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EFFECT OF ENGINE OPERATING CONDITIONS ON THE VAPORIZATION OF SAFETY FUELS

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EFFECT OF ENGINE OPERATING CONDITIONS ON THE VAPORIZATION OF SAFETY FUELS

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SUMMARY

Tests were conducted with the N.A.C.A. combustion apparatus to determine the effect of compression ratio and engine temperature on the vaporization of a hydrogenated "safety fuel" during the compression stroke under conditions similar to those in a spark-ignition engine. The effect of fuel boiling temperature on vaporization using gasoline, safety fuel, and Diesel fuel oil was also investigated. The results show that increasing the compression ratio has little effect on the rate of fuel vaporization, but that increasing the air temperature by increasing the engine temperature increases the rate of fuel vaporization. The results also show that the vaporized fuel forms a homogeneous mixture with the air more rapidly than does the atomized fuel spray.

INTRODUCTION

During the past few years considerable work has been done on various methods of diminishing the fire hazard in aircraft. The work has been divided into two general divisions: first, by improvement in the design of the intake and exhaust manifolds so as to lessen the probability of fire originating in the manifolds due either to back fires or crashes in which fuel comes in contact with the exhaust manifolds; second, by the use of fuels having a flash point higher than that of gasoline. Research in the second division has led to extensive investigations on the compression-ignition engine and to the more recent investigations on the use of hydrogenated safety fuels in the spark-ignition engine. The decrease in the fire hazard resulting from the use of safety fuels is due to the fact that their flash point is higher than that of the commercial gasolines, although not as high as the flash point of the fuels used in compression-ignition engines. The exact relationship between flash point of a fuel and its probability of causing fire in aircraft is not definitely known. However, a fuel with a flash point of 105°F. or greater is generally considered to present no fire hazard under ordinary conditions of handling. There have been no fires recorded with airplanes operating with compression-ignition engines although it must be remembered that the number of miles flown with such engines is very small in comparison to those flown with the conventional spark-ignition engines.

The use of low volatility fuels in spark-ignition engines is not new. Immediately following the World War there was considerable research conducted in Germany on this problem. The purpose in this case was, however, to determine the possibility of using cheaper domestic fuels in automobile engines. More recently research has been conducted both in this country and in France on the use of low volatility fuels to decrease the fire hazard in aircraft.

In the tests conducted in France with the "Ferrier" fuel which has a flash point of 63°F. satisfactory engine performance was obtained by heating the incoming mixture. Under this condition, although idling was not as satisfactory as with gasoline, the engine power and the fuel consumption were both slightly improved. The disadvantage of heating the incoming mixture is, as Grebel has pointed out (reference 1), that the danger of igniting the mixture from back fire is not eliminated.

Tests have been made by Schey and Young at this laboratory in which a single-cylinder test engine has been operated on safety fuels at nominal compression ratio. In these tests the carburetor was replaced by a conventional fuel-injection system such as is used on compression-ignition engines. The results showed that although the power obtained with the safety fuels was only slightly less than that obtained with gasoline, the fuel consumption was considerably increased. However, when the engine-coolant temperature was increased from 150°F. to 240°F. the fuel consumption with the safety fuel was materially decreased. At the time these tests were being conducted it was decided to conduct additional tests on the vaporization of safety fuel under several conditions of engine operation, as this physical characteristic of the fuel is considerably different from that of gasoline.

It is the purpose of this report to present the results of the vaporization tests, together with a brief analysis of their significance. The work was done by the National Advisory Committee for Aeronautics during the early part of 1932.

APPARATUS AND METHODS

The N.A.C.A. combustion apparatus was used for this investigation because it is designed to take high-speed moving pictures of the fuel injection process under conditions closely simulating those in internal-combustion engines. The apparatus has been completely described in reference 2. Diagrammatic sketches of the engine and injection system and of the photographic apparatus are shown in Figures 1 and 2. The windows have an unsupported diameter of 2.5 inches. The compression-release valve as described in reference 2 was also used in these tests.

The injection valve was of the automatic spring-loaded type. The multiorifice, fuel-discharge nozzle is shown in Figure 3. Three fuels were tested: hydrogenated safety fuel, gasoline, and Diesel fuel. The two latter were introduced to form a comparison of the effect of fuel volatility on the vaporization, the three fuels (fig. 4) covering considerable range in regard to this physical characteristic.

The operation of the apparatus is as follows: The engine is brought up to speed. The compression-release valve is then closed. After a few revolutions under compression a single charge of fuel is injected into the combustion chamber. Simultaneously with the injection the electric condensers are consecutively discharged at the rate of 1,000 discharges per second. The electric sparks across the gap in the reflector caused by the discharge of the condensers form the light source for taking the photographs of the fuel spray. The injection can be timed relative to the position of the crankshaft by means of the timing gear shown in Figure 1.

The temperature of the glycerin in the jackets of the combustion chamber and cylinder was varied between 100°F. and 250°F. The compression ratio was varied between 12.7 and 5.5 (the higher ratio being used for the sake of comparison) by increasing the distance between the glass walls of the combustion chamber. This increase of distance resulted in increased air velocities being produced between the cylinder and combustion chamber at the lower compression ratios. However, as the test results show, these air velocities were insufficient to have an appreciable effect on the fuel spray.

The following conditions were maintained constant unless otherwise stated:

Compression ratio	8.5
Fuel quantity per injection	0.00042 lb.
Outgoing glycerin temperature	100° F.
Engine bore	5 in.
Engine stroke	7 "
Engine speed	1,500 r.p.m.

In a four-stroke-cycle, spark-ignition, fuel-injection engine, injection takes place on the intake stroke and possibly during the first part of the compression stroke. This condition could not be obtained in the present tests because of the limitations of the apparatus. The greatest injection advance angle (I.A.A.) used in the present tests was 90 to 100 crank degrees before top center on the compression stroke. However, this limitation does not affect the interpretation of the results nor does it affect the physical phenomena which it is the purpose of these tests to show. In order to observe the vaporization of the fuel over a considerable range of crank angles, injection advance angles of approximately 40° before top center and of 0° before top center were also used.

TEST RESULTS AND DISCUSSION

Effect of compression ratio on vaporization.- Figures 5, 6, and 7 show the effect of the compression ratio on the vaporization of safety fuel at the three different injection advance angles. Vaporization of the fuel is shown by the disappearance of the fuel spray following injection cut-off. With an injection advance of approximately 90° before top center the fuel apparently vaporized more rapidly at the lower compression ratios than at the higher. With injection starting at approximately 35° before top center the time of vaporization was about the same for all compression ratios as was also the time of condensation. (The condensation of the fuel on the down-stroke of the piston is indicated by the blocking out of the light from the spark discharges which appears in the exposures at approximately 40° after top center.) The highest ratio showed some light to be transmitted until 70° after top center. This condition is probably caused by unequal distribution of the fuel vapor before condensation. With injection starting at top center the vaporization apparently improved as the compression ratio was increased although in every case the start of condensation was still approximately at 40° after top center.

Effect of the boiling temperature of the fuel.- Figure 8 shows the effect of the boiling temperatures of the fuel on the vaporization and condensation at three different injection advance angles. As was shown in reference 3 the higher the boiling range of the fuel the slower the vaporization of the spray in the engine and the sooner the fuel condenses, provided that combustion does not take place. With injection starting at top center the spray is visible for all three fuels but the completeness of the vaporization is decreased as the boiling temperature of the fuel is increased. With an injection advance angle of 35° to 45° the spray of the Diesel fuel is always visible after the start of injection, whereas it disappears with both the safety fuel and the gasoline. For injection starting at 90° before top center the Diesel fuel spray is visible until slightly after top center, whereas with the safety fuel no spray is visible after 20° before top center, and with the gasoline no spray is visible after 40° before top center.

Effect of engine temperature on vaporization.- Figure 9 shows the effect of engine temperature on the vaporization of the safety-fuel spray. With an injection advance angle of 90° the engine temperature decreased the time of vaporization. In the photographs for the later injection advance angles it is seen that the increase in engine temperature increased the time interval before condensation occurred.

ANALYSIS

With either fuel injection or conventional carburetion the mixture of the fuel and air in the engine cylinder is caused by two actions; first, by the dispersion of the small fuel drops throughout the air in the engine cylinder; and second, by the diffusion of the fuel vapor as it leaves the liquid drops. The spray photographs presented in this report show that there is little difference between the rate of diffusion of the atomized fuel drops for the three different fuels. In any case, as Figure 8 shows, the diffusion of the drops is not particularly rapid. The bottom photograph of Figure 7 shows that even after a period of 120 crank degrees the safety fuel had not formed a uniform mixture with the air in the combustion chamber. In fact, in no case was there any indication that a uniform mixture of air and fuel was formed before the fuel was vaporized. However, an examination of the first three photographs in Figure 8 shows that when vaporization took place the mixture became much more homogeneous than when vaporization did not take place. The homogeneity is shown by the fact that with gasoline in which vaporization was apparently quite complete, even at an injection advance angle of 0°, the condensed vapors blocked out all the light from the spark discharges within 10° after condensation started. On the other hand, with neither the safety fuel nor Diesel fuel in which the vaporization was less complete was all the light from the spark discharge obstructed. We can conclude, therefore, that the diffusion of the fuel vapors is more rapid than that of the small fuel drops in the atomized spray even though these drops had mean diameters in the neighborhood of 0.002 inch, as has been shown by Lee. (Reference 4.) Consequently, the vaporization of the fuel becomes an extremely important factor in determining the suitability of a fuel for spark-ignition engines.

Comparing Figures 5, 6, and 7 with Figure 9 we see that increasing the temperature in the engine cylinder by means of increasing the compression ratio had much less effect on the vaporization than did increasing the air temperature by means of heating the engine. An examination of the computed temperatures and pressures (assuming constant ratio of specific heats of 1.35) during the compression stroke gives an explanation of this phenomenon. The rate of vaporization of a fuel drop depends, among other things, on the excess of the air temperature over the boiling temperature of the drop. It must be remembered that we are dealing with extremely small quantities of a complex mixture of hydrocarbons in each individual drop so that accurate experimental data on the boiling temperatures are not available. However, qualitative results can be obtained from the data that have been determined. Consider the vapor-pressure curves of gasoline and kerosene as given in reference 6. (Kerosene is chosen in place of safety fuel because no vapor-pressure data are available for the latter and because their boiling ranges at atmospheric pressure are close together.) From these data the difference between the air temperature in the cylinder and the boiling temperature of the liquid under the same conditions of pressure as exist in the engine can be obtained. Such curves are shown for gasoline and kerosene in Figures 10 and 11, respectively. With gasoline an initial temperature of 760° F. absolute and a compression ratio of 6.5 the excess of the air temperature over the fuel-boiling temperature was always greater than with an initial temperature of 660° F. absolute and a compression ratio of 12.7 until 4° before top center. With the kerosene under the conditions mentioned in the preceding sentence the excess temperature with the 6.5 compression ratio remained greater than that with the 12.7 compression ratio until 10° before top center. The experimental and computed data showing the relationship between fuel-boiling temperature and engine air temperature are therefore in support of the experimental data already discussed. It can be concluded that increasing the compression ratio of a spark-ignition engine will not have any appreciable effect on the vaporization of the atomized fuel, but that increasing the temperature of the air in the cylinder either by increasing the temperature of entering air or by increasing the temperature of the engine will increase the rate of vaporization and therefore the rate of mixture formation.

CONCLUSIONS

The conclusions drawn from these tests are that in a fuel-injection spark-ignition engine:

1. The rate at which a uniform mixture of air and fuel is formed in an engine is more rapid with vaporized fuel than with unvaporized fuel.

2. Using a fuel of higher flash point to decrease the fire hazard results in a decrease in rate of vapor formation in the engine cylinder and consequently a decrease in the rate of mixture formation as compared with a more volatile fuel.

3. Increasing the compression ratio of an engine has little effect on the rate of fuel vaporization and consequently of mixture formation.

4. Increasing the temperature of the air during the compression stroke by increasing the engine temperature increases the fuel vaporization and rate of mixture formation considerably.

Langley Memorial Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., August 1, 1932.

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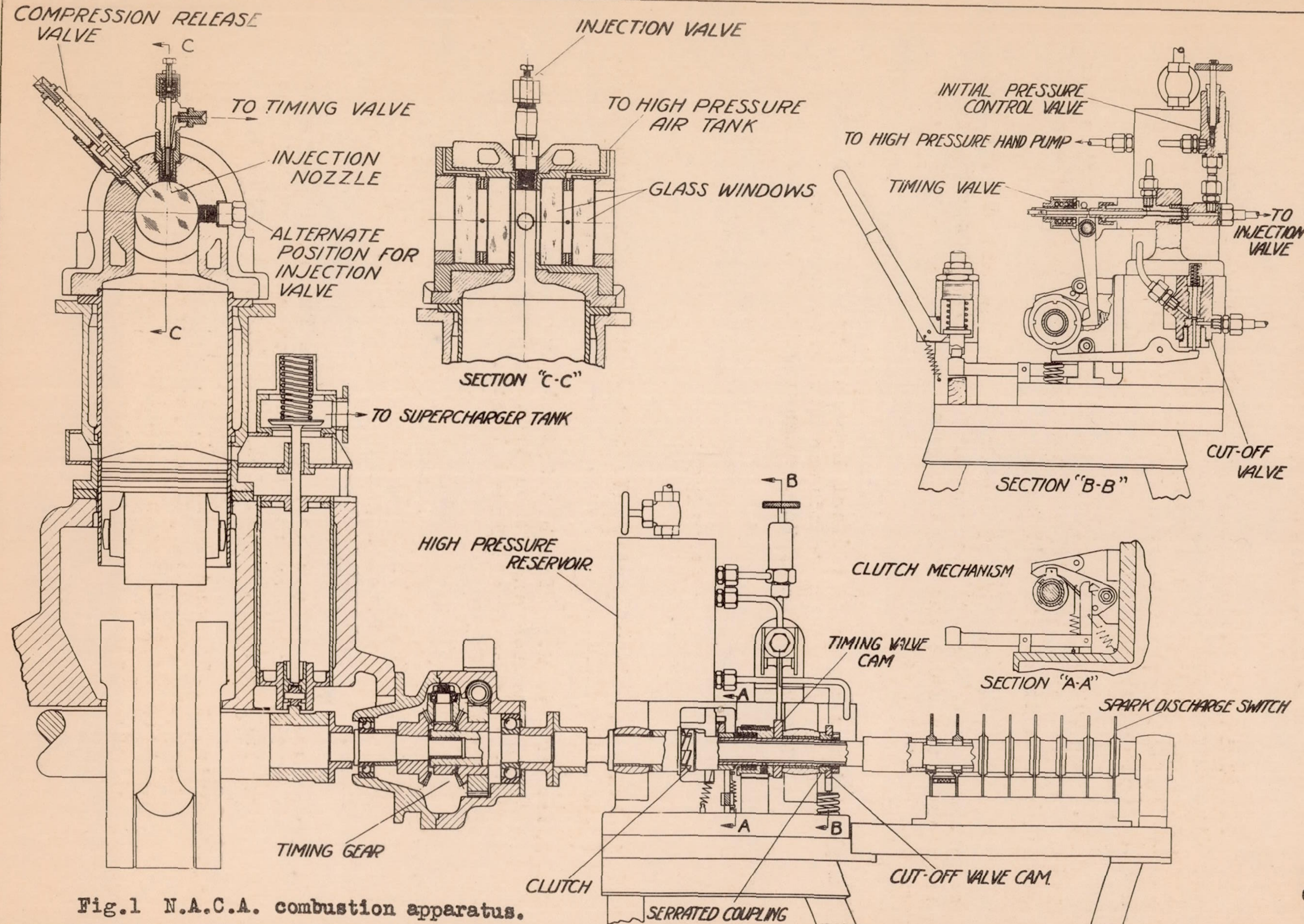


Fig.1 N.A.C.A. combustion apparatus.

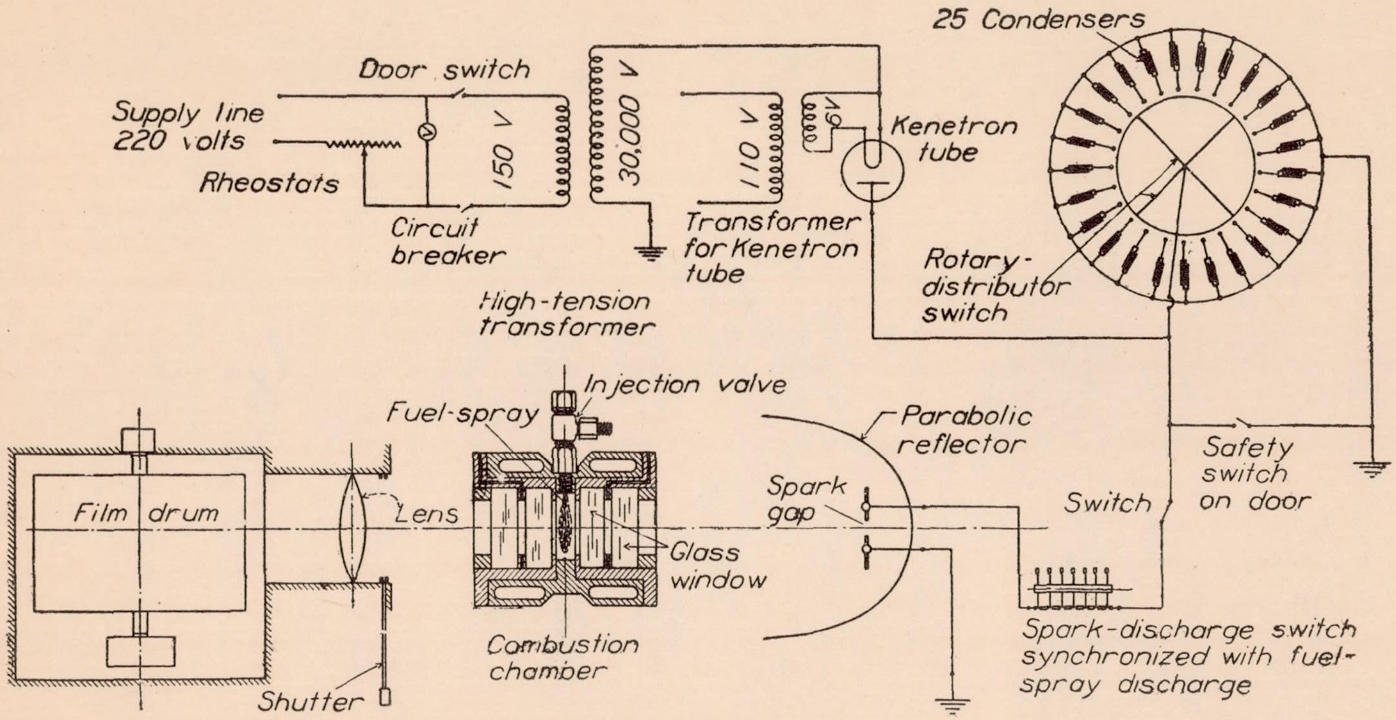
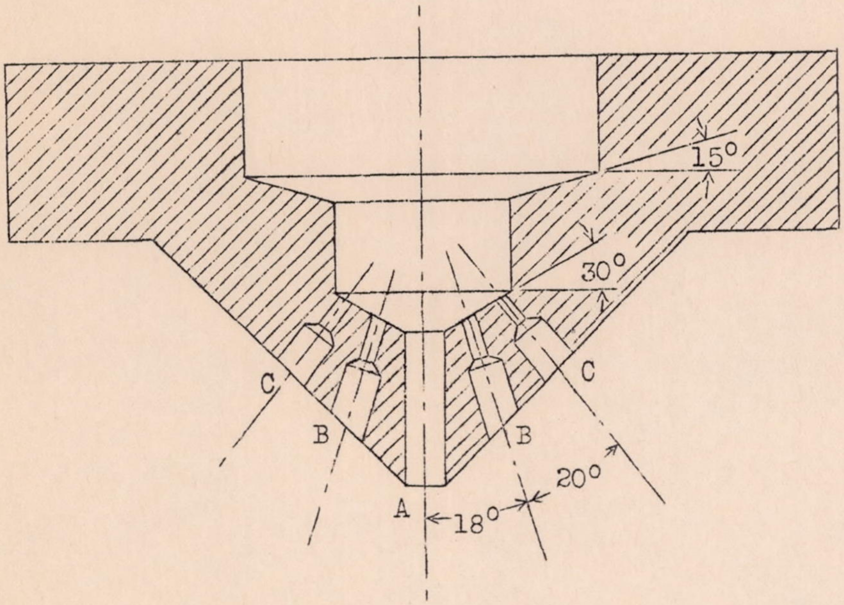


Fig. 2 Photographic apparatus.



Orifice	Diameter	Length
A	0.020	0.080
B	.012	.024
C	.006	.018

Fig. 3 Fuel discharge nozzle used in tests

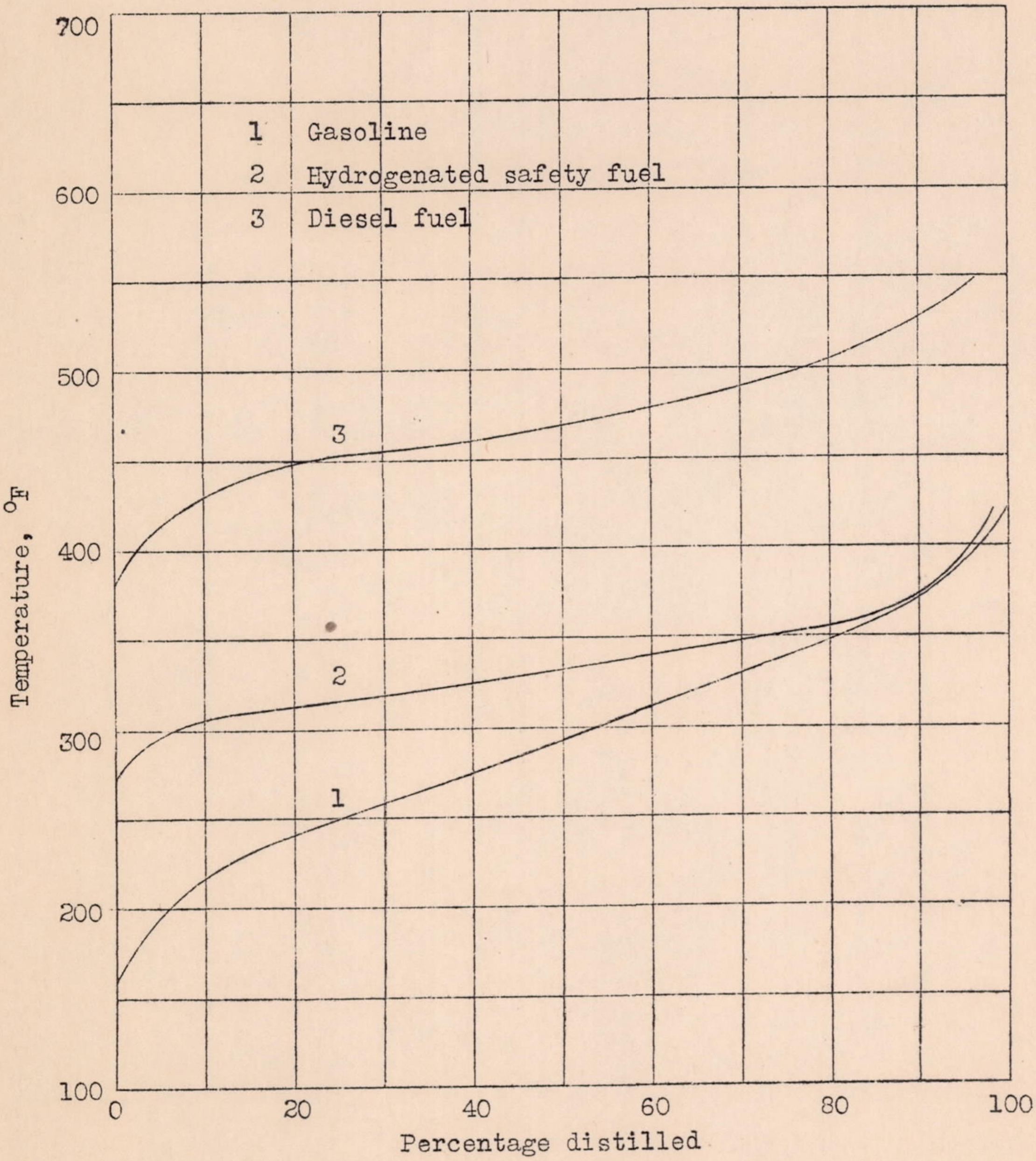


Fig. 4 Distillation curves of fuels tested (A.S.T.M. method)

Injection advance angle 85° - 90° B.T.C. Engine temperature 100°F

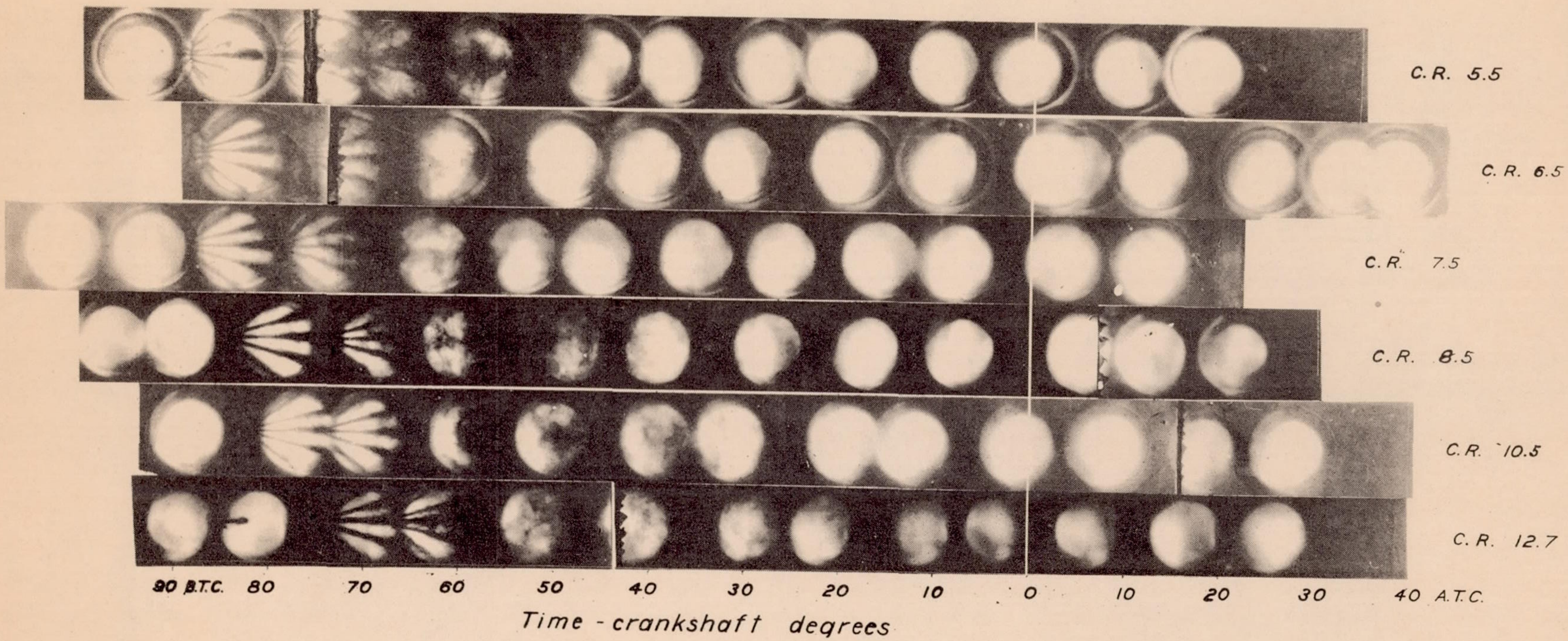


Fig.5 Effect of compression ratio on vaporization of safety fuel.

Injection advance angle 45° - 35° B.T.C. Engine temperature 100°F

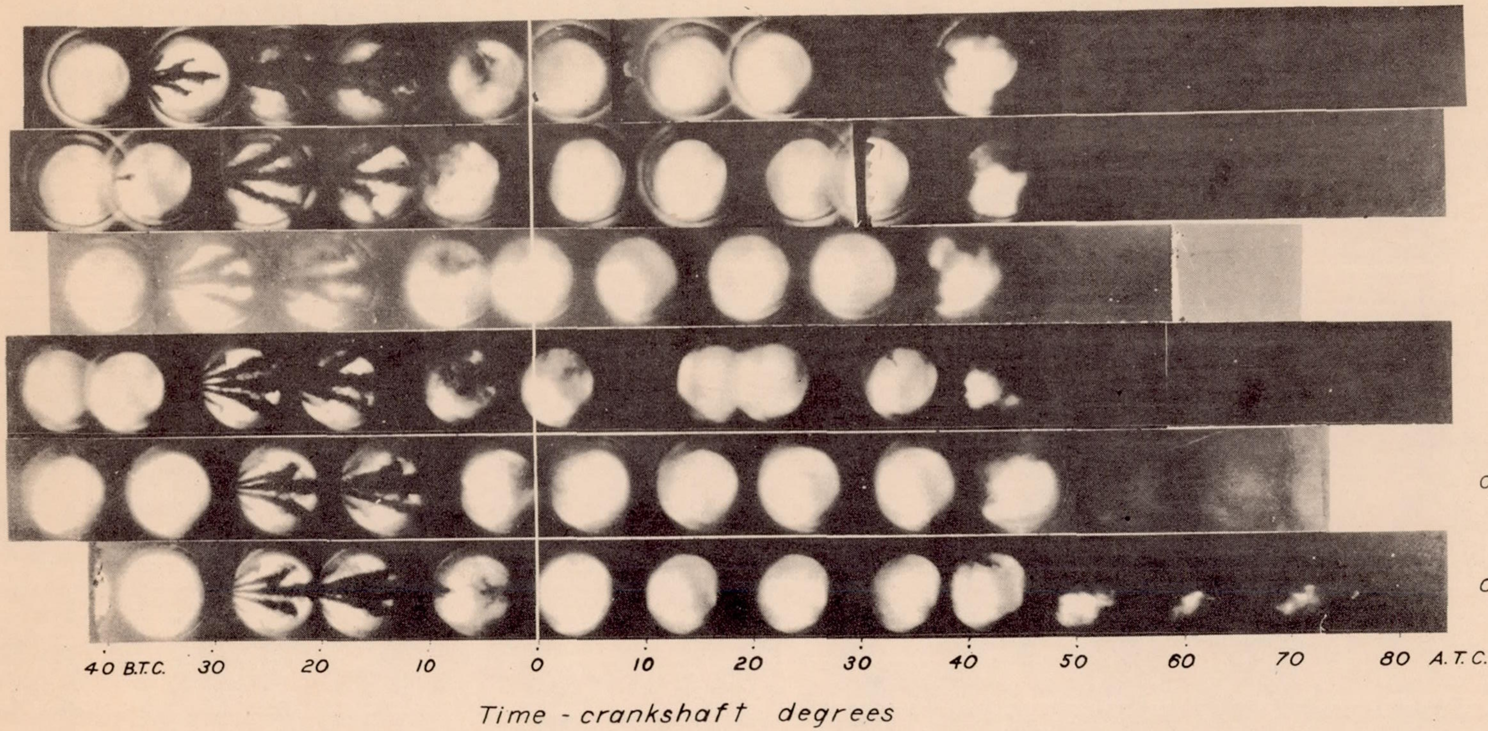


Fig.6 Effect of compression ratio on vaporization of safety fuel.

Injection advance angle 5° - 0° B.T.C. Engine temperature 100°F

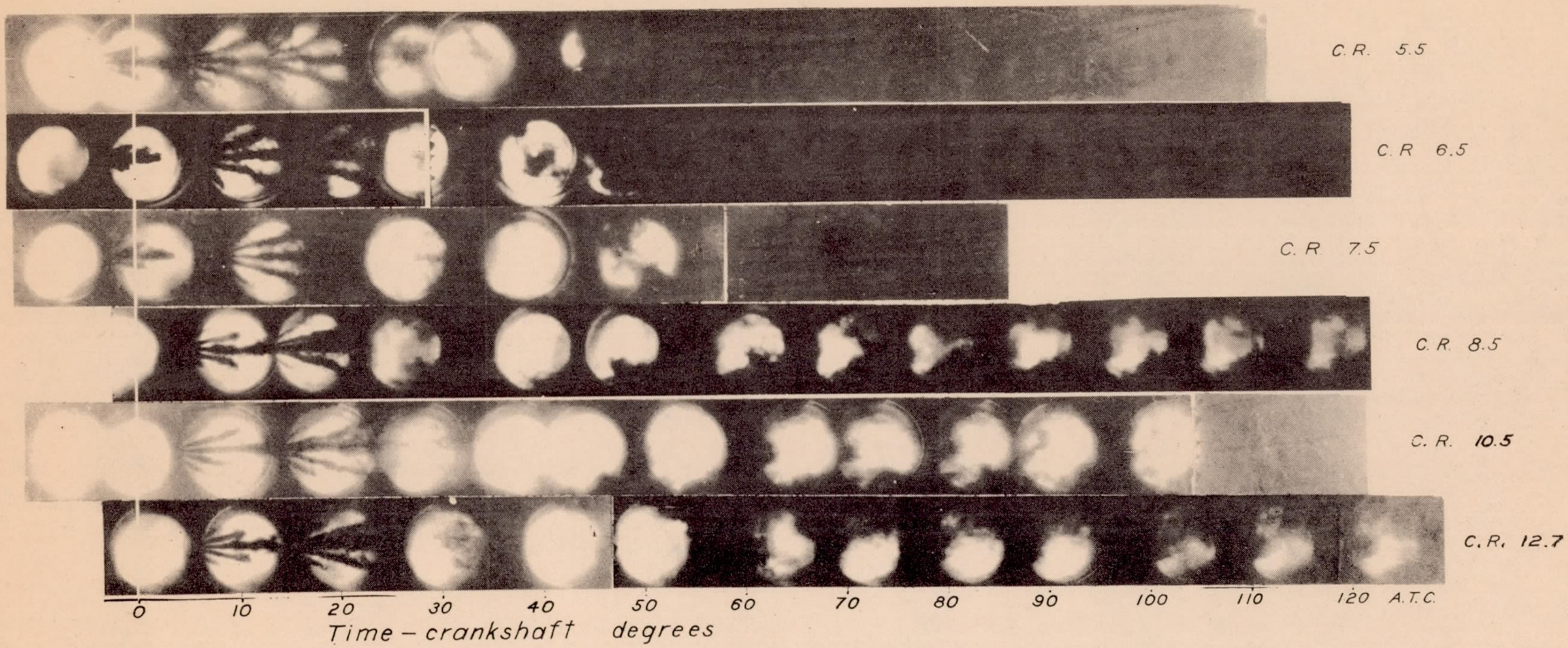


Fig.7 Effect of compression ratio on the vaporization of safety fuel.

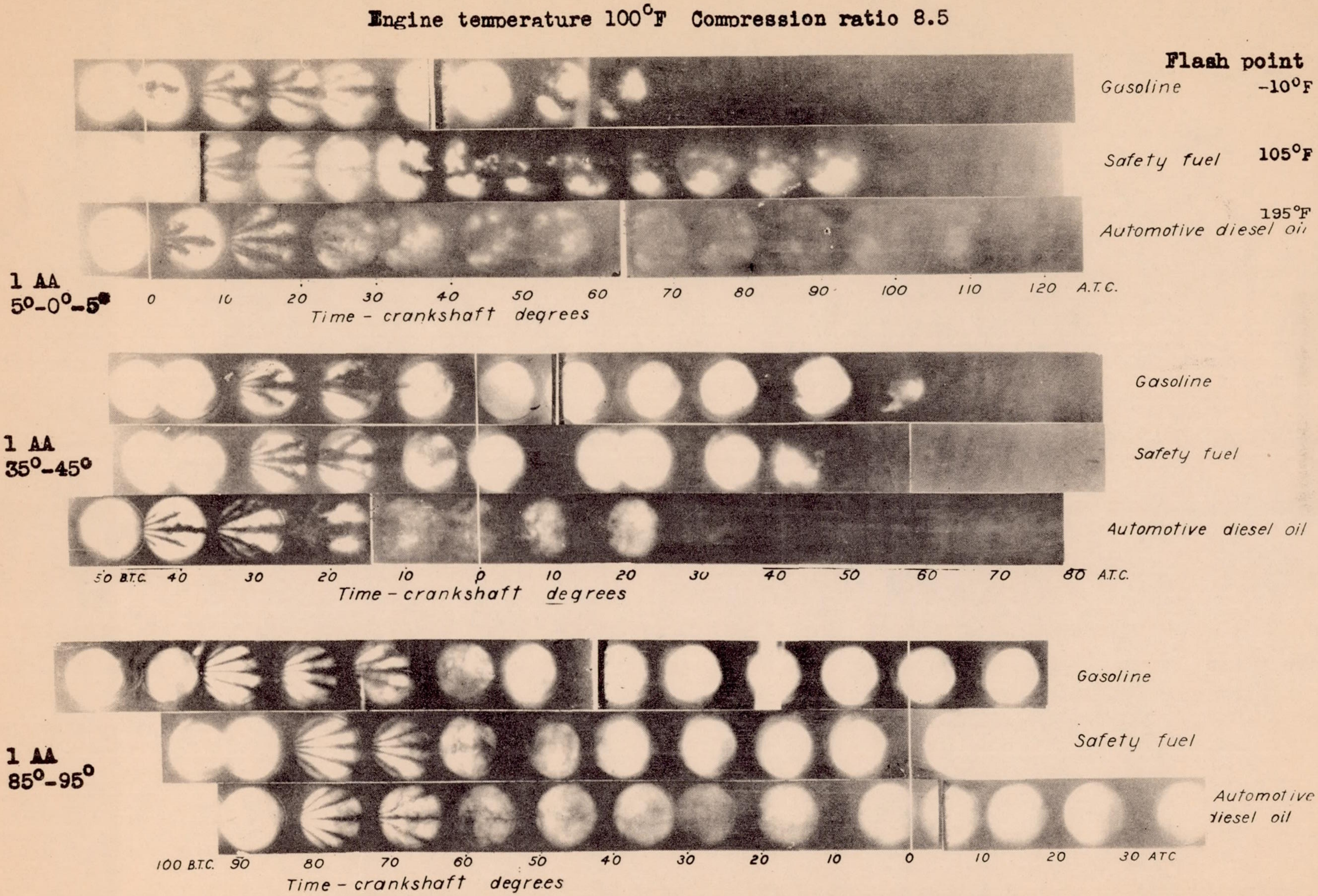


Fig.8 Effect of fuel boiling temperature on vaporization.

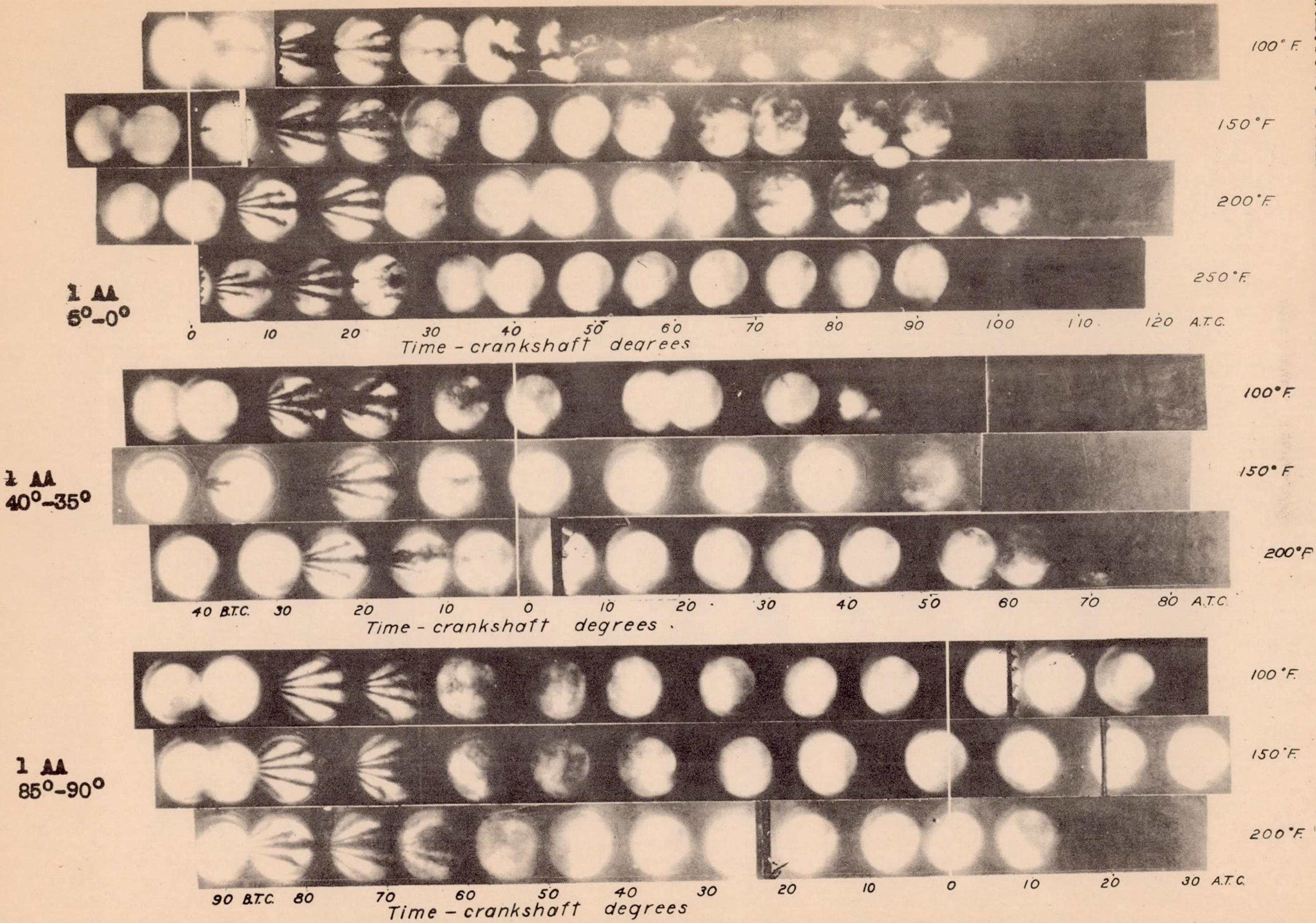


Fig.9 Effect of engine temperature on the vaporization of safety fuel. Compression ratio 8.5

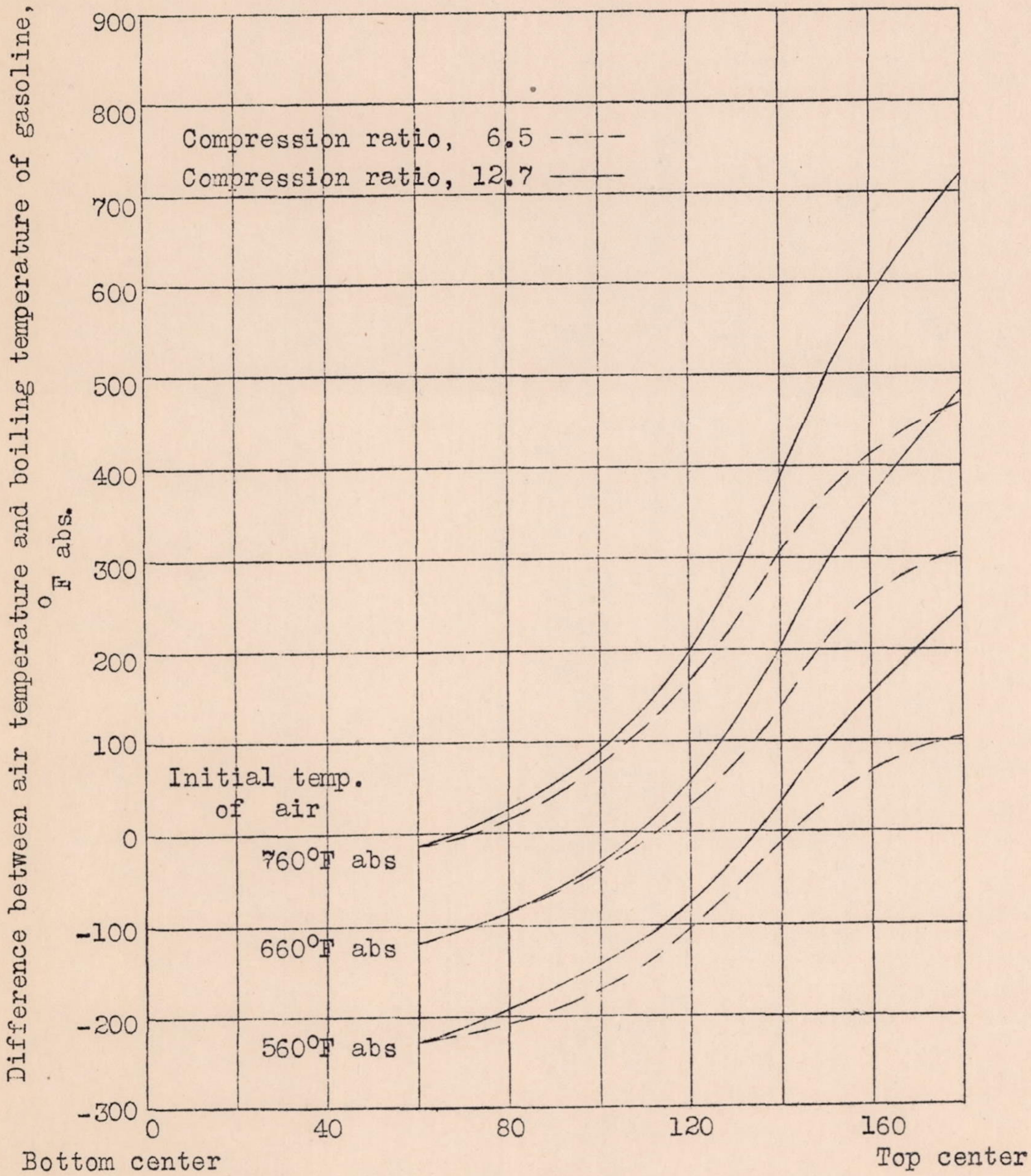


Fig. 10 Effect of initial air temperature and compression ratio on difference between air temperature and boiling temperature of gasoline.

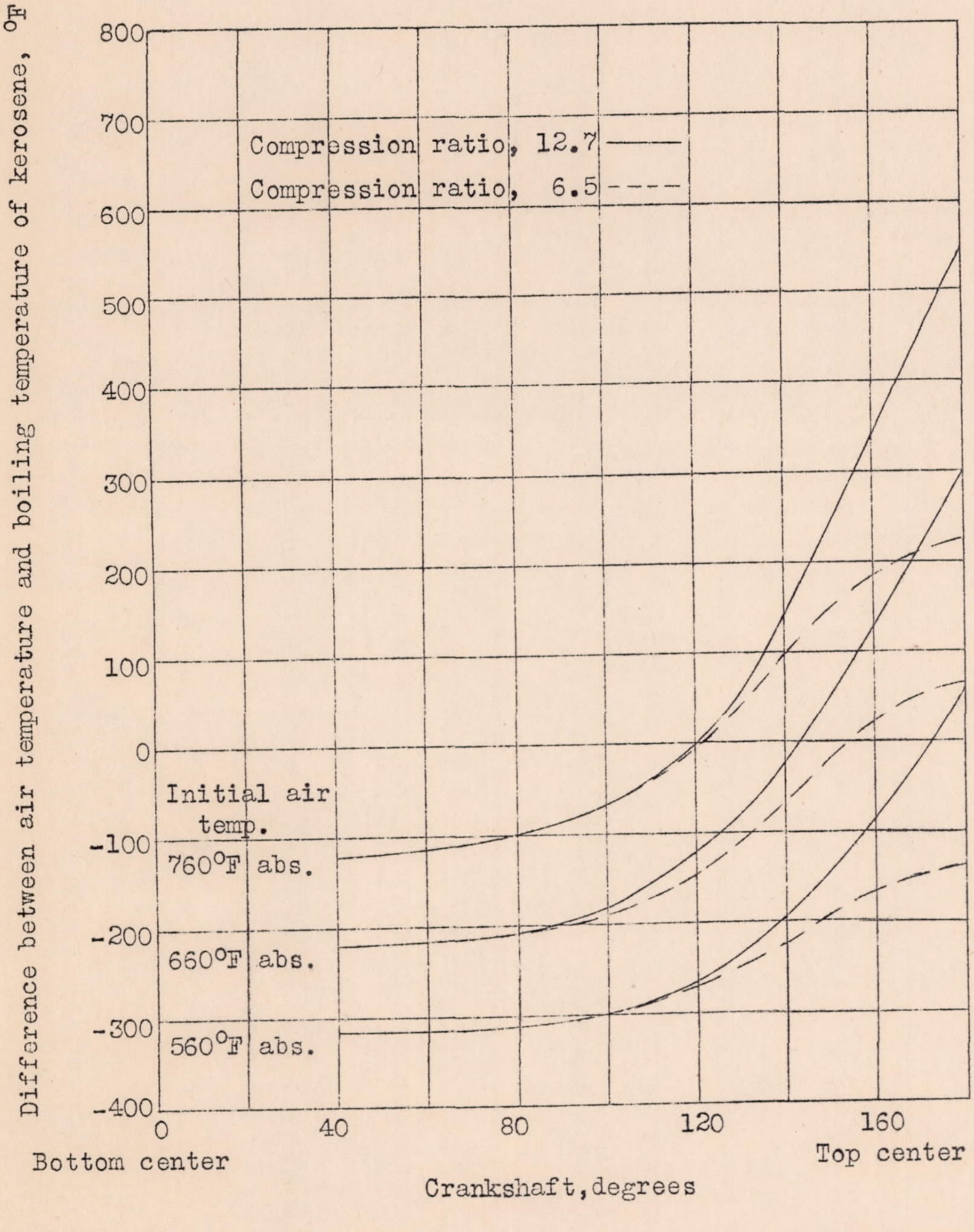


Fig. 11 Effect of initial air temperature and compression ratio on difference between air temperature and boiling temperature of kerosene.