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SOME EFFECTS OF AIR AND FUEL OIL TEMPERATURES ON SPRAY PENETRATION AND DISPERSION

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SOME EFFECTS OF AIR AND FUEL OIL TEMPERATURES ON SPRAY PENETRATION AND DISPERSION.

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Summary

This note presents experimental results obtained from a brief investigation of the appearance, penetration, and dispersion of oil sprays injected into a chamber of highly heated air at atmospheric pressure.

The development of single sprays injected into a chamber containing air at room temperature and at high temperature was recorded by means of the N.A.C.A. spray photography equipment.

A comparison of the spray records showed that with the air at the higher temperature the spray assumed the appearance of a thin, transparent cloud, the greatest part of which rapidly disappeared from view. With the chamber air at room temperature a compact spray with an opaque core was obtained. Measurements of the records showed a decrease in penetration and increase in dispersion of the spray injected into the heated air. No ignition of the fuel injected was observed or recorded until the spray particles came in contact with the much hotter walls of the chamber about 0.3 second after the start of injection.

Introduction

Most of the research work carried out thus far on the various factors affecting the characteristics of fuel sprays for compression-ignition engines has been conducted at room temperatures. The design of an engine with favorable ignition lag and efficient burning of the fuel injected, however, requires among other things a knowledge of the effect on the spray of the factors involved under the temperature and pressure conditions in actual engine operation. The investigations that have been made on sprays injected into air and other gases at varying pressures and temperatures indicate that the temperatures of the fuel and air considerably influence spray penetration and dispersion. An outstanding investigation on oil sprays injected into heated air was presented in a paper by Bird (Reference 1). He found that increasing the temperature of the fuel decreased penetration and increased dispersion of the spray. Increasing the viscosity of the air alone by increasing its temperature had no appreciable effect on penetration. As the spray advanced through the heated air in the chamber, however, a large part of the fuel was vaporized.

The purpose of this note is to present spray records and data obtained from a brief investigation of the appearance, penetration, and dispersion of oil sprays when injected into air at high temperature and atmospheric pressure.

Methods and Apparatus

The method employed in this investigation was to record by means of the N.A.C.A. spray photography equipment (Reference 2) the development of single sprays injected from an automatic injection valve into heated air. With this apparatus, motion pictures at the rate of 2000 per second were taken of a single fuel spray.

A diagrammatic arrangement of the heating chamber and of the fuel injection system is shown in Figure 1. A special spray chamber was installed in which the air could be heated to a high temperature by means of electric heating coils. This chamber was a sheet steel cylinder, with closed ends, $5\frac{1}{2}$ inches in diameter and 18 inches in length. It had two mica windows 1/64 inch thick along its entire length through which the spray was photographed. The chamber was insulated with asbestos covering. Nichrome wire heating coils were mounted on hard asbestos millboard crosspieces, as shown in the figure. Asbestos coverings were also placed over the windows, while the chamber air was being heated to the desired temperature. A calibrated pyrometer-thermocouple unit was used to indicate the temperature of the air in the chamber at about 4 inches from the tip of the nozzle and in the spray path. The thermocouple was not shielded against radiation from the walls, and consequently the indicated temperatures were possibly several hundred degrees higher than the actual temperature of the air in the chamber. The temperatures given throughout this note for the air in the chamber are those indicated by the pyrometer with the thermocouple thus connected. For these tests, provisions were made to water-cool the injection valve while heating the air in the chamber. The fuel injection system and its operation are fully described in a previous report of the Committee (Reference 2).

A high-grade Diesel fuel oil having a specific gravity of 0.86 at 80°F. was used. The discharge orifice in the injection valve had a diameter of 0.004 inch. Injection pressures of 4000, 6000, and 8000 pounds per square inch were employed. Since the spray chamber was not air-tight, all tests were made at atmospheric pressure. Air temperatures of 800° and 1100°F. as indicated by the thermocouple, were used for the tests with the heated air. The temperature of the fuel oil for the tests with the heated air was 110°F. at the junction of the injection tube and injection valve, and for the tests with the unheated air was at room temperature, which varied from 70° to 80°F.

The test procedure was as follows: The asbestos window coverings were clamped in position at the start of each test. The electric current was turned on to the heating coils. Fifteen to twenty minutes later the pyrometer indicated the approximate desired temperature. Fifteen minutes were allowed for the pyrometer reading to become steady, after which the fuel pressure in the injection system was brought up to the test conditions and the thermocouple was withdrawn from the spray path.

The asbestos window coverings were then rapidly lifted out of the path of the light to be projected on to the spray and, at the same time, the oil spray was injected into the heated air of the chamber. The time required from the instant the asbestos coverings were lifted from the mica windows until the spray was injected and photographed was less than 1 second.

Results and Discussion

The results obtained in this investigation are shown in Figures 2 to 6. A photographic record of the spray when injected from a 0.004-inch diameter orifice into air at atmospheric temperature and pressure is shown in Figure 2a. A record of the spray injected from the same orifice into air at an indicated temperature of 1100°F. and atmospheric pressure is shown in Figure 2b. The injection pressure in both cases was 4000 pounds per square inch. The oil at the entrance to the injection valve was at room temperature for record 2a, and at about 110°F. for 2b.

Comparing the two photographic records, the thinning out of the spray injected into the highly heated air is noticeable. The opaque core, which characterizes the spray injected into the air at atmospheric temperature and pressure, appears to have changed into a translucent cloud when injected into the heated air. Following the cut-off of injection, which comes between 0.002 and 0.003 second after the start, there are left only traces of the fuel when injected into the air at high temperature, and these rapidly disappear from view. Whether this thinning out and rapid disappearance of the spray is due to the vaporization, or whether the size of the spray particles was so small and the dispersion so great that the particles would not reflect sufficient light to be photographed, cannot be definitely concluded.

A photographic record of the spray injected into air at room temperature and atmospheric pressure, but with an injection pressure of 8000 pounds per square inch is shown in Figure 3a. A record of the spray injected into air at an indicated temperature of 1100°F., and with the same injection pressure, is shown in Figure 3b. The temperatures in the fuel injection system were approximately the same as for the sprays of Figure 2. The same fading out of the spray injected into the heated air is noticeable. After cut-off of injection, there is only a slender core left extending about 3 inches from the tip of the nozzle. Part of the spray can be observed in the act of breaking away from the main body, and the greatest part of the fuel injected into the heated air is rapidly lost to view. However, comparing Figure 2b with 3b, it will be observed that after cut-off the visible volume of the spray injected at 4000 pounds per square inch injection pressure remained suspended along the entire length of its penetration. On the other hand, the bulk of the visible spray injected at 8000 pounds per square inch penetrated to a distance of about 4 inches before losing its velocity, and then remained suspended as a gradually disappearing cloud.

This rapid diminishing in volume of the spray when injected into the heated air is well illustrated by the photographs in Figure 4. These spray records were taken with the heating chamber at right angles to the position at which the records of Figures 2 and 3 were taken. The injection pressure was 6000 pounds per square inch and the chamber pressure atmospheric. The air in the chamber for the record of Figure 4a was at room temperature, and for Figure 4b was 800°F. Although the individual spray pictures cannot be clearly distinguished because of overlapping and the further disadvantage of unfavorable light reflecting conditions for the Figure 4b, the records serve to show the rapid disappearance from view of the spray injected into the heated air as compared to that injected into air at room temperature. In Figure 4a, the injected fuel persists in the form of a mist until the end of the photographs. In Figure 4b it fades from view almost immediately after cut-off.

Penetration-time curves obtained from the spray records of Figures 2 and 3 are plotted in Figures 5 and 6, respectively. Both sets of curves show a marked decrease in penetration of the spray when injected into the heated air. The work by Beardsley (Reference 3) has shown that for room temperatures the penetration of the fuel spray is dependent upon the density of the medium into which it is injected. If this was the only factor affecting the spray penetration, the penetration into the heated air should have been the greater, because the density was only one-third that of the air at room temperature. Evidently, other factors such as the viscosity of the medium and of the fuel, initial velocity, and size of spray particles, which vary with temperature, have considerable effect on spray penetration.

An examination of the records shows that the loss of penetration by the sprays injected into the heated air was accompanied by a gain in the dispersion. This appears more pronounced with the spray injected at 8000 pounds per square inch injection pressure, indicating that both higher temperature and higher injection pressure favor spray dispersion.

No attempt has been made in this brief investigation to vary separately each one of the factors affecting the spray penetration and atomization. However, the combined effect of the decrease of oil viscosity, increase of chamber air viscosity, and the decrease of air density, by the increase of oil and air temperature, can be clearly seen by examining and comparing the spray records presented. The decreased penetration and the increased dispersion of the spray are probably due to the increase of the oil temperature as was found by Bird (Reference 1). Thus, the decreased penetrative power of the spray caused by the increase in fuel temperature more than offsets the decreased resistance of the air caused by the lowering of its density. The fading out of the spray is probably due to the air temperature which caused the injected fuel to diffuse with the surrounding air.

The results of repeated observations during these tests showed that there was no visible ignition of the spray until it reached the side walls of the chamber. The photographic records show no flame, although they extend for 0.008 second after the start of injection. The film used was sufficiently sensitive to record the appearance of the flame had there been any. The fuel particles burst into a flame only when they came close to or actually in contact with the side walls of the chamber, where the temperature was estimated from the color of the steel walls to be approximately 1400°F. A record obtained with a slow moving film drum showed the appearance of a flame about 0.3 second after the start of injection.

Neumann (Reference 4) gives the relation of ignition temperature to density of air, which he derived from the experimental results of Tausz and Schulte, as

$$t_s = C\,\gamma^{-m} - 460$$

where

t_s is the lowest temperature in degrees Fahrenheit at which ignition occurs.

C and m are constants which, for fuels composed primarily of aliphatic hydrocarbons, are given as 819 and 0.16, respectively.

γ is the density of the air in pounds per cubic foot.

For the density at the temperature of 1100°F. and atmospheric pressure, t_s equals 1010°F., which is about 100°F. below the temperature indicated in these tests. Neumann found that for an initial pressure of 8 atmospheres, an ignition temperature of 510°F. and an air temperature of 610°F., the ignition time delay was 0.2 second.

Even had the actual temperature of the air been that indicated by the pyrometer-thermocouple unit, the ignition delay of 0.3 second was comparable to that obtained by Neumann for the same temperature difference.

Conclusions

The spray records and test results presented show that immediately after injection, under the conditions of these tests, the spray that was injected into air at an indicated temperature of 1100°F. assumed the appearance of a cloud which rapidly disappeared from view. An examination of the spray records and the curves plotted from these records shows that the changed properties of air and fuel under high temperatures decreased the penetration and increased the dispersion of the oil sprays.

Langley Memorial Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., April 14, 1930.

References

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3. Joachim, W. F. and Beardsley, E. G. : The Effects of Fuel and Cylinder Gas Densities on the Characteristics of Fuel Sprays for Oil Engines. N.A.C.A. Technical Report No. 281, 1927.

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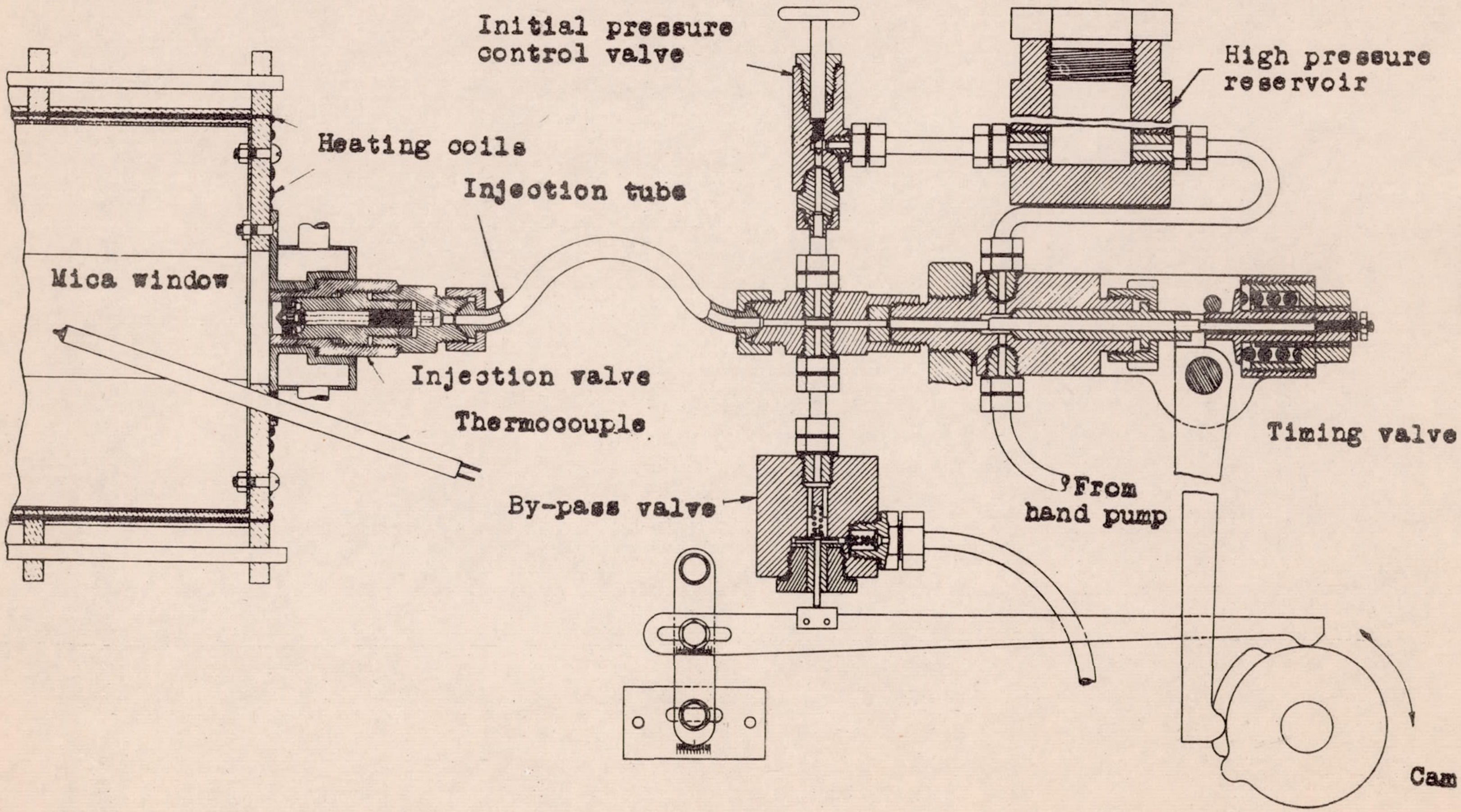

Fig.1 Fuel spray injection system.

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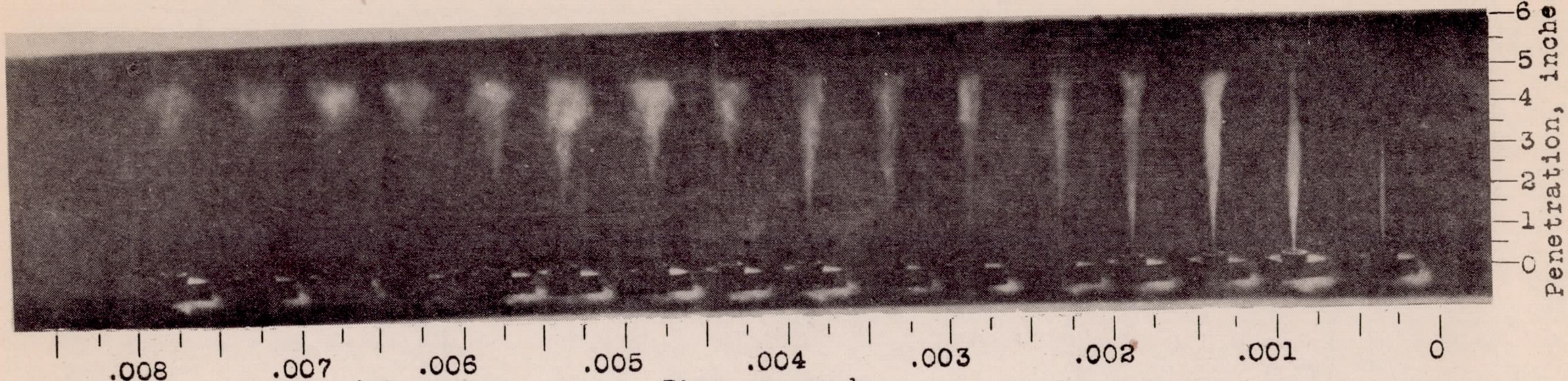
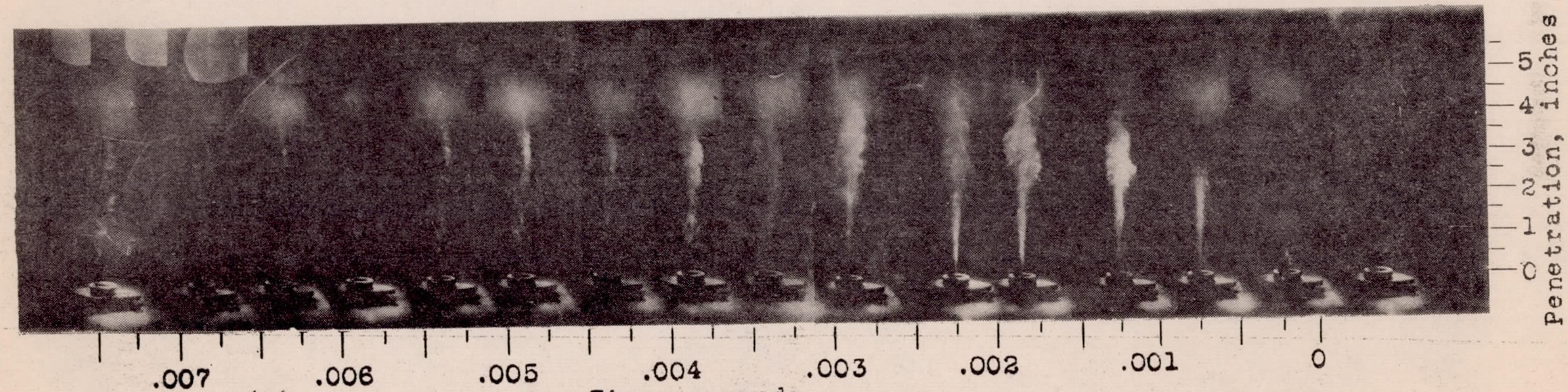


(a)

Chamber air and fuel oil at room temperature



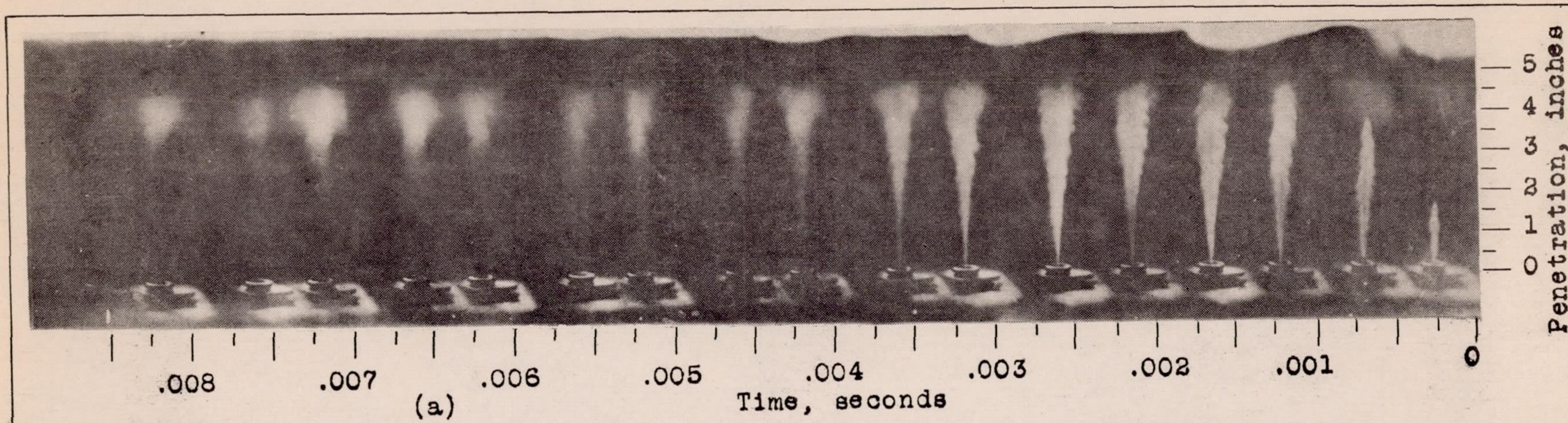
(b)

Indicated chamber air temperature 1100°F. Fuel oil temperature 110°F.

Fig.3 Effect of air and fuel oil temperatures on oil sprays.

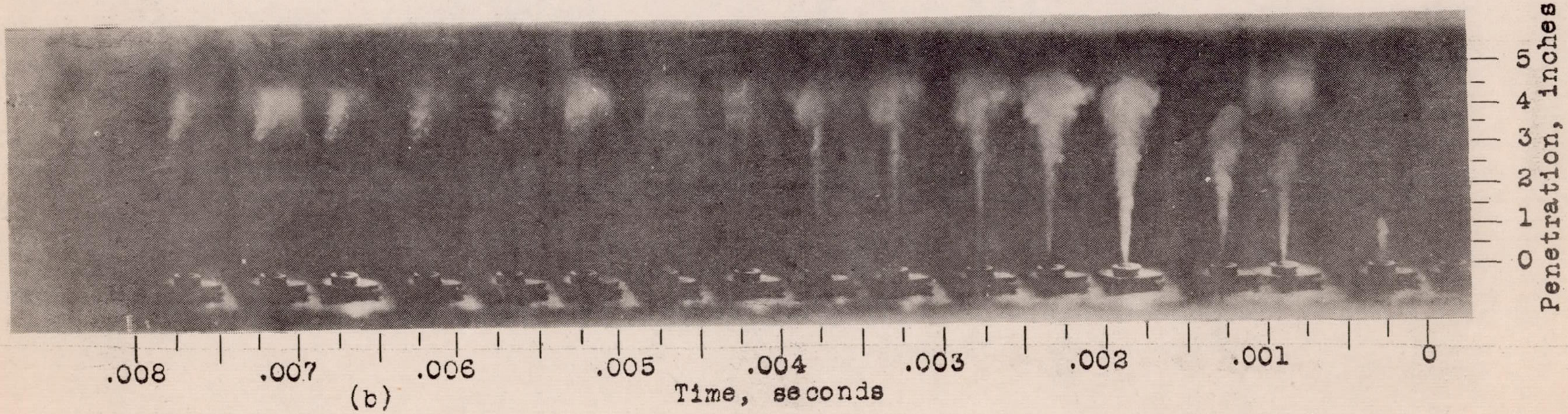
Orifice diameter .004 inch.
Chamber pressure atmospheric.

Injection pressure 4000 lb. per square inch.



(a)

Chamber air and fuel oil at room temperature.



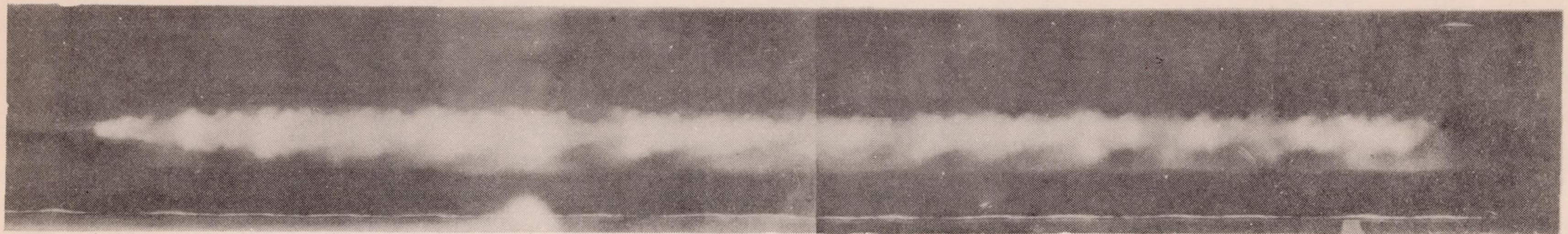
(b)

Indicated chamber air temperature 1100°F. Fuel oil temperature 110°F.

Fig.3 Effect of air and fuel oil temperature on oil sprays.

Orifice diameter .004 inch.
Chamber pressure atmospheric.

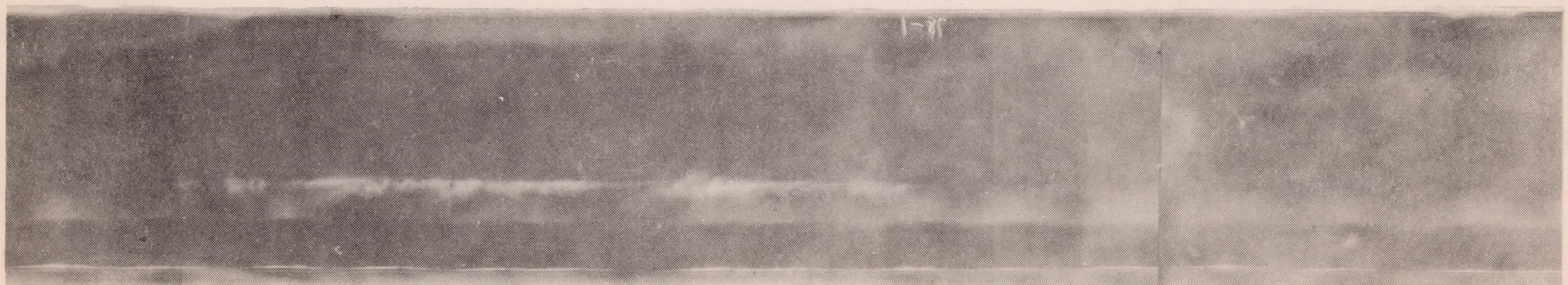
Injection pressure 8000 lb. per square inch.



.000 .001 .002 .003 .004 .005 .006 .007 .008

(a) Time, seconds

Chamber air and fuel oil at room temperature



.000 .001 .002 .003 .004 .005 .006 .007 .008

(b) Time, seconds

Indicated chamber air temperature 800°F. Fuel oil temperature 110°F.

Fig.4 Effect of air and fuel oil temperature on oil sprays.

Chamber pressure atmospheric. Injection pressure 6000 lb. per square inch.

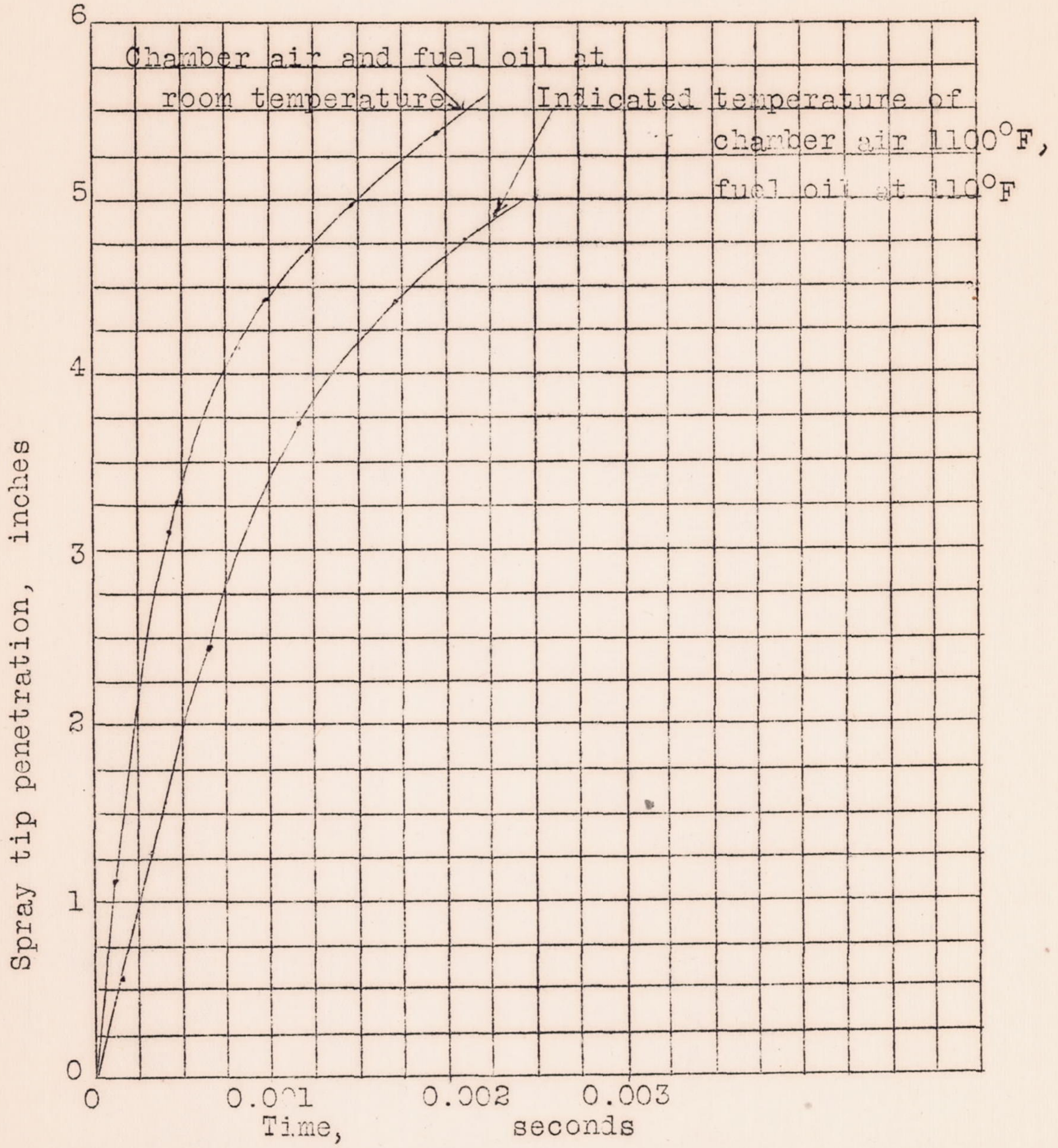


Fig.5 Effect of air and fuel oil temperature on spray penetration. Orifice diameter 0.004 inches. Injection pressures 4000 lb. per square inch. Chamber pressure atmospheric.

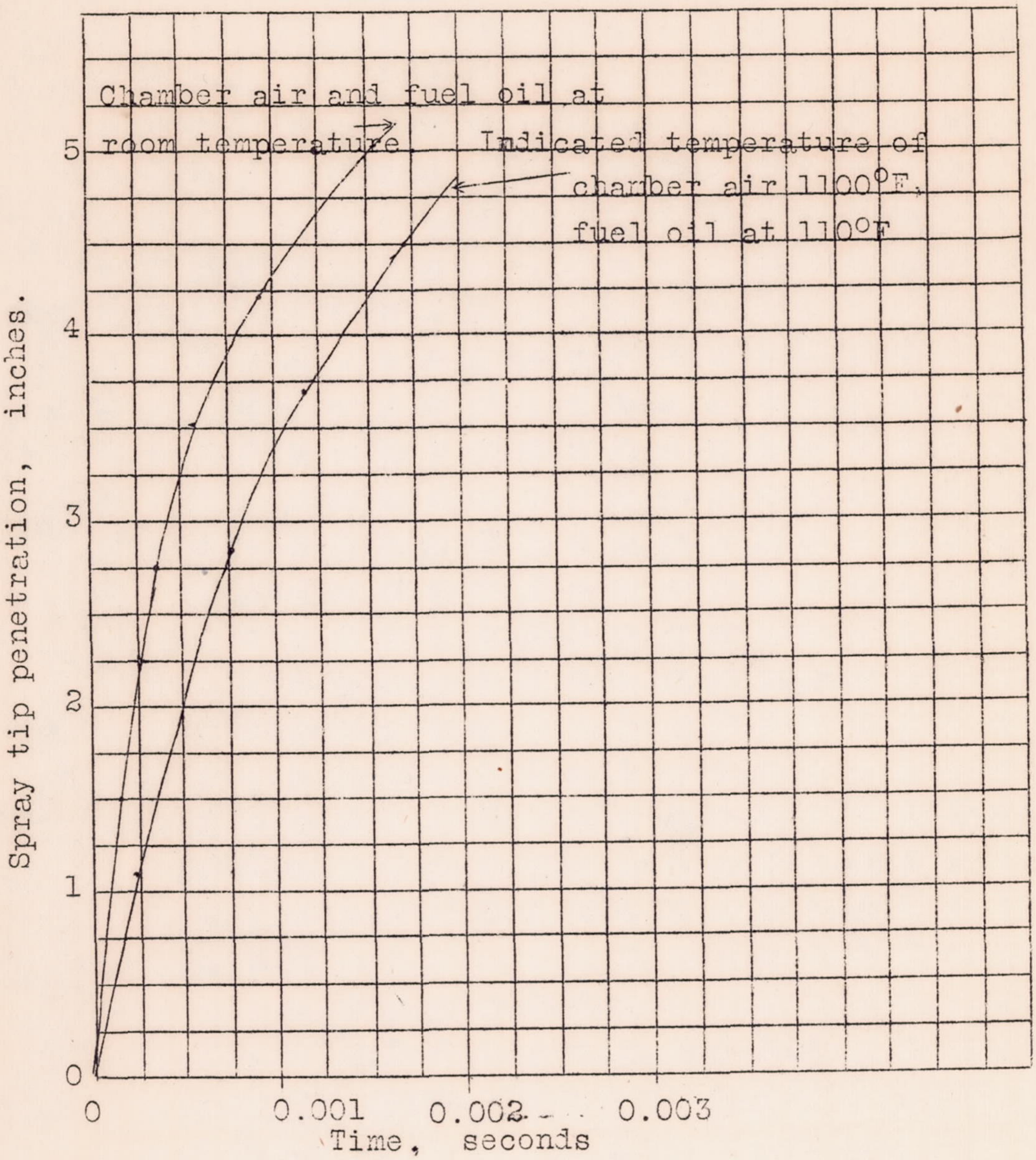


Fig.6 Effect of air and feul oil temperature on spray penetration. Orifice diameter 0.004 inches. Injection pressure 8000 lb. per square inch. Chamber pressure atmospheric.