5. Tests on Carburetter.—The results of numerous tests made on the experimental carburetter, firstly with fan-suction and later with the engine, all show that the "characteristic" or fuel-air curve is a straight line, not passing through the origin. The curve may be represented by the equation

$$q = \alpha Q - \beta.$$

A comparison of tests, made with the same choke-tubes and jets, and under the two methods of suction, showed that, for purposes of determining the characteristic curve of a carburetter, the fan-suction method was quite suitable, and, being very much more convenient, is generally to be preferred. Of course, the fan-suction method will not show when a firing mixture is being produced. This is perhaps of importance, since some carburetters undoubtedly require a richer mixture than others before combustion will occur. This is because the atomisation and vaporisation is not carried out so thoroughly in the former, and some liquid molecules are probably carried through to the exhaust, or are possibly decomposed before vaporisation.

Apart from this question, suitable steady conditions for experimental purposes are much more easily obtained by using a fan to produce suction; and, within its limits, this method is preferable.

One interesting result of the engine experiments was to verify the correct mixture curve, which had previously been arrived at from a consideration of the chemical constituents of the benzine (Appendix A). This correct mixture curve passes through the origin and the co-ordinates, 1 gallon per hour and ·5 cubic feet per second; and, in practice, the greatest difficulty was experienced in getting the engine to fire on a mixture weaker than this. The engine ran very steadily on the gas supplied by a 39·5 mil jet and a ·9in. diameter choke, giving a characteristic curve (Figure 4) lying just above the correct mixture curve, for points over ·4 cubic foot per second. At speeds producing a suction less than this, the engine would not fire, because, as the curve shows, the mixture was too weak, and "popping" in the carburetter occurred.

Examination of Curves.—A little consideration would lead one to expect that the characteristic curve would be a straight line, for both quantities involved are fluids, obeying fluid laws. The liquid is forced through the jet orifice and the air through the choke-tube under exactly the same pressure.

Expressed algebraically:—

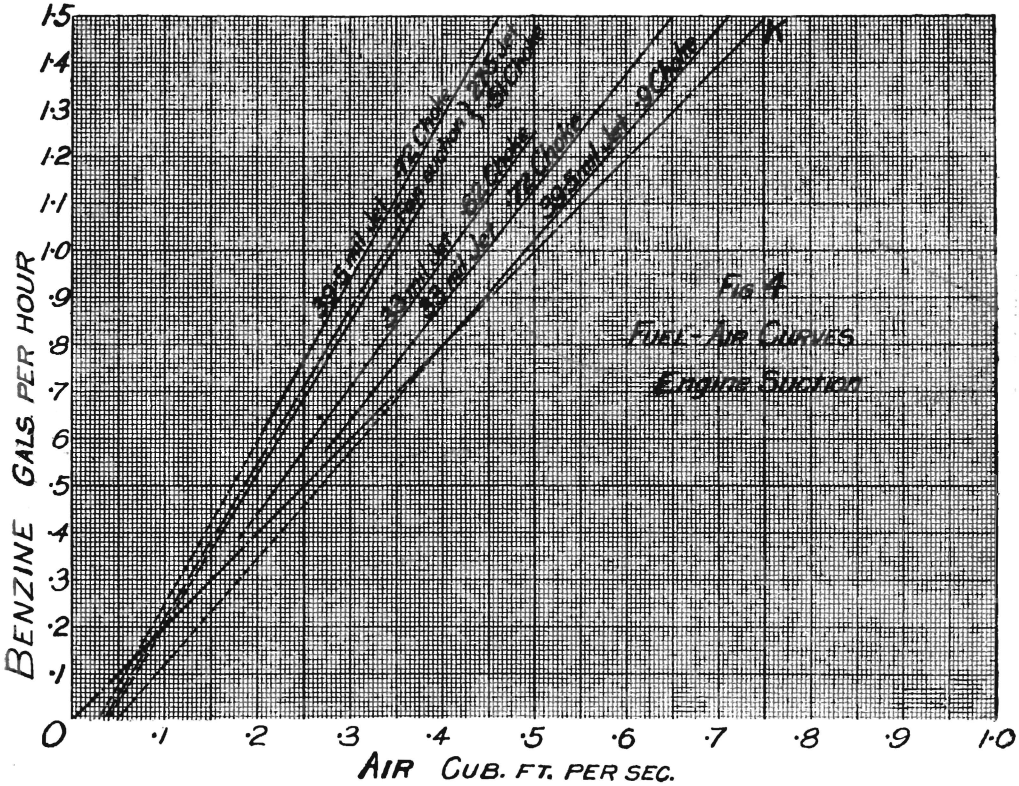
$$Q \propto A\,V$$

$$\text{that is} \quad \propto A\sqrt{h}$$

$$\text{also } q \propto a\,v$$

$$\propto a\sqrt{h}$$

$$\text{therefore } Q \propto q$$



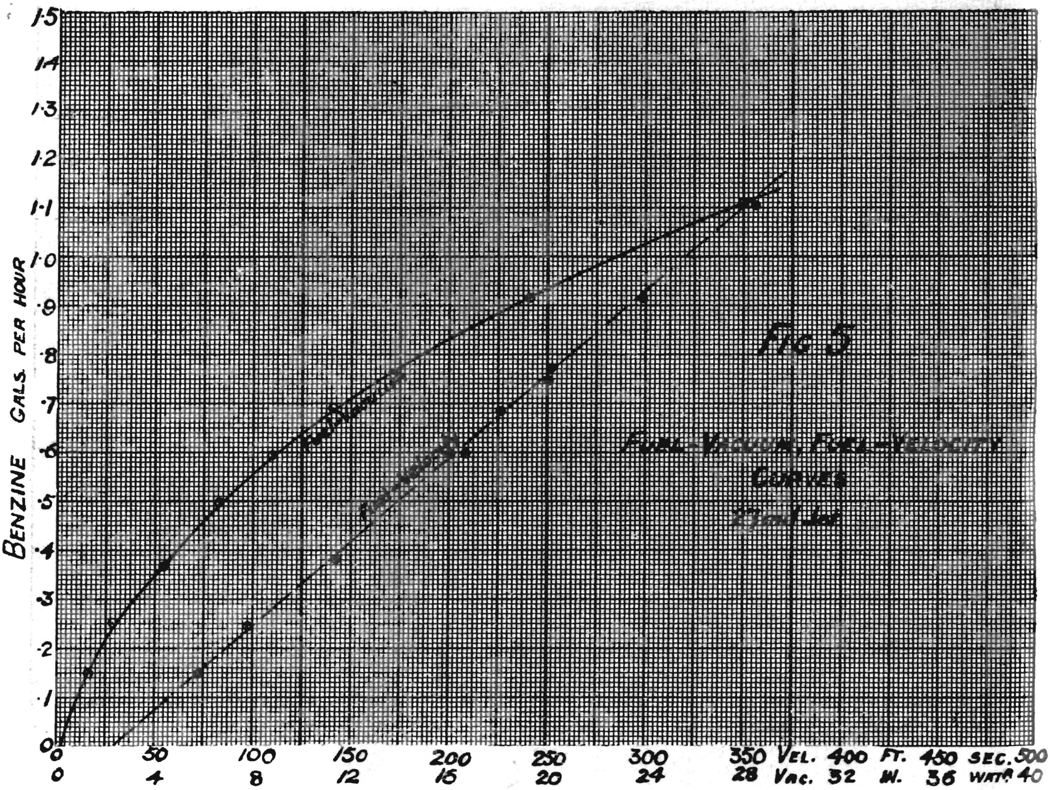
since A and a remain constant for any one curve. That is, the fuel is directly proportional to the air, and the relation is represented by a straight line curve.

Figure 4 shows a series of characteristic curves for different sizes of jets and choke-tubes. Three of the most typical curves have already been described in discussing the defects of the simple carburetter.

A curve, Figure 5, plotted to quantities of benzine and suction head, as measured on the manometer in the choke-tube, developes into a square-root curve, since $q \propto a\sqrt{h}$ The quantity of fuel ejected depends only upon the area a of the jet orifice and the suction-head, consequently the benzine suction curve is the same for one jet, whatever size the choke-tube may be.

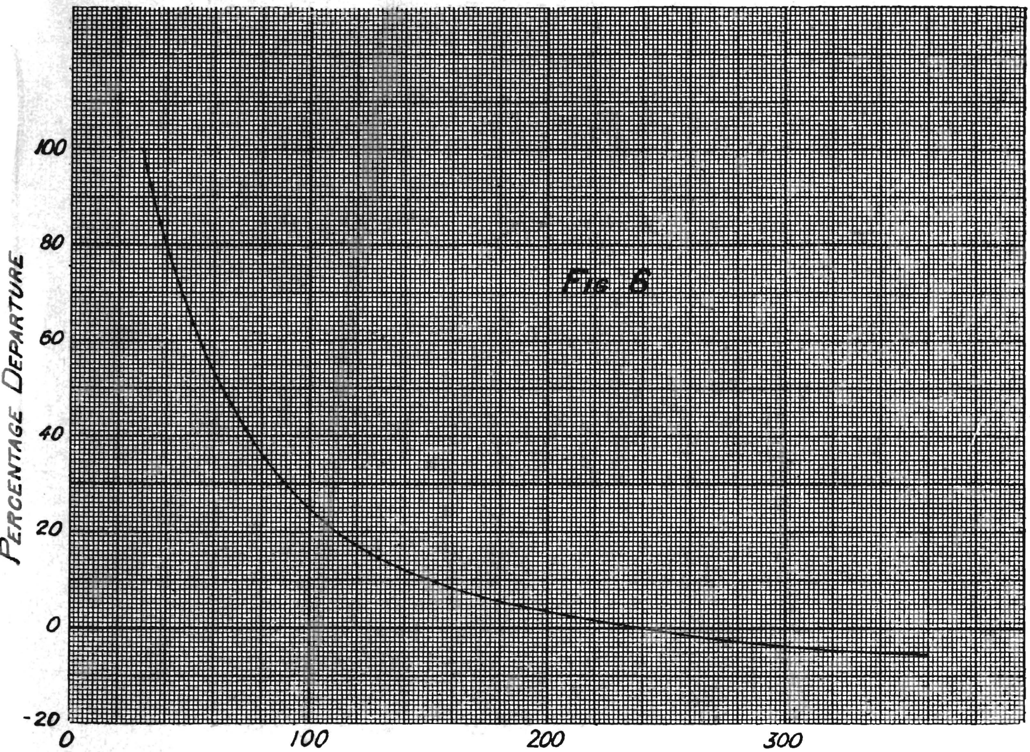
A fuel-velocity curve, drawn with ordinates benzine and velocity of air past jet, is a straight line; and, again, one curve represents all the tests on the same jet (Figure 5).

From these two curves it is seen that the fuel does not begin to discharge till a velocity of nearly 30 feet per second is



reached, or a corresponding suction-head of ·2in. This is due, as stated before, to the surface tension of the liquid requiring a certain force to break it down, before the liquid can leave the orifice.

Finally, another interesting curve may be drawn from the comparison of a characteristic curve and the correct mixture curve. At any point in a characteristic curve, such as C (Figure 2), at ·1 cubic foot per second, the benzine is ·16 galls. per hour, whereas a correct mixture requires ·2 gallons per hour. Therefore, the mixture is ·04 in ·2 gallons per hour, too weak; that is, 20 per cent. It is convenient to plot this percentage departure from the correct quantity as an ordinate, and the corresponding air velocity as an abscissa (Figure 6). A motor, running at its highest speed, should not cause a greater air velocity through the choke-tube than 300 feet per second, and it should be able to run comfortably at a speed one-tenth of this value, giving a choke velocity of 30 feet per second as the lowest value. From the percentage-departure curve, drawn for a 27·5



mil jet, it is at once seen that neither the ·62in. or ·51in. diameter choke would enable an engine to run at a low enough speed to produce a choke velocity of 30 feet per second.

VAPORISATION.—It was very striking to see the stream of benzine spraying up the glass induction pipe, a considerable quantity being still unvaporised, even at a distance of nearly a foot from the jet.

When using the ·62in. choke and 27·5 mil jet (a combination that gave a firing mixture), the benzine streamed right up the glass pipe, apparently almost unvaporised; and, collecting on the sides, the liquid ran down again until it found a ledge where it piled up, and, overflowing, was caught again by the draught. This shows that there should be a clean sweep from the choke-tube to the engine, offering no corners for liquid fuel to collect.

Another noticeable feature was the temperature of the mixture. This was always in the region of 25° F. below room temperature, whether large or small quantities of fuel were being vaporised.

A liquid requires an amount of heat, equal to its latent heat, to vaporise it. The benzine gets this necessary heat from the incoming air. Therefore the air, on entering the choke, should not be below about 55° F., or the temperature of the gas will fall below 32° F., and freezing of the moisture in the atmosphere will result in an ice-caked choke-tube.

In climates where the temperature is seldom below 60° an unjacketed carburetter is perfectly suitable. In fact, it is advisable to work with the mixture as cold as it can be vaporised satisfactorily, since a greater weight of fuel will be taken in per stroke, and an increase in power result. This is very marked in an air-cooled engine, in which even the inlet valve gets very hot, and a heated and rarified charge is produced, with a consequent loss of power.

6. Data for Carburetter Design.—An equation may be written to represent any one of the characteristic curves. For instance, the curve for a ·51 choke and a 27·5 mil jet is

$$q = 3{\cdot}0Q - {\cdot}1.$$

But since the quantity of fuel flowing through the jet depends only on the suction around it, a general equation for this size of jet, and any size of choke, may be found by substituting instead of Q the corresponding suction head. This may be obtained from the choke-tube suction-head calibration curves, the equation for the ·51in. choke being

$$Q = {\cdot}066 \sqrt{h}$$

whence is obtained

$$q = {\cdot}20 \sqrt{h} - {\cdot}1$$

This is true, whatever the size of choke. In this way a complete set of equations for all of the jets was worked out.

Jet 27·5 mils	$q = {\cdot}20 \sqrt{h} - {\cdot}1$
33·0 ,,	$= {\cdot}29 \sqrt{h} - {\cdot}095$
36·5 ,,	$= {\cdot}36 \sqrt{h} - {\cdot}09$
39·5 ,,	$= {\cdot}42 \sqrt{h} - {\cdot}1$

Comparing these equations, it is seen that one equation of the form

$$q = \gamma a \sqrt{h} - \beta$$

will very closely embody all of them.

This general equation for benzine of sp. gr. ·70, and at a temperature 70° F., is

$$q = 270\, d^2 \sqrt{h} - {\cdot}1$$

and from it may be found the quantity of benzine in gallons per hour, flowing from a jet of d inches diameter under a known suction h, in inches of water.

As shown in Appendix B, the velocity of the air in a choke-tube will be given ordinarily by the equation

$$V = \frac{K\ L\ A^1 N n}{1440 \times c \times A}$$

and the suction pressure at the jet by

$$h = \frac{V^2}{3600}$$

Two examples will best show the application of these formulae:—

(1) "The sizes of choke-tube and jet are required for a single cylinder, high-speed benzine engine. It is desired that the choke velocity should not be lower than 100 feet per second at the starting speed of engine, 350 R.P.M. Bore and stroke 3in."

For starting, the throttle will be open far enough to enable the engine at this speed to take, say ·9 full charge, so K will be ·9; and a suitable value for c, the co-efficient of efflux of the choke, will be ·8. The number of cylinders n is one.

$$V = \frac{K\ L\ A^1 N n}{1440 \times c \times A},\ i.e.,\ 100 = \frac{\cdot 9 \times 3 \times 7 \times 350 \times 1}{1440 \times \cdot 8 \times A}$$

whence A = ·058 square inch.

In order to allow for a jet of 3/16in. outside diameter, the gross choke area will be ·09 square inch, or the choke-diameter $\frac{3}{8}$ inch.

The quantity of air drawn in Q is given by

$$Q = \frac{c\ A\ V}{144} \text{ cu. ft. per sec.}$$

$$= \frac{\cdot 8 \times \cdot 06 \times 100}{144}$$

$$= \cdot 033.$$

Benzine in gallons per hour, necessary to mix with this to produce a suitable mixture, is

$$q = 2\ Q$$
$$= \cdot 066.$$

Suction at a choke velocity of 100 feet per second is

$$h = \frac{V^2}{3600}$$
$$= 2 \cdot 8\text{in.}$$

Size of jet, to give q = ·066, at h = 2·8in.,

$$q = 270\ d^2 \sqrt{h} - \cdot 1$$
$$d = \cdot 0154\text{in.},$$

that is, a suitable jet would be 16 mils and choke would be $\frac{3}{8}$ in. At higher suctions the carburetter, will, of course, require an extra air-port.

2. "Required the size of a 'constant addition' carburetter for the experimental engine described in this paper."

Max. speed 1,000 R.P.M., K = ·8, V = 300.

$$A = \frac{\cdot 8 \times 4{\cdot}72 \times 8{\cdot}82 \times 1000 \times 4}{1440 \times \cdot 8 \times 300}$$

$$= \cdot 385 \text{ square inches.}$$

Add about ·04 for the area taken up by the jet, and the gross choke area is ·425 square inches, giving a diameter of ¾in.

Quantity of air at this speed,

$$\dot{Q} = \frac{\cdot 8 \times \cdot 385 \times 300}{144}$$

$$= \cdot 64 \text{ cubic feet per second.}$$

Choke suction, corresponding to a velocity of 300 feet per second,

$$= \frac{V^2}{3600} = 25\text{in.}$$

The size of the auxiliary jet necessary will be such as to discharge ·1 gallons per hour under a constant head in the float chamber, of, say, ¾in. of benzine, or about ½in. head of water.

$$q = \cdot 1 = 270\ d^2\ \sqrt{\tfrac{1}{2}} - \cdot 1,$$

$$d = \cdot 0325\text{in., i.e., } 32{\cdot}5 \text{ mil jet.}$$

The total quantity of benzine required for ·64 cubic feet of air per second, is

$$q = 2\ Q = 1{\cdot}28 \text{ gallons per hour,}$$

of which ·1 is supplied by the auxiliary jet,

$$1{\cdot}18 = 270\ d^2\ \sqrt{25} - \cdot 1,$$

$$d = \cdot 031\text{in.,}$$

requiring a main jet of 31 mils diameter.

Experimental Constant Addition Carburetter.—A carburetter was built to the above dimensions, though arranged to supply an auxiliary quantity of about ·15 instead of ·1 gallons per hour.

The jets were fitted with finely-tapered needles, to readily adjust the size of jet opening. The characteristic curve produced is shown in Figure 2 by points, the curve K drawn in being the correct mixture curve. The different points were obtained by varying the position of the throttle and by altering the load on the engine.

As is seen from the numerical example given, it is quite a straight-forward matter to work out the dimensions of the "constant addition" carburetter, with the surety that, under all conditions except change of temperature, the carburetter will give a correct mixture. The same cannot be said about any other type of carburetter; but it must be admitted that the "constant addition" carburetter suffers from the defect of low velocity past the jet at slow engine speeds. In this respect, perhaps the best form of carburetter is that in which the choke-tube and jet orifice are varied by the suction and controlled by gravity.

APPENDIX A.

Proportion of air and benzine to give a rapid firing mixture and complete combustion:—

The chemical formula of benzine may be taken to be fairly represented by $C_7 H_{16}$

Composition by weight, 84% C and 16% H.

Composition of air by weight, 21% O and 79% N.

That is, 1 cubic foot of oxygen is contained in 4·8 cubic feet of air, and 1lb. of oxygen in 4·35lbs. of air at 60° F.

For complete combustion. 1lb. of benzine vapour requires 15·1lbs. of air, which, at 60° F., occupies a volume of 203 cubic feet.

Hence, 1lb. of benzine requires approximately 200 cubic feet of air to completely combine with the benzine constituents; but as diluted oxygen does not combine as readily as pure, the benzine requires more oxygen to be present, and therefore more air. For this reason, about 30% more air is necessary than is theoretically required for complete combustion.

That is, 260 cubic feet of air is required for the rapid combustion of 1lb. of benzine, 1,800 cubic feet of air for 1 gallon of benzine, and ½ cubic foot per second of air for 1 gallon per hour of benzine.

APPENDIX B.

Suction Produced by an Engine.—The quantity of air drawn into a cylinder per stroke,

$$= \frac{LA^1}{12 \times 144} \text{ cu. ft.}$$

If n is the number of cylinders in the engine, the air drawn in per minute

$$= \frac{LA^1 Nn}{12 \times 144 \times 2} \text{ cu. ft.}$$

Owing to wire drawing, the density of the charge will be reduced to some fraction K of the density at atmospheric pressure. Therefore, quantity of air at atmospheric pressure

$$= \frac{KLA^1 Nn}{12 \times 144 \times 2} \text{ cu. ft. min.}$$

also through the choke the quantity of air at atmospheric pressure

$$= \frac{c\ A\ V \times 60}{144} \text{ cu. ft. min.}$$

$$\therefore \frac{KLA^1 Nn}{1440} = c\ A\ V.$$

In a slow speed over-loaded test, in which the engine was receiving the fullest charge possible, K was taken as unity, and V was calculated from the known dimensions of the engine, and the conditions of the test, which were: N = 420, A = ·38, c = ·8, h = 7·1,

giving $V = 142$ ft per sec.
but $V = \kappa\sqrt{h}$

whence $\kappa = \frac{V}{\sqrt{h}} = \frac{142}{\sqrt{7 \cdot 1}}$

$= 60.$

That is, in cases where κ is given the above meaning, the suction head in a carburetter may be taken as $\frac{V^2}{3600}$