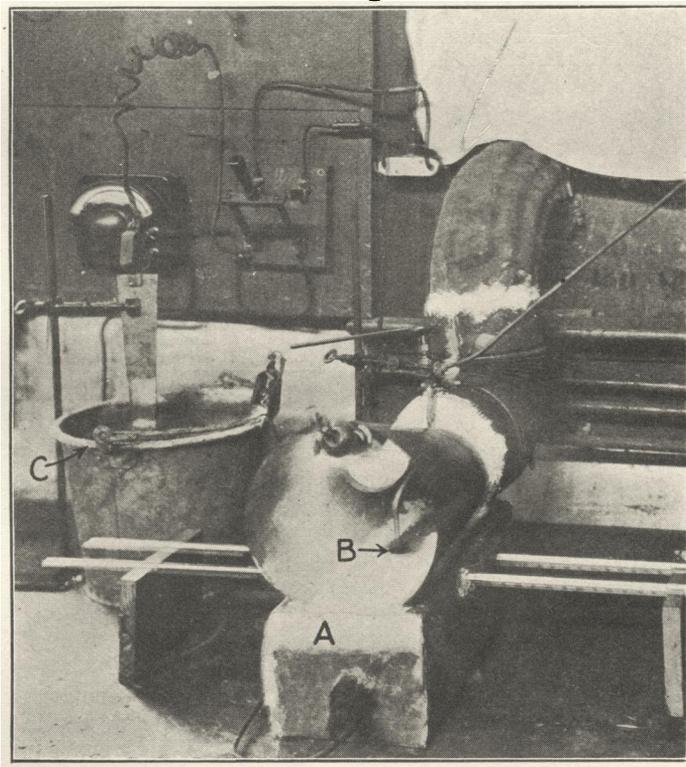


FIG. 1—GENERAL VIEW OF THE APPARATUS USED IN MAKING THE TESTS

TABLE 1—SPECIFIC GRAVITY AND DISTILLATION DATA OF FUELS TESTED

Percentage Distilled Off	Baumé Gravity of Fuel, deg.			
	70.0	64.2	56.5	41.5
Initial boiling point	97	120	96	346
10	127	155	162	386
20	143	169	210	400
30	155	179	247	408
40	165	187	272	413
50	176	196	295	424
60	187	205	313	432
70	193	215	335	440
80	206	227	356	452
90	225	245	381	476
Maximum	300	312	425	524

rected in the computation of the tests. The larger error is the evaporation from the surface of the fuel in the beaker. This is especially large for the lighter gasolines. This evaporation will vary according to the saturation of the air in the scale box. The temperature of the air above the beaker was recorded for each series of tests and from calibration tests this error was corrected with a considerable degree of accuracy.

#### FUELS TESTED

One kerosene and three gasoline samples were tested. The specific gravity and distillation data are shown in Table 1. These fuels were obtained directly from a refinery through the courtesy of one of the leading manufacturers of petroleum fuels.

The distillation curve of a fuel is very valuable because the temperatures at which the fractions distill are the criteria by which comparisons of different fuels for volatility should be made. The specific gravity is a very uncertain indication of quality, because several combinations of petroleum fractions may have the same specific gravity and yet be wholly different fuels. The end-points and boiling temperatures of the fractions determine the character of the fuel more than the specific gravity.

The results of the tests are shown in Fig. 2, which gives the curve for each of the fuels tested. In these

curves the temperature is plotted horizontally in fahrenheit degrees; vertically the time in minutes required to vaporize 0.01 lb. of fuel per sq. in. of hot surface is shown. The temperatures are in all cases those indicated by the thermometers nearest to the hot-spot in the hot plate. They represent 70.0-deg. high-test gasoline, 64.2-deg. domestic aviation gasoline, 56.5-deg. commercial power gasoline and 41.5-deg. kerosene, as shown on the Baumé scale. The curves are similar in general characteristics, the difference being that increasingly high temperatures are necessary to vaporize the less volatile fuels.

It was necessary to hold the temperature constant and continue the evaporation for a considerable length of time before each test was started. When the fresh gasoline was first introduced into the hot well, its rate of vaporization was rather high, the more volatile portions evaporating and leaving the heavier parts as a comparatively inert mass in the hot well. After a time, however, a state of equilibrium would be reached, when the fumes leaving the hot well would contain the same percentages of the lighter and heavier fractions as the original gasoline, and the proper rates of vaporization would be reported.

The fuel showed evidences of cracking during the period of rapid boiling, and a deposit of solid matter was left on the edges of the well. The two lighter gasolines, 70.0 and 64.2 deg. Baumé, left a deposit that resembled paraffin, while the deposit from the heavier gasoline and the kerosene had more the appearance of tar or carbon. When the liquid film was allowed to seep over the edge of the well these deposits were dissolved and carried out with the vapor. This vapor afterward re-deposited some of the solid matter in the hood behind the well. When the spheroidal state was reached, the deposition of solid matter ceased entirely. This is very important to the designer of a hot-spot manifold. The temperatures that cause a deposition of solid matter are rather limited in extent and are entirely below those that will throw the fuel into the spheroidal state. The very high temperatures are not the ones that cause the clogging of the manifold.

The appearance of the vapor under different conditions was interesting. When the liquid was boiling from a wetted surface the vapor was very wet and condensed easily. In fact, its appearance as it was carried to the

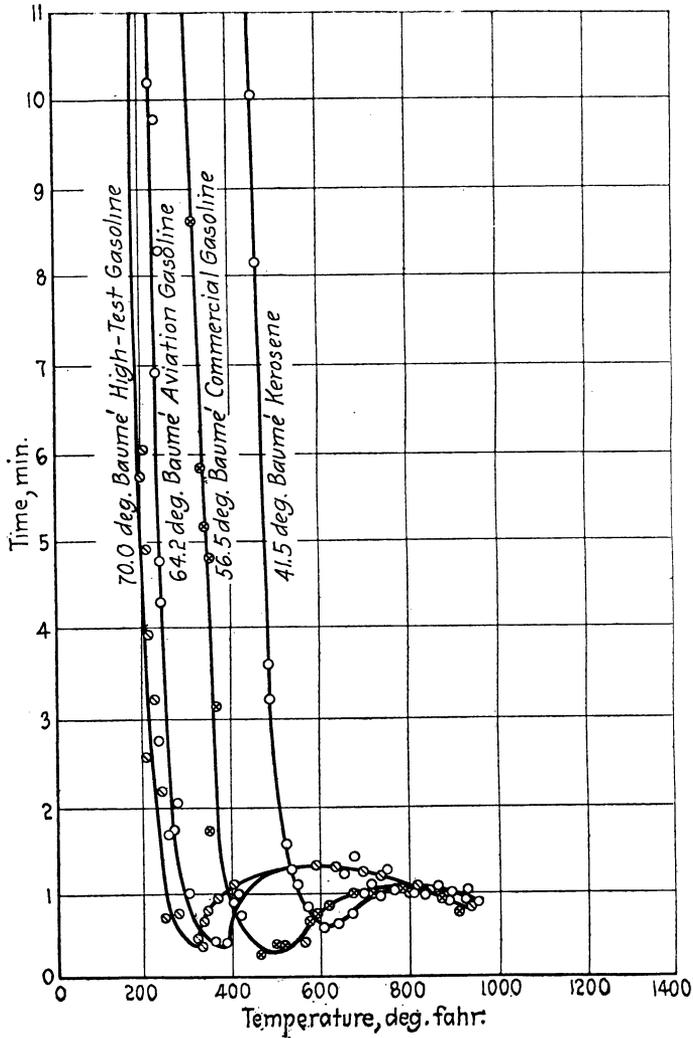


FIG. 2—CURVES GIVING RESULTS OF FUEL TESTS ON KEROSENE AND THREE GRADES OF GASOLINE

rear of the hood was that of a dense fog. In the spheroidal state, the vapor was dry and almost invisible; so that, even after it had traveled a few feet in a cool pipe, no appreciable condensation was noticed.

The curves in Fig. 2 show that the effectiveness of the hot-spot drops off very rapidly at the lower end of the temperature range. A similar curve for the fuel to be used will show the lowest temperature that it will pay to use with that fuel. It is not wise to attempt to make use of the highest rate of vaporization for two reasons. The temperature range is too narrow and this is where cracking and deposition of solid matter takes place. It is better to use the higher temperatures that produce the spheroidal state. After the spheroidal state is once reached, an increase in temperature does not make any very great change in the rate of vaporization. The metal in the hot plate was often red-hot during these tests, but at no time were the fumes from the hot-spot ignited by the plate when the latter was below 1425 deg. fahr. This makes it practicable to use a very wide range of temperatures in the metal of a hot-spot, and eliminates the necessity of using a thermostat.

#### EXHAUST-GAS TEMPERATURE TESTS

The second group of tests was intended to determine the exhaust-gas temperature of an automobile engine under different running conditions. Some very careful work had been done previously by several investigators to determine these temperatures under specific running conditions, but little attention had been given to the factors influencing them. The more important of these factors are as follows:

- (1) Temperature of the cooling water
- (2) Temperature of the inlet air
- (3) Timing of the spark
- (4) Richness of the fuel mixture
- (5) Speed of the engine
- (6) Load carried by the engine

Therefore, tests were carried out to determine the effect of each of these factors on the temperature of the exhaust gases. The apparatus used was an Oakland-Northway six-cylinder engine having a 2 13/16-in. bore and a 4 3/4-in. stroke, mounted on the test-block and connected to a Diehl electric dynamometer as shown in Fig.

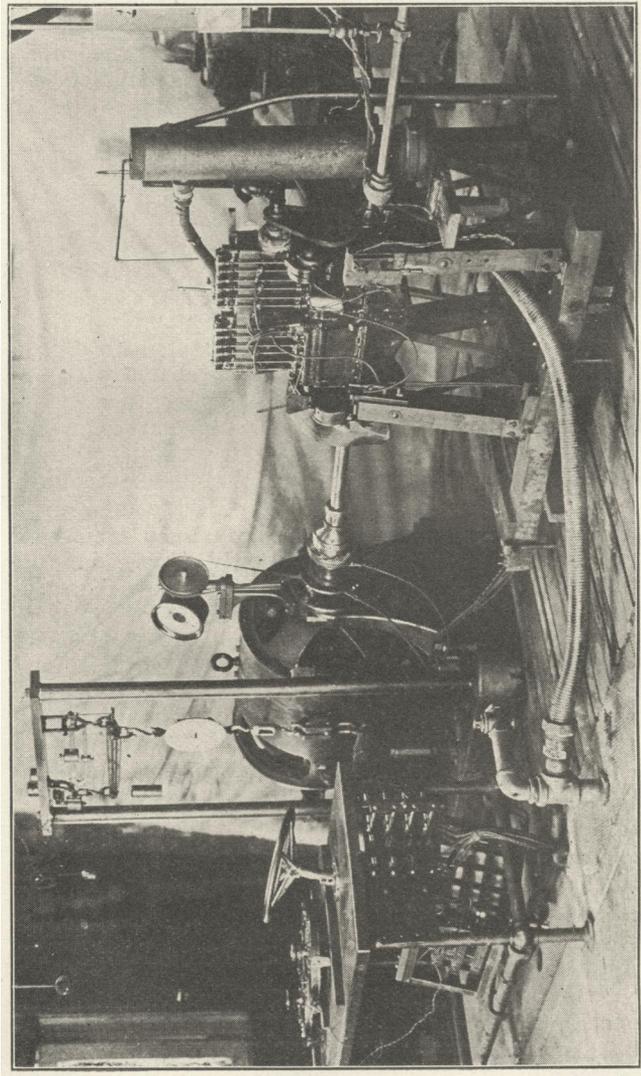


FIG. 3.—THE SIX-CYLINDER ENGINE USED IN MAKING THE TESTS WAS MOUNTED ON A TEST-BLOCK AND CONNECTED TO AN ELECTRIC DYNAMOMETER

3. Two manifolds were used, designated as manifolds *A* and *B*. Manifold *A* had the early conventional type of hot-spot formed by passing a very small portion of the exhaust gases around the exterior of the three headers of the intake-manifold. Manifold *B* had the intake cast on top of the exhaust and enough contact between the two headers to cause considerable flow of heat. These were interchanged for some of the tests. The air was measured by an Emco No. 4 diaphragm meter reading to cubic feet, the dial being arranged so that an accurate estimation to tenths was possible. The gasoline was siphoned from a 2-liter beaker on a large chemists' balance. The speed was measured by a tachometer on the dynamometer and verified by the stop-watch and revolution-counter readings. The watch, the revolution counter and the air meter were electrically controlled by the scales, to start and stop the measurement of these quantities at the same instant. The air was heated to any temperature desired by a gas-heater that could be regulated by controlling the gas-burners. All temperatures, such as those of the inlet air, and the cooling water, and all the hygrometer readings, were measured with mercury thermometers; the exhaust-gas temperatures were measured with iron-constantin thermocouples, and these were calibrated carefully. These thermocouples were placed near the outlet end of the exhaust manifold. The manifold was drilled and the couples allowed to extend a little more than half-way through the passageway. The couples were not covered, thus allowing the gases to come directly into contact with them, and the point where they entered the manifold was packed with asbestos, to prevent them from being cooled by the manifold walls. The temperatures reported, therefore, represent the actual temperature of the gases at the point where they would be most likely to be used in producing a hot-spot.

The tests to show the effects on the exhaust temperature of the temperatures of the cooling water and of the inlet air, the timing of the ignition and the richness of the fuel mixture were all run at one-half load at an engine speed of 1000 r.p.m., holding all of the running conditions constant except the one to be tested. The engine was allowed to run under test conditions for a considerable length of time until all of the temperatures had come to an equilibrium before each test was started.

The temperature of the cooling water was varied be-

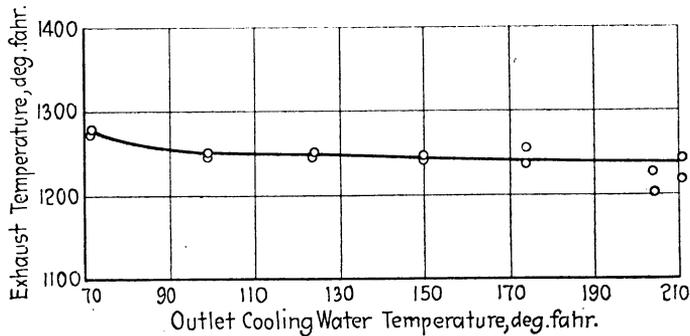


FIG. 4—THE EFFECT OF THE TEMPERATURE OF THE COOLING WATER ON THE EXHAUST TEMPERATURE IS RATHER SMALL

tween 70 and 212 deg. fahr., the tests being run at one-half load, at 1000 r.p.m. The results are represented graphically by the curve in Fig. 4. Contrary to what might be expected, the effect is shown to be rather small, and heating the engine produces a slightly lower exhaust-gas temperature.

Two series of tests at one-half load, at 1000 r.p.m., were run to determine the effect of changing the inlet-air temperature, this being varied between 59 and 335 deg. fahr. The results are shown in Fig. 5. The peculiar shape of the curve can possibly be explained by saying that the 59-deg. air probably did not enable the engine to burn all of the fuel. As the temperature increased to

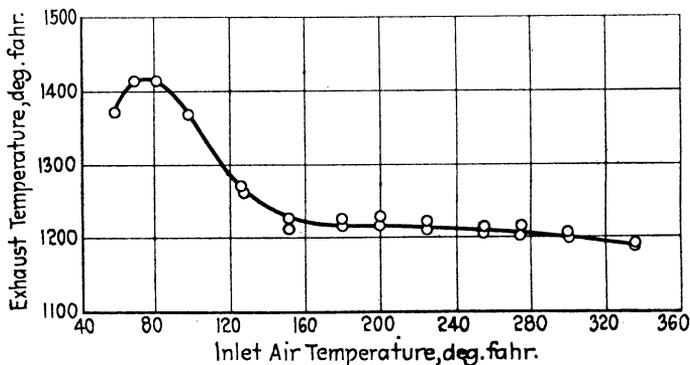


FIG. 5—CURVE SHOWING THE EFFECT OF CHANGING THE TEMPERATURE OF THE AIR ENTERING THE CARBURETER

about 80 deg. fahr., the combustion became complete and, since it was so very slow, the loss of temperature due to radiation and work were at a minimum and the exhaust-gas temperatures were at a maximum. During the period between 80 and 160 deg. fahr. the vaporization of the fuel improved very rapidly, the combustion became more and more rapid until it was complete at the begin-

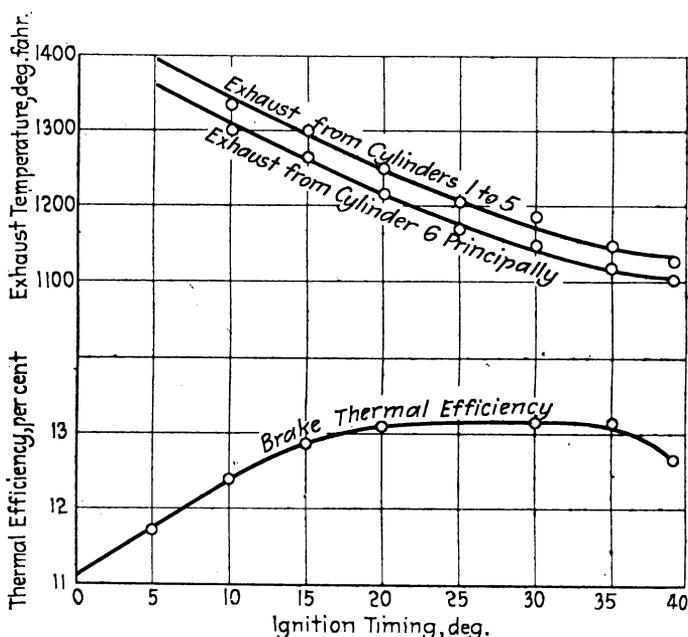


FIG. 6—THE EFFECT OF CHANGING THE SPARK-TIMING ON THE EXHAUST TEMPERATURE AND THE BRAKE THERMAL EFFICIENCY

ning of the working stroke, the loss of temperature due to radiation and useful work reached a maximum, and the heat left in the gases at the time they were exhausted from the cylinder decreased rapidly. The decrease in the exhaust temperature above an inlet temperature of 160 deg. fahr. was not so pronounced, since an increase in the rate of combustion beyond the point where it was complete before the beginning of the working stroke could not have very much effect.

The effect of changing the spark-timing was studied with the engine running at one-half load, at 1000 r.p.m. The tests showed that advancing the spark reduces the

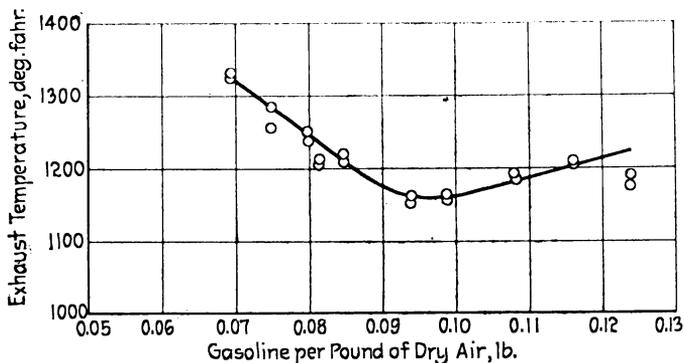


FIG. 7—HOW CHANGES IN THE FUEL-AIR RATIO AFFECT THE EXHAUST TEMPERATURE

exhaust temperature, but that the effect is not large. Fig. 6 shows the results graphically.

The effect of changing the fuel-air ratio was checked by running three series of tests at one-half load, at 1000 r.p.m. Two series were run with manifold A and a third series with manifold B. The tests on manifold A checked very well, the results being shown in Fig. 7.

In determining the effect of changing the speed, tests were run at speeds varying from 300 to 2000 r.p.m. and at light, one-half and full load, using manifold B. Figs.

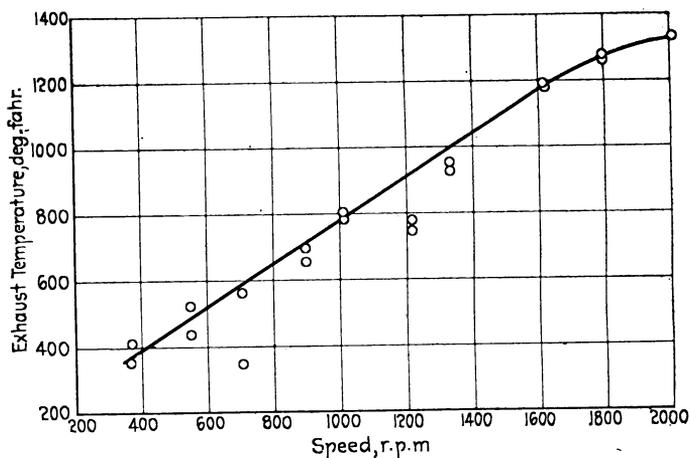


FIG. 8—RELATION BETWEEN CHANGES IN SPEED AT LOW LOAD AND THE EXHAUST-GAS TEMPERATURE

8 and 9 show results that are characteristic of these tests.

The speed tests also show the effect of changing the load, as is indicated by Fig. 10. The maximum difference in exhaust temperatures between no load and full load is 270 deg. fahr., which occurs at the lowest speed used in these tests, namely, 300 r.p.m. As the speed increased, this difference decreased until, at 2000 r.p.m., it was only 110 deg. fahr.

The maximum exhaust temperature obtained at 2000 r.p.m. was 1460 deg. fahr., under full load, with a 31-deg. spark advance, a mixture temperature of 220 deg. fahr. and a mixture ratio of 0.08 lb. of gasoline per lb. of dry air. A special test was made at 300 r.p.m. with all of the conditions adjusted to produce the lowest possible temperature. It was possible to get down to 300 deg. fahr. under these conditions. It is obvious that the main factor in determining the exhaust temperatures is the speed at which the engine is running.

#### DISCUSSION OF RESULTS

The tests show that the temperature of the exhaust gases from an engine vary through a wide range, according to the conditions under which the engine is running. They seldom get below 300 deg. fahr., even when the engine is idling at a very low speed, and do not often reach 1500 deg. fahr., even at full load and maximum

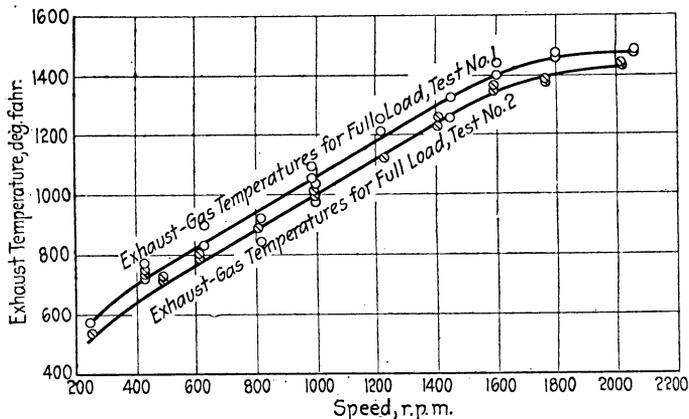


FIG. 9—RELATION BETWEEN CHANGES IN THE SPEED AT FULL LOAD AND THE EXHAUST TEMPERATURE

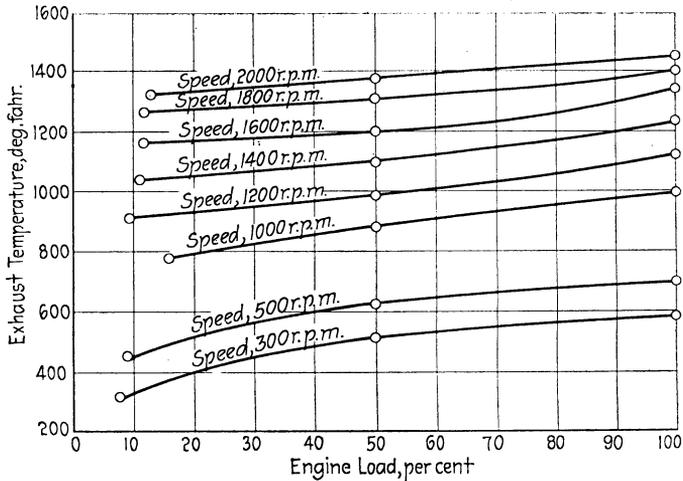


FIG. 10—RELATION BETWEEN THE ENGINE LOAD AND THE EXHAUST TEMPERATURE AT DIFFERENT SPEEDS

speed. The lower end of this range is too low to be effective in vaporizing many of the fractions of petroleum that are offered to the public as fuel. There is little choice left to the designer or operator of an engine, however, as to what he can do to influence the exhaust temperatures. Nearly all of the factors influencing the engine performance must be adjusted to meet other more important requirements.

The speed and load of the engine are the main factors in determining the exhaust-gas temperatures, but they are governed usually by the service. To prevent getting below any specified exhaust-temperature, it will be best to operate the engine under conditions that will result in good performance and maximum power and efficiency, but to plan to stay above the special speeds and loads that are shown to be necessary in producing the desired temperature. The speed is more important than the load; so the principal requirement will be to stay above some specified speed.

An effort should be made to heat the fuel without heating the air in the manifold itself. There are two main reasons for this. The fuel can thus be vaporized at a very high temperature without the use of a great amount of heat, and this vaporization can be accomplished very rapidly. The dry fuel-vapor can then be

mixed with cool air and drawn into the cylinder before it has time to condense and drop out of the mixture. The final mixture can thus be made usably dry at the lowest possible temperature. When the air is allowed to come into contact with the hot-spot, it becomes unnecessarily heated itself and tends to keep the metal in the hot-spot at too low a temperature to be most effective in vaporizing the fuel.

After completing this work, we feel that the greatest cause of the poor carburetion of our present engine-fuel is due to improper manifold design and that a great opportunity for progress lies in the improvement of the manifolding of engines. The advance will be made through learning how to use the heat in the exhaust gases and by introducing this heat into the intake charge in the proper amount and in the best way.

An important element in this problem, but one that lies outside of the scope of this paper, is the thermostatic control of carbureter temperatures. There is enough heat in the exhaust gases and the temperatures are high enough so that properly designed manifolds, together with thermostatically controlled carbureter temperatures, should make possible the satisfactory carburetion of fuels considerably heavier than our present "power" gasoline, without seriously limiting the power, efficiency or flexibility of passenger cars or resulting in any of the difficulties that are now due to poor manifolding systems. By a small increase in the minimum engine speed, still heavier fuels can be used. A careful study of how to use the exhaust heat best should therefore prove a great benefit to the whole motoring public, and a real step in the direction of progress. The manufacturers of the cars already built should take this fact seriously and provide not only for their future models but also produce improved manifolds that can be installed on the older cars, thus improving the quality of their service and prolonging their years of usefulness. It is our hope that the information we have assembled will prove of assistance to those in the industry who are striving to accomplish these results that are greatly to be desired.

#### THE DISCUSSION

P. S. TICE:—It lately has been impressed upon the minds of automotive engineers that at least a close ap-

proximation to complete vaporization in the intake is essential. Not only does it increase the utilization of fuel but it is utterly impossible without it to use fuel-metering characteristics in the carbureter that result in maximum utilization. When considering the use of exhaust heat to produce vaporization, it must be noted that as combustion of the fuel in the cylinder becomes more complete less heat is available in the exhaust. However, the ratio between the heat available and the heat needed for vaporization always increases as utilization is increased.

A study of the curves presented by Messrs. Berry and Kegerreis brings out the fact that all the data presented were obtained under conditions of comparatively small utilization. For instance, consider their curve of exhaust temperature versus mixture-ratio. With the greatest possible utilization, this curve is not only lower on the temperature scale but it has a different shape and a different general slope. What complete vaporization really does is to give to the effective mixture in the cylinders proportions equal to those of the overall or metered mixture. Unvaporized fuel does not burn; hence, the effective mixture is poorer in fuel than the overall or metered mixture by the relative amount of liquid in the cylinders at ignition. There are, of course, other aggravating circumstances. Chief of these is the one that admission of liquid fuel to the cylinders can result only in non-homogeneous mixtures.

The brake thermal efficiency of just over 13 per cent at one-half load, as in the curve in Fig. 6 of the paper, presupposes an overall or gross mixture-ratio of between 9 and 10. While it is probable that the brake efficiency here shown was not the maximum that could have been obtained under the conditions established by the authors at one-half load, it is equally probable that it could not have been much higher. In this connection it is interesting to note that, with complete vaporization and therefore equal distribution and high utilization, such an engine at the same speed and relative load shows a brake thermal efficiency of 22 per cent with a mixture-ratio of between 15 and 16. Experimental observation shows that, in general, with conventional service methods of vaporization, an overall ratio of between 9 and 11 is required to secure an effective ratio of from 13 to 16.

The authors' results on vaporization from a hot plate are interesting, even if they are inconclusive. They at

least point out the fact that it is easily possible to secure data from which one can design to secure fuel vaporization.

In any car, it is possible to plot with great definiteness the two extreme sets of conditions surrounding vaporization of fuel by exhaust as shown in Fig. 11. I made such plottings some years ago for several cars that were available for experimental work. I was forced to conclude, with Messrs. Berry and Kegerreis, that the only doubtful combination of conditions might be that existing at the smallest loads at the lowest speeds. But, even there, considering that the heat is available only at comparatively low temperatures, its quantity and the temperatures at which it is available are sufficient for our needs if advantage is taken of the conditions that exist in a throttled engine. The only thing that the designer is forced to create for himself in such a case is a reasonably efficient heat-transfer from the exhaust gas to the fuel liquid.

My early work directed toward the attainment of this reasonably efficient heat-interchange showed definitely

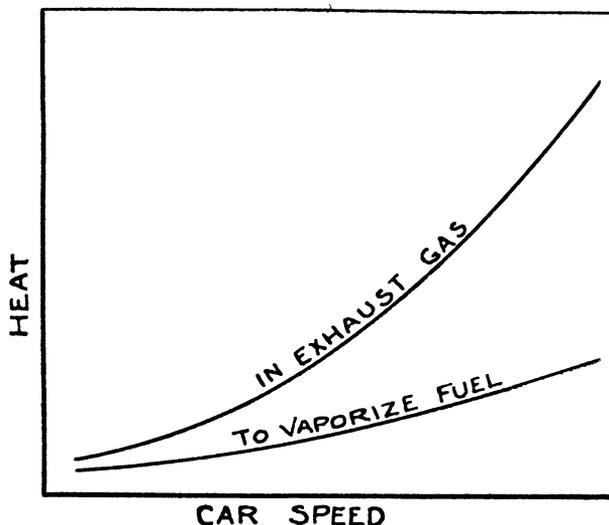


FIG. 11—CURVES SHOWING THE GENERAL RELATION BETWEEN THE HEAT REQUIRED TO VAPORIZE FUEL AND THAT PRESENT IN THE EXHAUST GAS AT DIFFERENT CAR SPEEDS

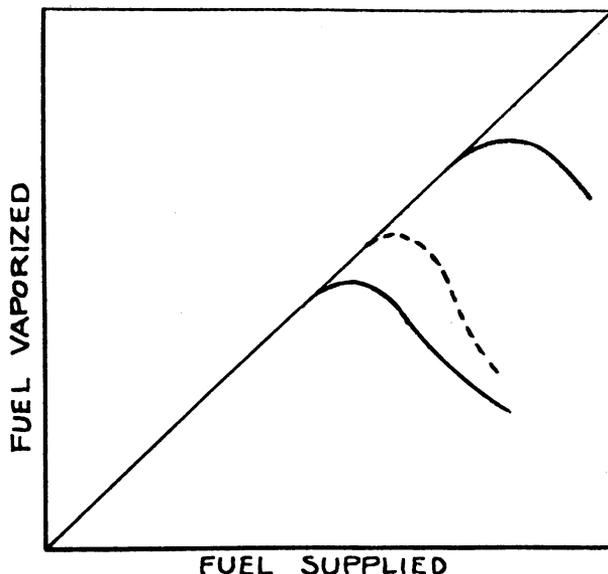


FIG. 12—CURVES OF THE CAPACITY FOR VAPORIZING FUEL

that a simple flow of liquid, either in streams or in a thin film over a heated surface, did not result in a usefully high vaporizing capacity expressed in terms of weight of fuel evaporated from a unit surface in a unit time. The authors' plots of time versus temperature of a hot plate show in some measure why this is so. Furthermore, it soon was found that the effective capacity of a unit surface depends very importantly upon the manner in which the liquid is brought to the surface; this, in general, was independent of the temperature of the surface.

Briefly, the highest vaporizing capacity of a unit surface results from finely spraying the fuel upon a hot surface at such a rate as just to fall short of wetting the surface. When the fuel is so applied, the vaporizing capacity of a unit surface having a given amount of available heat is an inverse function of the size of the liquid particles or globules. With an intake embodying this idea and arranged so that the vaporized fuel can be quantitatively determined, plottings of capacity assume the general form shown in Fig. 12. Each curve represents a constantly available quantity of heat at a constant temperature. As soon as the surface shows wetting, the ratio  $Q/V$  starts to fall with great rapidity. The dotted

curve shows the general effect of increasing the division of the liquid before it comes into contact with the heated surface.

Not only does this spraying method greatly increase the capacity of a unit surface under given heat-supply conditions, but it makes possible the uniform loading of whatever surface is employed. Most important of all, I believe, the spheroidal condition is never found at any temperature encountered in such a system. From the spacings of the curves in Fig. 12, it is seen that an increased heat application under car-operating conditions results in an increase in capacity. This increase is substantially one of direct proportionality so long as wetting of the surface is avoided.

A plotting of the required vaporizing surface versus car speed, for any car, assumes the form shown in Fig. 13. Such a result shows that the end of the range of operation that determines the extent of surface for vaporization is that of the small load and low-speed. Having designed for this set of conditions, the remainder of the range takes care of itself. If it were physically possible to apply all the fuel in the form of a fine spray to a surface of 2 sq. in., this surface would be adequate to secure dryness in the intake of a Ford engine, provided heat could be made available to it at a sufficient rate.

The practically controlling factor in the use of the method of finely spraying the fuel upon a heated surface, is not the extent of the surface per se, but the application of the spray to that surface. That is to say, the heated surface must be so located and of such a size as to include all the fuel particles. The fact that the liquid is finely divided presupposes that it is occupying a considerable volume. To return to the case of the Ford engine, the extent of vaporizing surface to give complete dryness under all conditions is represented by the surface and one end of a cylinder 2 in. in diameter and  $\frac{3}{4}$  in. long, or a total area of 8 sq. in. Further practical service considerations make it desirable to exceed by from two to three times the extent of surface actually needed to secure dryness under normal operation.

Let us consider the case where a man goes to his unheated garage, starts his car, drives off at about 20 m.p.h. and continues to run at that rate until the temperatures throughout the engine shall have come into equilibrium. The first temperature to do so will be that of the exhaust; but one must run for some 20 min. or more be-

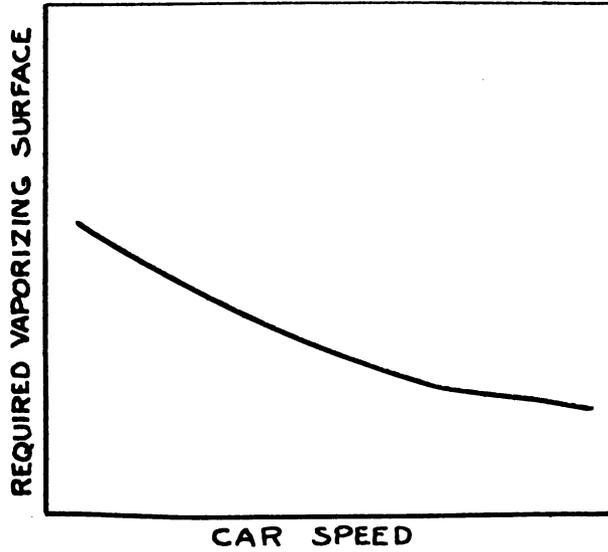


FIG. 13—THE RELATION BETWEEN THE REQUIRED AMOUNT OF SURFACE TO VAPORIZE THE FUEL AND THE CAR SPEED

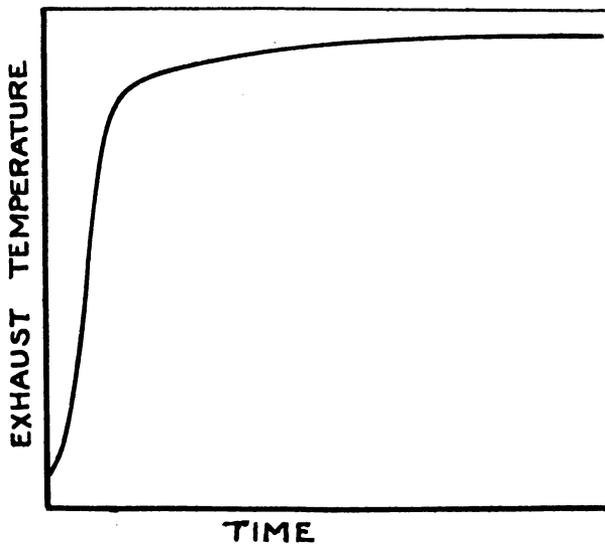


FIG. 14—HOW THE EXHAUST TEMPERATURE INCREASES AS THE TIME OF RUNNING INCREASES

fore that temperature becomes stable, as indicated in Fig. 14. This means that, for several minutes after starting, liquid fuel will pass into the cylinders and cause more or less trouble in addition to impoverishing the effective mixture.

Practically to eliminate this condition, it is my practice to make the extent of the vaporizing surface two to three times that actually needed. This enlargement of the vaporizing surface in no way alters the normal temperatures of the charge, but it does enormously accelerate their rise to normal values.

L. C. MARBURG:—In these curves showing temperatures at varying speeds, how was the variable speed obtained? Was the spark changed or was the speed secured entirely by opening and closing the throttle? If the latter was the case, where was the spark set? It seems to me that the curve must be different with an early spark than with a late one.

E. D. THURSTON, JR.:—How were the exhaust temperatures measured and at just what point? I know of some experiments which showed that, in the movement of the thermocouple or other means employed, a very short distance will make a considerable difference in the temperatures found for the exhaust gases.

R. E. WILSON:—How did the temperature at which this spheroidal condition began compare with the end-point of the fuel? An interesting fact in connection with the work of these authors is that the composition of the mixture boiling at a constant rate on the hot-spot that is described was presumably identical with what we have prepared and termed the "equilibrium solution" in determining the "condensation temperatures" of fuels. It is also interesting to note that the temperature of the liquid when it takes on the spheroidal condition must actually be *lower* than that of the more rapidly vaporizing liquid when the temperature of the metal is lower. In other words, as we go for a considerable distance above the point where the spheroidal condition is approached, the *higher* the temperature of the metal is, the *lower* the temperature of the liquid will be, since the rate of vaporization of the liquid is a good measure of its mean effective temperature. This undoubtedly accounts for the fact that less decomposition was observed when the fuel was in the spheroidal condition than when the rate of vaporization was at a maximum just before the spheroidal condition was approached.

O. C. BERRY:—Mr. Tice has developed a method of vaporizing liquid fuel by spraying it onto a heated surface. As he points out, the amount of fuel that can be vaporized per square inch of surface is greater under these conditions than when the liquid flows onto the heated surface. We are therefore pleased to get his figures showing the rates of vaporization that can be obtained in this way. The fact nevertheless remains that the majority of heated manifolds make use of the other method, and the figures presented in this paper are directly applicable to these cases.

We do not wish either Mr. Tice's remarks or our own to be interpreted as indicating that the critical condition for a manifold, or the one where failure is most likely to occur, is when operating at low speed and low load. This is more critical than when higher speeds or higher loads are maintained steadily, but the real danger point is when a heavy load is thrown upon the engine immediately following an extended period of slow-speed low-power operation.

In reply to Mr. Marburg, the various speeds were obtained by changing the load on the dynamometer. The throttle was wide-open in all cases for the full-load tests. The spark setting was a compromise and was kept constant at all speeds at the same load during a variable-speed series.

In reply to Mr. Thurston, the location of the thermocouple was near exhaust-valve No. 5. The thermocouple was allowed to project into the intake-manifold, into the gases themselves. Considerable care was taken to insulate the wire from the metal by asbestos, to prevent the flow of heat from the wires to the exhaust-manifold wall. One can well understand that the wires would have considerable heat-conducting capacity and, if they were brought into intimate contact with the colder metals of the exhaust-manifold, the temperature recorded would be much too low. It is true that the temperature will vary markedly with any change in the location of the thermocouple. It is our effort here not to get exact figures that would be universally applicable, but simply to get a general idea of the magnitude of the forces with which we have to deal.

As to Professor Wilson's question of the comparison of the spheroidal state and the end-point, unfortunately I had not thought of it in that way. One can take from

the curves the temperature at which the spheroidal state begins, and we have figures showing the distillation curves of the fuel in 10-per cent increments. The endpoint is given in each case.

## PHOTOGRAPHIC RECORDING OF ENGINE DATA<sup>1</sup>

BY AUGUSTUS TROWBRIDGE<sup>2</sup>

Believing that it is one of the functions of the purely scientific man to direct engineering attention to practical possibilities that will be of use in solving important problems, the author outlines the history of the photographic recording apparatus he describes later in detail and comments upon its general features that are of advantage in engineering practice, with illustrations, inclusive of the use that is made of the string galvanometer.

The subject of indicators for high-speed engines is discussed in general terms introductory to a full and detailed description of how this automatic photographic recording apparatus can be used to overcome difficulties that pertain to ordinary indicator-diagrams taken on the internal-combustion engine by former methods. A further use of this apparatus is in anti-knock research and its recent usage for this purpose is described and illustrated.

Until a few years ago I shared what I believe to be the general feeling among technical scientific men that photographic methods of recording experimental data such as pressure-volume variations in an engine cylinder, vibrations of shafting and motion or timing of valves, could not be rendered sufficiently simple, cleancut and foolproof to be reliable in the hands of the ordinary intelligent mechanic, but nearly two years' experience in France during the war convinced me that photographic recording is the quickest, cheapest, most cleancut and foolproof method that exists. I was in charge of the sound-ranging service in the American Army, the object of which was to locate the positions of the enemy large-caliber guns by record-

<sup>1</sup> Annual Meeting paper.

<sup>2</sup> Professor of physics, Princeton University, Princeton, N. J.