TECHNICAL MEMORANDUMS

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

No. 518

INVESTIGATION OF ATOMIZATION IN CARBURETORS

By J. Sauter

From Zeitschrift des Vereines deutscher Ingenieure
November 3, 1928

Washington
June, 1929

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS.

TECHNICAL MEMORANDUM NO. 518.

INVESTIGATION OF ATOMIZATION IN CARBURETORS.*

By J. Sauter.

In explosion engines using liquid fuels the mixture of fuel and air is formed almost exclusively by means of a so-called "carburetor," the simplest form of which is represented by Figure 1. The fuel emerging from the nozzle d, by reason of the negative pressure, is atomized by the air stream and mixed with it. As a result of the atomization, the contact area, which the fuel presents to the combustion air, is extraordinarily enlarged.

Significance of the Fineness of the Atomization and of the Fuel Deposit on the Wall of the Intake Pipe

Very easily boiling fuels can be so finely atomized that they will completely evaporate, without special heating, in the intake pipes of explosion engines. Difficultly boiling fuels, however, even including ordinary gasoline, are not atomized so finely, and the fuel drops are evaporated only by the heat produced by the combustion. Since the combustion in the engine must be completed in a very short time, it is important to obtain a sufficiently fine atomization. The difficulties in the

*"Untersuchung der Zerstäubung durch Spritzvergasser," from Zeitschrift des Vereins deutscher Ingenieure, November 3, 1928, pp. 1572-1574. Extract from No. 312 of the Forschungsarbeiten auf dem Gebiete des Ingenieurwesens, published by the V. D. I. (Society of German Engineers), Berlin, 1928.

operation of engines with heavy oils were the reason for numerous investigations of the process of atomization.

No theoretical computation of the fineness of the atomization in carburetors is yet possible, due to the complicated conditions. Previous investigations of the fineness of the atomization have been conducted almost exclusively with atomizers by which the fuel was injected under high pressure into still air. The results of experiments with such atomizers, however, cannot be applied to carburetors, for they furnish no solution of the atomization under varying conditions.

For the further improvement of carburetors it is important to determine experimentally the fineness of the atomization under conditions corresponding to the operation of explosion engines. The available methods have been previously described.* By these methods, which were developed in the physical laboratory of the Munich Technical High School, it is possible to determine, in a simple manner, both pressure atomization and carburetor atomization.

The chief difficulty in the operation of a carburetor engine lies in the fact that, on the way from the fuel nozzle to

*J. Sauter, "Grossenbestimmung der Brennstofftropfen im Gemischnebel von Verbrennungskraftmaschinen," V.D.I., July 31, 1926, pp. 1040-1042 (N.A.C.A. Technical Memorandum No. 390: "Determining Size of Drops in Fuel Mixture of Internal Combustion Engines.")

J. Sauter, "Die Beurteilung der Güte einer Zerstaubung nach ihrer Feinheit und Gleichmassigkeit," Forschungsarbeiten, No. 279, 1926, pp. 4-15 (N.A.C.A. Technical Memorandum No. 396: "Determining the Efficiency of Atomization by Its Fineness and Uniformity.")

the cylinders, some of the atomized fuel is always deposited on the wall of the intake pipe. The amount of this deposit is often very great, even exceeding half of the atomized fuel.

With light oils, like gasoline, this is not very noticeable, because the precipitated fuel evaporates with sufficient rapidity in the air stream, while the large surface area of the intake pipe acts as a "surface carburetor." With heavy fuels, on the other hand, regularity of functioning is obtainable, only by means of special devices, especially by heating the intake pipe. Nevertheless, the engine does not functiom so smoothly as with gasoline, since variations occur in the formation of the combustible mixture with changes in the load and especially with a lessening of the load and when the engine is idling.

Figure 2 shows the experimental arrangement. The air was drawn through the carburetor by means of a Siemens-Schuckert air pump w, which has a maximum capacity of 120 liters (4.24 cu.ft.) per second. The fresh air drawn through the carburetor is regulated at will by the valves t and z. The suction or intake side of the air pump is connected with an air receiver v of about 0.8 m^3 (28.25 cu.ft.) capacity. From the air receiver v a 3" pipe leads through a shut-off valve u and an inlet valve t, through which the pipe can be connected with the outside air, to the real measuring apparatus, which, together with the subsequently described optical device for meas-

uring the mean size of the drops, is installed in a separate room which can be darkened. The pipe first leads to the liquid separator or trap s, a small receiver with built-in baffle plates. The fuel drops are mostly separated from the mixture coming from the carburetor by the several deflections of the air stream and collect in the bottom of the trap, from which the liquid can be drawn off after the experiment. The horizontal pipe i, leading from the carburetor, ends in the trap. For the latter, metal tubes of 38 and 94 mm (1.5 and 3.7 in.) diameter were used. The intake pipe has two opposite openings or windows k of 20 mm (.787 in.) diameter for the passage of the beam of light serving for the photographic determination of the mean size of the drops.

Since there is generally a strong negative pressure in the intake pipe, these openings are closed by glass windows. As already established by L. Heuser ("Untersuchung des Vorganges im Spritzvergasser," Autotechnik, Vol. II (1922), No. 12), such windows become overcast in a very short time. This had to be avoided here, since the change in the transparency of the glass might cause errors in measuring. Therefore, revolving glass windows l were used, which were run by electricity and were made tight over the openings by means of felt rings.

The observation point k was 30 to 40 cm (11.8 to 15.8 in.) from the carburetor, corresponding to the mean distance traversed by the fuel drops from the point of atomization to

the cylinder of an explosion engine. The fuel deposited on the wall of the pipe between the carburetor and observation point was collected and measured. At this point the pipe has a downward branch n, which leads through a graduated measuring glass o, past the stopcock p to a receiver q. The carburetor f was inserted at the beginning of the intake pipe. The intake air was measured by means of the Pitot tube h in the pipe g. The fuel was measured by means of the gauge c.

Determining the Fineness of the Atomization

Since the mixture contains fuel drops of very different sizes, some definite mean size must be adopted as the gauges of the fineness. The idea of the "mean size" denotes that, instead of the actual mixture which contains drops of different sizes, a mixture is assumed with drops of one uniform size. This mean size is such that the actual and the imaginary mixture coincide in a certain size. The size chosen depends on the object of the determination of the fineness.

In the present instance, the object is to determine the combustion characteristics of the mixture. This is governed by the total surface area of all the drops. Hence their mean size is so chosen that the drops of the actual mixture and the drops of the imaginary mixture will have the same total surface area O for the same volume V. Then $r_m = 3V/O$, r_m being the radius of the mean fuel drop. In order to calculate r_m, we

must know the total surface area O of the drops, in addition to their total volume V_{tot}.

One must measure the volume V' of the air flowing through the intake pipe of diameter D per unit of time, the volume V of the fuel atomized per second and the percentile diminution u' in the strength of the beam of light in passing through the opening in the intake pipe. Thus one obtains

$$r_m = - 0.75 \frac{V D}{V' \ln\left(1 - \frac{u'}{100}\right)} .$$

The quantity u' is determined by means of an arrangement shown in Figure 3. The photometer m can be moved along the track k on the photometer stand. The zero position of the photometer is found by setting it so as to give equal illumination of both halves of the dial, when the pipe g contains no weakening mixture (hence for u' = zero).

The weakening u' of the illumination produced by the mixture flowing through the pipe, is then determined from the displacement Δ of the photometer with reference to the zero position, which is necessary to obtain equal illumination of both halves of the disk. The amount of this displacement is read by means of a pointer i, attached to the photometer car, on a scale h, attached to the photometer stand. Since a calculable value of u' corresponds to every displacement, we can use, instead of a millimeter scale, one that gives directly the corresponding values of u' or, still better, of $u=100 \ln\left(1 - \frac{u'}{100}\right)$.

We can then read directly the value of u corresponding to a given mixture. By the introduction of u we obtain

$$r_m = \frac{3\ V'}{O} = .75\ \frac{V\ D}{V'\ u}$$

for the mean size of the drops.

Tests were made both with the simplest and also with the newest carburetor types:

1. Simple carburetor (Fig. 1);
2. Claudel-Hobsom carburetor AR 26;
3. Zenith carburetor HK 36;
4. Pallas intensive carburetor ID 3 H.

The last two function with multiple atomization and are designed especially for kerosene. There were determined:

1. The air volume V'_o flowing through the carburetor in l/s (liters per second);
2. The negative pressure h_1 in the pipe in mm of Hg and the volume of air V'_1 flowing through the pipe in l/s;
3. The atomized fuel V_{tot} in cm^3/s;
4. The fuel V_{dep} in cm^3/s deposited on the walls of the pipe between the carburetor and the observation point;
5. The value u, which depends on the fineness of the mixture.

From V_{dep} and V_{tot} we can determine the wall deposit $W = 100 \frac{V_{dep}}{V_{tot}}$ in per cent of the atomized fuel. When there is no evaporation, the volume of the atomized fuel in the air stream at the observation point is $(V_{tot} - V_{dep})$ cm^3/s. It was established experimentally that 5 to 10% of the liquid evaporated on the way to the trap s (Fig. 2). Accordingly, the amount of the fuel still in the air stream at the observation point was less than $V_{tot} - V_{dep}$.

To this circumstance is due the assumption that about 10% of the atomized fuel evaporates, which is sufficiently accurate, considering the limited degree of accuracy attainable any way in the determination of the mean size of the drops. At the observation point the air stream accordingly carries in suspension the quantity of fuel

$$V_{obs} = 0.9 \ (V_{tot} - V_{dep})$$

The mean size of the drops at the observation point is accordingly

$$r_m = \frac{3 \ V_{obs}}{O_{obs}} = 75 \ \frac{0.9 \ (V_{tot} - V_{dep}) \ D}{V' \ u} .$$

It is easily seen that even then r_m can still be very small, when the largest portion of the atomized fuel is deposited on the wall during its passage from the carburetor to the observation point, because it is principally the larger drops which are precipitated . The quantity r_m therefore represents only the degree of atomization still existing at the observation point.

As regards the regular functioning of an explosion engine, it does not matter so much how large the drops are in the intake pipe or on their entrance into the cylinder, or how finely the whole of the atomized fuel is divided. Hence, if we take into account, in the calculation of the mean size of the drops, not only the quantity of liquid at the observation point, but also the total atomized amount V_{tot}, we obtain a second value R_m for the mean size of the drops

$$R_m = \frac{3\ V_{tot}}{O_{obs}} = .75\ \frac{V_{tot}\ D}{V'\ u}\ .$$

When W is greater than O, R_m is always greater than r_m.

In the experiments, tests were made of the effect of the special conditions under which the atomization took place. Therefore carburetors of various types were tested at various air velocities, whereby kerosene (S.G. 0.8) and water, being liquids with the most widely differing capillarity constants (3 and 7.7), were atomized, since, from theoretical considerations, an important effect of the magnitude of the capillarity on the fineness of the atomization could be expected. There were further tested:

1. The effect of the diameter of the pipe on the atomization, by using two different pipes;
2. The effect of the diameter of the air nozzle, by using air nozzles of 24, 26, and 28 mm (.945, 1.02, and 1.1 inches) diameter;

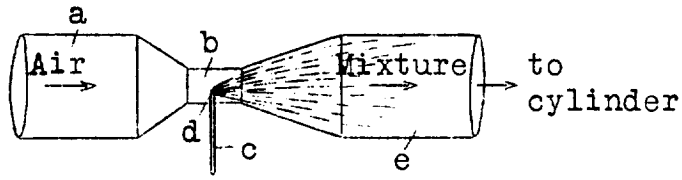
3. The effect of the mixture ratio Q, by using different fuel nozzles.

Figures 4-6 represent some of the results. With a small negative pressure h_1 the atomization was relatively coarse. For the horizontal carburetor, with h_1 = 20 mm (.787 in.), Hg, R_m = 23 to 33 μ for kerosene, according to the type of the carburetor and the diameter of the air nozzle. With h_1 = 100 mm (3.937 in.) Hg, R_m = 5 to 7.5 μ and, with h_1 = 200 mm (7.87 in.) Hg, R_m = 3 to 5 μ. The atomization was therefore very fine for kerosene with large values of h_1.

The mean size of the drops and the wall deposit W were more unfavorable with water than with kerosene. The closer connection was investigated, as likewise the dependence of the size R_m of the drops on the volume of air flowing through the pipe. In both cases it was found that the results were greatly affected by the type of the carburetor.

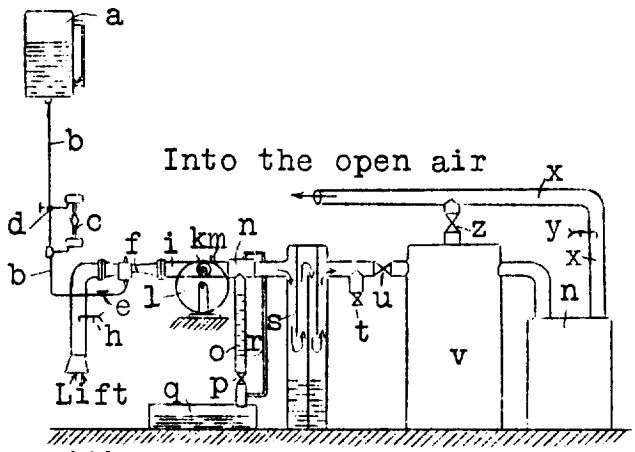
The experiments show that the apparatus is suitable for investigating the phenomena in carburetors. It affords a means of testing carburetors for the fineness of the atomization and of determining the effect of structural changes in them.

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



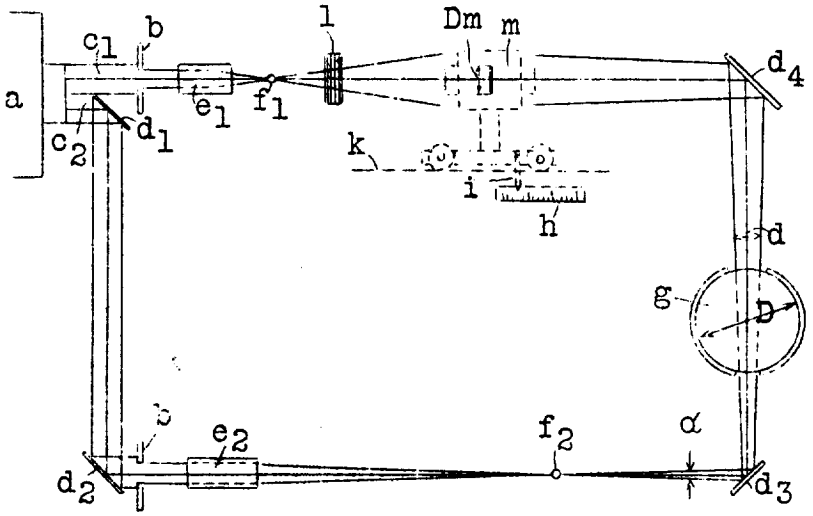
a, Air pipe
b, Air nozzle
c, Fuel pipe
d, Fuel nozzle
e, Intake pipe

Fig.1 Simple carburetor.



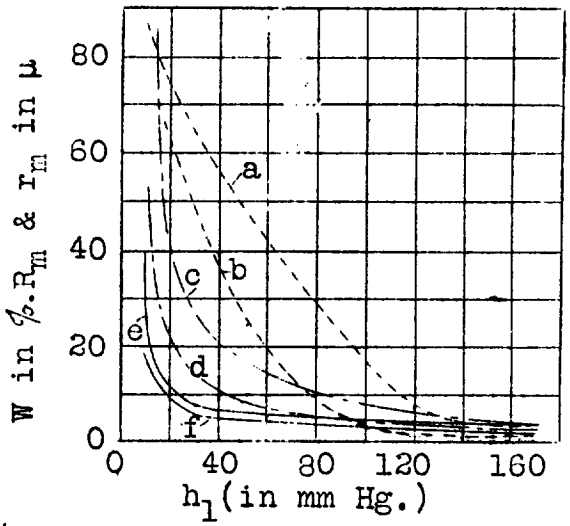
a, Fuel container with glass gauge.
b, Fuel pipe to carburetor.
c, Gauge for determining amount of liquid atomized per second.
d, Three-way cock.
e, Stop-cock in fuel pipe.
f, Carburetor.
g, Air-intake pipe to carburetor.
h, Pitot tube for measuring air.
i, Intake pipe to cylinder.
k, Openings in intake pipe.
l, Revolving glass window.
m, Device for measuring static pressure in intake pipe.
n, Branch for separating water deposited on wall of pipe
o, Measuring glass for wall deposit.
p, Stop-cock for same.
q, Receiver for wall deposit.
r, Pressure-equalization pipe.
s, Trap for liquid with baffle plates and gauge.
t, Valve for regulating air intake by carburetor.
u, Stop-cock. v, Air container. w, Air pump. x, Exhaust pipe.
y, Pitot tube for measuring exhaust air. z, Air-outlet valve.

Fig.2 Diagram of apparatus.



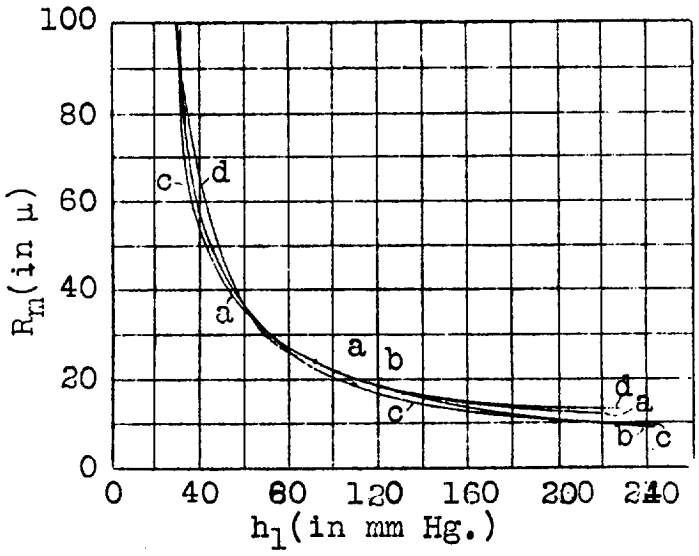
a, Projection apparatus.
b, Shutters.
c_1 and c_2, Parallel beams of light.
d_1 d_2 d_3 d_4, Mirrors.
e_1 and e_2, Lenses.
g, Intake pipe with windows.
h, Scale on photometer stand.
i, Pointer on photometer car.
k, Track on photometer stand.
l, Glass plates.
m, Photometer.

Fig.3 Arrangement for determining the diminution u in the strength of the light caused by the drops.



Fuel nozzle ϕ 1.3 mm Air nozzle ϕ 26 mm Intake pipe ϕ 38 mm
Comparison of R_m, r_m, and W for water and kerosene.
a, W for water. b, W for kerosene. c, R_m for water.
d, R_m for kerosene. e, r_m for water. f, r_m for kerosene.

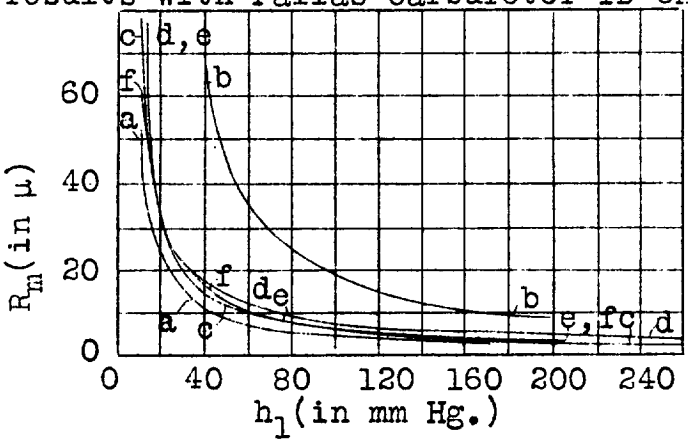
Fig.4 Test results with simple carburetors, using water and kerosene.



Air nozzle ϕ 24 mm Intake pipe ϕ 94 mm Comparison of R_m for different fuel nozzles.

a, Main nozzle ϕ 1.30 mm Equalizing nozzle ϕ 0.95 mm
b, " " " 1.30 " " " " 1.40 "
c, " " " 0.95 " " " " 1.20 "
d, " " " 0.80 " " " " 0.95 "

Fig.5 Test results with Pallas carburetor ID 3H, using water.



a, Simple carburetor Air nozzle ϕ 26 mm
b, Clandel-Hobson carburetor " " " 26 "
c, Zenith HK36 " " " " 24 "
d, Pallas ID 3H " " " " 24 "
e, " " " " " " " 26 "
f, " " " " " " " 28 "

Fig.6 Determination of mean size of drops R_m with different carburetors, using kerosene.