TECHNICAL MEMORANDUMS

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

No. 390

DETERMINING SIZE OF DROPS IN FUEL MIXTURE OF INTERNAL COMBUSTION ENGINES

By J. Sauter

From "Zeitschrift des Vereines deutscher Ingenieure"
July 31, 1926

Washington
December, 1926

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS.

TECHNICAL MEMORANDUM NO. 390.

DETERMINING SIZE OF DROPS IN FUEL MIXTURE OF INTERNAL COMBUSTION ENGINES.*

By J. Sauter.

In compressorless Diesel engines and in explosion engines using fuels with high boiling points, it is difficult to effect a good combustion of the fuel mixture. For this reason many attempts have been made in recent years to discover the processes involved in the formation of the fuel mixture.

Fineness and lack of uniformity of mixture.- In internal combustion engines the atomized fuel is mixed with air. Aside from the uniform distribution of the fuel drops, the combustion properties of the mixture depend, for a given fuel, mainly on the fineness of the atomization. Experiments show that the size of the drops in a fuel mixture varies greatly.** While the smallest drops have diameters of only a few thousandths of a millimeter, other drops have diameters of 0.1 mm (0.004 in.) and more. The quality of a fuel mixture, as regards its combustion properties, depends on the following considerations.

---

* "Grossenbestimmung der Brennstofftropfen im Gemischnebel von Verbrennungskraftmaschinen" from "Zeitschrift des Vereines deutscher Ingenieure," July 31, 1926, pp. 1040-1042.

** Cf. F. Hauser and G. Strohl, "Zeitschrift fur Technische Physik," 1924, p. 157.

With respect to the size of the fuel drops, a mixture is improved:

a) By the fineness of the atomization;

b) By the uniformity of the atomization, i.e., by diminishing the difference between the sizes of the individual drops. Great differences cause disturbances in the passage from the nozzle into the combustion chamber and also in the combustion.

In order to characterize the fineness of a mixture, one must measure the size of the drops or some function of the size. If the fuel drops were all of the same size, the fineness of the atomization would be given directly by the size of the drops. Since, however, there are always drops of very different sizes, the actual task is to determine their mean size.

The definition of the mean value to be chosen for given conditions depends on the object served by the mixture. The mean size of the drops must therefore be so defined that it will constitute a criterion for the combustion characteristics. The latter depend (other things being equal) essentially on the magnitude of the total surface area O of the drops into which a definite liquid volume V is converted. It can be demonstrated that the value $r_m = \frac{3V}{O}$ furnishes, as the mean size of the drops, a criterion for the combustion characteristics of fuel mixtures.

Aside from the fineness determined by the quantity r_m, the excellence of an atomization depends on its uniformity. The

more the individual drops differ from one another in size and the less uniform the mixture is, the less excellent the atomization. A criterion for the degree of lack of uniformity of a mixture can be deduced, and this must be a non-dimensional coefficient, in contradistinction to the mean size of the drops r_m which represents a linear dimension. The considerations which lead to this criterion are therefore just as complicated, so that reference must be made here to the complete work ("Forschungsarbeiten" published by the "Verein Deutscher Ingenieure," No 279).

The measurement and computation of the "degree of lack of uniformity" is difficult and tedious. One can therefore generally confine himself to the determination of the mean size of the drops as the most important quantity for the combustion characteristics of the mixture.

Methods.- The possible methods can be fundamentally divided into two groups. In one group a mean value of the drops can be found directly without measuring the individual drops. In the other group the individual drops are measured and the corresponding mean value is computed therefrom.

In order to determine the size of the individual drops, we must arrest the swiftly moving drops for the duration of the measurement. There are the following possible ways of doing this:

1. Catching the drops on a screen and measuring the spots with a microscope or ocular micrometer (F. Häuser and G. Strol, "Z. f. techn. Physik," 1924, pp. 157 and 624);

2. Brief illumination and microscopic observation or microphotography of the drop by the light of electric sparks (which cause the drops to appear at rest).

Among the numerous possibilities for the direct determination of the mean size of the drops, the following methods are included:

1. Catching the drops on a screen and determining their total volume V and their number n;*

2. Measuring the dynamic pressure exerted by the drops on a screen (W. Riehm, "Zeitschrift der Vereines deutscher Ingenieure," 1924, p.641);

3. Determining the mean size of the drops by measuring their vaporization speed (B. Klaften, "Motorwagen," 1921, pp. 221, 242 and 279).

4. Measuring the quantity of electricity carried by the particles, when the nozzle is charged to a certain potential;

5. Measuring photometrically the weakening of a ray of light transmitted through the mixture.

The above-mentioned methods furnish directly a mean value of the size of the drops, methods 3, 4 and 5, giving the value $r_m = \frac{3V}{O}$, while 1 and 2 yield a mean value differing from r_m.

* R. Kuehn, "Ueber die Zerstäubung flüssiger Brennstoffe" in "Motorwagen": 1924, July 10 and 20, Oct. 10 and 20, Nov. 30, Dec. 10; 1925, Jan. 30, Feb. 10 (for English translation, see N.A.C.A. T.M. 329, 330 and 331).

There is therefore a considerable number of possible methods for determining the mean size of the drops. In practice, however, a large share of them can not be used for exact measurements, partly due to the difficulties incident to their execution and partly because they can not be adapted to the desired experimental conditions. Some of the methods mentioned require much time for each measurement, thus rendering systematic experimentation very tedious.

Methods 4 and 5 fulfill the need of a rapid and sufficiently accurate process for determining the mean size of the drops. These were tested, under the conditions obtaining for explosion engines, with suitable apparatus as shown in Figs. 1-2. The making of the measurements is simple by both methods and requires but little time for sufficient accuracy.

Method 4 is based on the principle that the liquid particles become charged in leaving the mouth of the atomizing nozzle which, for example, is under an electric tension of 100 volts. If the mouth of the nozzle is spherical, then, since the drops may be regarded as small spheres, there exists a simple mathematical relation between the size of the drops and the quantity of electricity carried by them (F. Harms, "Annalen der Physik," 1903, p. 816 ff). If the drops are collected in an insulated vessel, they impart their electricity to the vessel, which thus becomes charged. The receiving vessel is grounded over a mirror galvanometer through which the electricity, imparted by the drops

to the vessel, continually flows away. The current i, indicated by the mirror galvanometer, and the volume V, of the liquid atomized per second, are measured. The mean size of the drops is then determined from the simple formula $r_m = K\frac{V}{i}$, in which K is a constant of the experimental apparatus.

In method 5, it can be demonstrated that there is a simple relation between the weakening of the light and the size of the drops. If it is first assumed that the drops are perfectly opaque, they then weaken the beam of light passing through the fuel mixture in proportion to the fineness of division of a given volume V of the liquid, since, with the fineness of the drops, their total superficial area and cross-sectional area increase. The opaque drops therefore cover a part of the beam of light in proportion to the fineness of the atomization. If a beam of light is passed through a fuel mixture, which is flowing through a tube of diameter D, perpendicular to the axis of the tube and if the volume v of air passing through per second, the volume V of the liquid atomized per second and the diminution U of the light in per cent of the undiminished light is measured, the mean size of the drops, in a not too dense and therefore not too light-reducing mixture ($U < 20\%$), can then be determined from the formula $r_m = 75\frac{VD}{vU}$, whereby U is read on the scale of the correspondingly calibrated photometer.

In dense fuel mixtures with fine atomization, where the

strength of the light is greatly reduced, it must be remembered that the drops (viewed in the direction of the light) partially shade one another and hence some of the drops do not weaken the light. Computation shows that instead of U another quantity u must be introduced which is connected with U by the equation $U = 100 \left(1 - e^{-\frac{u}{100}}\right)$. It is more practical to substitute the value of u obtained from this equation instead of the corresponding value U on the photometer scale. For mixtures of any desired density and fineness, the mean size of the drops is given by the formula $r_m = 75 \frac{VD}{vu}$.

The above equations apply to opaque drops, but in reality the drops are more or less transparent. In addition to the light passing between the drops, a certain share of the light passing through the drops also falls on the photometer screen. It may be demonstrated that this share can be made as small as desired by increasing the distance between the photometer screen and the mixture, so that the effect of the light passing through the drops falls below the sensitivity of the photometer and consequently does not affect the measurement. This circumstance is decisive for the practical applicability of this optical method, since very complicated relations would otherwise occur.

In the experiments water was used as the mixture-forming (or "cloud-forming") liquid. The atomizing device employed gave for the two methods, the same values for the radius r_m of the drops, for which a value of 0.073 mm (0.003 in.) was found.

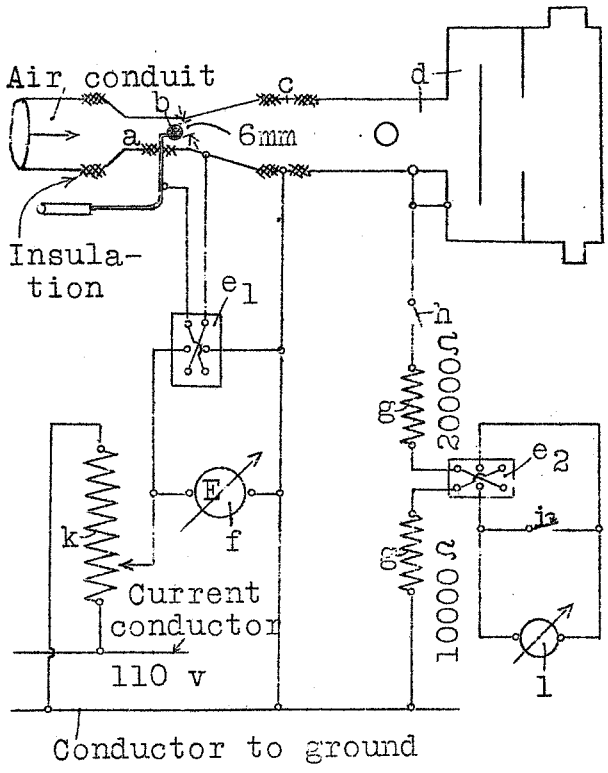
Since the method based on the transference of electricity by the drops measures the atomization produced in the immediate vicinity of the spraying nozzle, while the optical method enables the measurement of the atomization at some distance from the nozzle, a glimpse into the manner of the production of the atomization can be thus obtained. If the drops formed at the mouth of the nozzle by the breaking up of the liquid jet are still further divided by the dispersive action of the air stream, then the simultaneous use of both methods at different points in the mixture gives different values of r_m, from which the dispersive effect of the air stream on the drops can be determined.

At the relatively low air velocities which could be employed in the experiments, the dispersive effect of the air stream was not very noticeable.

Further experiments, which are now being tried in the laboratory of the Technical High School, have to do with the testing of the atomization produced by the various atomizing devices under different conditions and with different fuels. Their purpose is to determine the effect of various conditions on the atomization and the best arrangement for given conditions.*

* The experimental apparatus employed rendered it possible to test the effect of atomizing nozzles of all kinds found on the market.

Translation by Dwight M. Miner,
National Advisory Committee
for Aeronautics.



a = Air nozzle.

b = Atomizing nozzle.

c = Grounded safety wire.

d = Mixture conduit with receiving vessel.

e_1, e_2 = Current switches.

f = Voltmeter.

g = Series resistance.

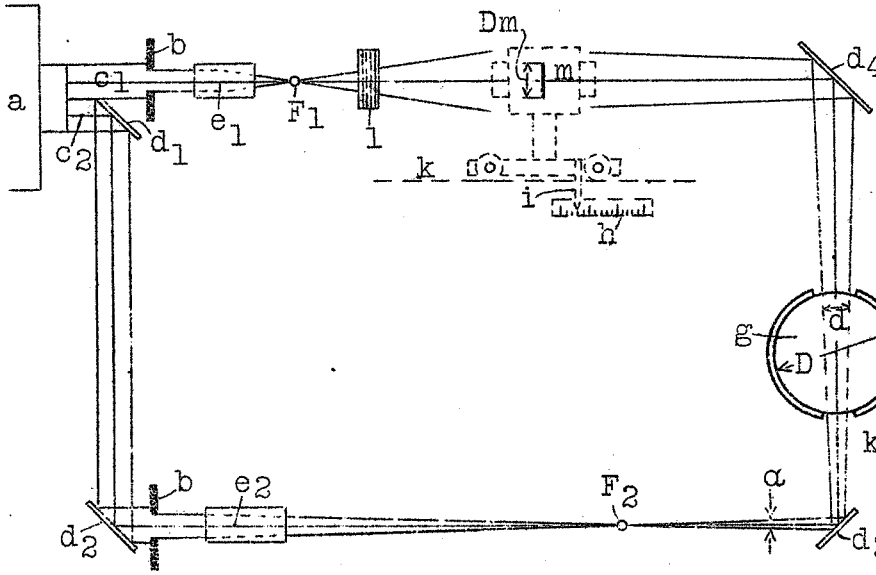
h = Circuit closer.

i = Short-circuit switch.

k = Tension distributer.

l = Mirror galvanometer.

Fig.1 Arrangement for determining r_m from the quantity of electricity carried away by the drops.



a=Projection apparatus.
b=Screen
c_1, c_2=Parallel rays of light.
d_1, d_2, d_3, d_4=Mirrors,
e_1, e_2=Lenses.
g=Mixture conduit with windows.
h=Distribution on the photometer bench.
i=Pointer on the photometer car.
k=Rails for the photometer bench.
l=Set of glass plates
m=Photometer.

Fig.2 Arrangement for determining r_m from the diminution of the light by the drops.