MOTORCYCLE ENGINEERING—30

CARBURATION

A short survey of theory and practice

By PHIL IRVING

PETROL, in the form of vapour, combines completely with air when in the proportions of 15 parts of air to 1 of petrol—by *weight*, not by volume.

If there is more petrol present, the mixture will still burn effectively, but a limit is reached at about 10 : 1, at which point misfiring will be severe and the exhaust will become sooty due to the presence of unburnt carbon. On the weak side, the mixture can be reduced to 17 : 1, or even down as far as 20 : 1 on some engines which are specially designed to run with very lean mixtures in order to achieve outstanding economy.

However, as the mixture is progressively weakened the combustion process becomes delayed, and burning may still be taking place when the exhaust valve commences to open—a fact which may be verified by observing the blue flames issuing from the exhaust port of an engine running with a weak mixture.

This delayed burning, coupled with the presence of unburnt oxygen in the exhaust gas, in turn causes overheating and burning of the exhaust valve, so that endeavouring to run with excessively weak mixtures usually costs as much in exhaust valves as it saves in petrol. On the other hand, running with a rich mixture, though uneconomical and eventually leading to reduced power, does no actual harm.

Where sheer power is concerned, it is essential to remember that it is the combination of oxygen with the fuel which counts. Consequently, it is important first to get the maximum weight of air into the cylinder, mixed with fuel in such a way that every molecule of oxygen is burnt—and not at any old time, either, but at or near top dead centre so that the maximum use can be made on the power stroke of the expansion created by the heat of combustion.

The Fuel Factor

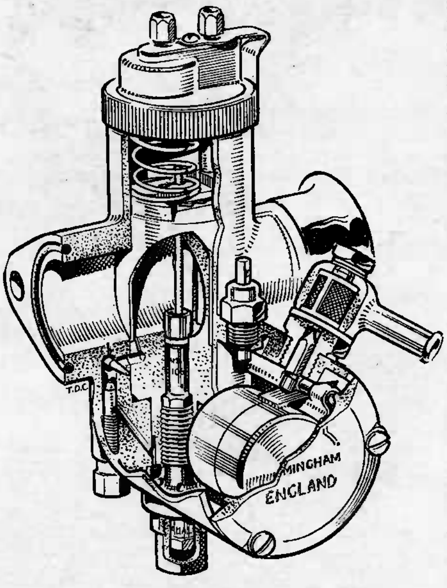
The nature of the fuel, provided it is not an oxygen-carrier like nitro-methane or a high explosive like picric acid, does not actually matter. Any of the regular fuels, ranging from kerosene through ordinary petrol to benzole and the alcohols, ethyl and methyl, will provide almost exactly the same theoretical emission of energy in the form of heat, the actual amount being, on average, equivalent to 46 ft./lb. per cubic in. of mixture at normal temperature and pressure (60° F. and 29.92 in. of mercury).

Alcohol in fact gives slightly less than 46 ft./lb., benzole slightly more; this is no mere matter of opinion, but of remorseless scientific fact. Any doubters can speedily set their minds at rest by studying Harry Ricardo's book, "The Internal Combustion Engine," Vol. II, Chap. 2.

The basic difference between petrol and alcohol is that the former is prone to detonation above a certain compression ratio, whereas the latter is almost knock-free and can be run at ratios of 14 : 1 or higher, even in a relatively hot-running engine. Advances in petrol technology, marching hand-in-hand with engine development, have steadily reduced the gap until ratios of 11 : 1 are now usable with petrol even in large-bore half-litre cylinders.

The other theoretical advantage of alcohol is its high latent heat of evaporation (that is to say, the large amount of heat which is required to convert it from a liquid to a vapour) which results in a colder, and therefore heavier, charge of mixture and also provides a perceptible amount of internal cooling. This advantage, though real, does not have such a profound effect on power output in practice as it does in theory, and the better the engine is cooled externally the less important does the internal cooling become.

However, this is not the time to discuss the very wide subject of fuels, but to consider the ways in which they are introduced into the air-stream by the carburetter with the necessary accuracy, under every possible combination of engine speed, throttle opening and air temperature.



In this Amal "Monobloc" touring carburetter, flow is controlled progressively by pilot jet, throttle slide with tapered needle, and main jet.

On any carburetter feeding fewer than four cylinders, the air-flow fluctuates violently from zero to a maximum on every induction stroke. It may even at times reverse in direction and flow outwards due to the air bouncing back off the closed inlet valve, or being actually blown back under conditions of low engine speed, high throttle opening and a late-closing inlet timing.

This fluctuation has been turned to good account in nearly all motorcycle carburetters because it permits the use of some form of sliding throttle valve instead of one of the butterfly type. The latter variety, which is standard in car carburetters, rotates about a central axis and is balanced against pressure; it can therefore open or close quite freely even when subjected to very low manifold pressures.

The sliding type, on the other hand, will not close readily against the friction produced by a steady (or nearly steady) pressure unless fitted with an inconveniently strong spring, but it will do so if the pressure fluctuates. Even on a twin-cylinder two-stroke, a single carburetter will close properly, because the port-controlled induction periods do not overlap as they do in a multi-cylinder four-stroke.

The most common form of throttle valve is the annular one, familiar in Amal carburetters, but it can equally well be solid (Villiers) or made from sheet metal as in some Fisher instruments. As will be shown, the sliding throttle exercises a "variable choke" effect—a very valuable feature.

Basic Principle

Carburetters work on the principle that if a restriction is placed in a pipe conveying a gas, a depression is created at the narrowest point of the restriction—which preferably has a rounded entering edge and a conical exit, and is termed a venturi, or choke-tube. If a jet is arranged to project into the neck of the venturi, the reduction in gas pressure will draw petrol through the jet into the air-stream, only a low pressure difference being required if the jet is supplied with fuel from a float-chamber so that the normal level is very close to the top of the jet.

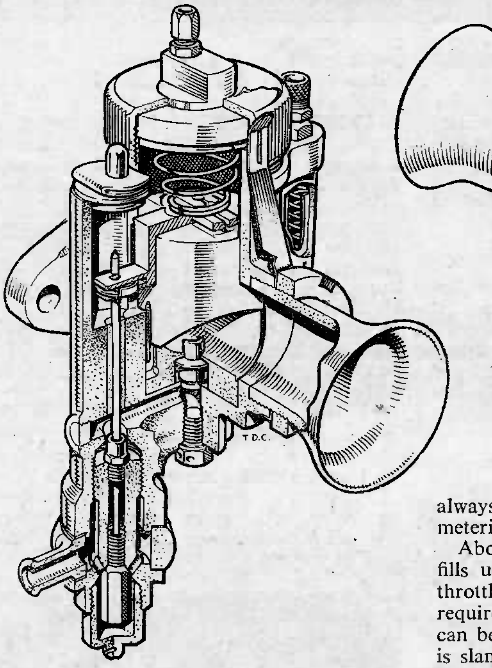
Advantage is also taken of the fact that merely blowing a stream of air across the top of a jet will draw liquid through it. This principle is to be seen in operation in a spray-gun or barber's scent-spray and historians will recollect the "Senspray" carburetter which derived its trade name from the latter source.

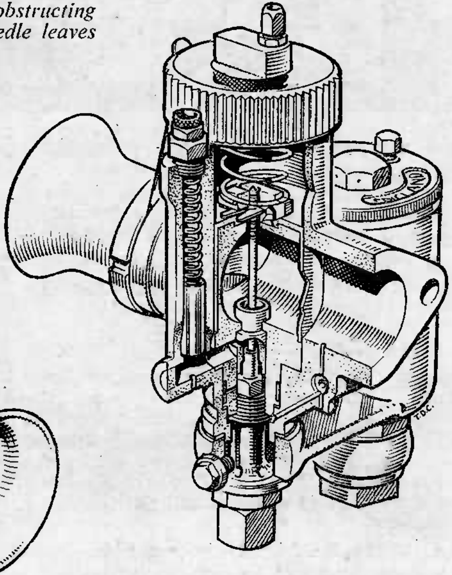
Unfortunately, the rate of delivery of fuel from the jet is not directly proportional to the air-speed through the venturi. Instead, the amount of liquid discharged increases more rapidly than the increase in the amount of air passing through.

Therefore any selected combination of venturi and jet can deliver a mixture of correct strength at only one air-speed. At higher speeds the mixture will be too rich and at lower speeds it will be too lean. In any of the butterfly-type carburetters with fixed chokes, correction has to be made for this by the addition of compensating jets, air-bleeds, or a combination of both.

Another method of correction would be to vary the choke size according to speed or throttle opening. This is achieved to a degree in the Amal and kindred instruments by the action of the throttle valve which, as it closes, automatically decreases the area available for gas-flow in the immediate vicinity of the fuel orifice and thus provides a variable-choke effect.

Further control of mixture strength at small throttle openings is provided by varying the height of the outer edge of the slide in relation to the engine side. Increasing this height, termed the "cutaway," decreases the suction on the jet and weakens the mixture; decreasing the height has the opposite effect.





Amal racing carburetters—the R.N. (below) and the T.T. In both, the air control beside the mixing chamber permits mixture variation without obstructing the main air-flow. The R.N.'s remote needle leaves the orifice completely clear.

In the carburetters developed for tracks such as Brooklands used to be and for speedway work, when the throttle is usually either open or shut and is seldom in a midway position, sufficient accuracy can be obtained by the cutaway alone in conjunction with a main jet of the correct size. For road work, where greater flexibility is desired, a tapered needle is attached to the throttle slide and exerts an effect on fuel flow which is most pronounced at around half to three-quarter throttle. In later designs, such as the Amal G.P., an air-bleed has been added to avoid over-richness at very high air-speeds.

At the very low air-speeds, which occur at starting or when idling, virtually no petrol would be drawn through the main jet, so a small auxiliary jet and air-passages are provided to deal with these conditions. These tiny passages are brought into action only when the throttle is almost closed; that is why it is almost impossible to obtain a start with what is termed a "handful of throttle," unless for some reason, such as excessive flooding, the mixture has accidentally become over-rich.

If the jet were to be placed on the same level as the fuel in the float chamber, slight alterations in level—such as might be caused by leaning the machine to one side or by braking or acceleration—would cause the fuel either to flood from the jet or to recede from the outlet, obviously affecting the rate of delivery. To avoid this, the main jet is located somewhere about level with the bottom of the float chamber, so that it is always submerged and acts purely as a metering device.

Above the jet is a space or well which fills up with fuel during periods when the throttle is nearly closed and little fuel is required. This provides a reservoir which can be drawn on instantly when the throttle is slammed open and the air-speed over the spray-tube through which the fuel finally emerges into the mixing-chamber is low until the engine picks up speed.

Further to assist vaporization of the fuel, and also to provide a greater measure of automatic control of mixture strength, a small amount of air is bled into the system between the main jet and the spray-tube. In racing instruments the quantity of air so admitted can be varied by the air control in order to modify the mixture strength without interfering with the main air-flow. In touring instruments the air control is used only for starting, not as a mixture-strength corrector, and if closed partly or wholly does restrict the main orifice. In fact, it is often omitted and a simple strangler is fitted for use only when starting conditions demand it.

Very briefly and baldly, that is the principle of operation of orthodox motorcycle carburetters. In addition, there are many other factors which affect their application to the engine. It has been found, for instance, that in order to obtain adequate atomization and subsequent vaporization of the fuel by the time the spark occurs, a considerable air velocity is essential and maximum torque is usually obtained at a nominal mean air velocity of 300 ft./sec.

The mean air velocity is determined by multiplying the mean piston speed by the factor $\frac{D^2}{d^2}$ (where D is the cylinder bore and d is the inlet diameter). If D, d, and also the stroke S are quoted in inches, the mean air velocity, in feet per second, is given by the expression:—

$$\frac{S \text{ x } 2}{12} \times \frac{\text{r.p.m.}}{60} \times \frac{D^2}{d^2}$$

From this it will be found that a 500 c.c. engine will have a mean velocity of 300 ft./sec. through a 1⅛-in. bore carburetter at 3,500 r.p.m. This speed is close to that at which maximum torque is developed in an engine for sports use and indicates a good correlation between theory and practice. Maximum power is usually attained at a much higher speed than maximum torque, because the drop-off in torque due to air restriction is less rapid than the gain in power due to increase of rotational speed.

Racing Requirements

For racing, however, where greater power is demanded even at the expense of low-speed performance, a larger choke size is required. A 1½-in. carburetter on the same engine will have a mean air velocity of 300 ft./sec. at 6,200 r.p.m., so should provide maximum torque at somewhere near that figure, with maximum power perhaps 1,000 r.p.m. higher. These theoretical figures are borne out in the G50 Matchless, which develops 52½ b.h.p. at 7,200 r.p.m. with a 1½-in. G.P.3 Amal. Because neither the piston velocity nor the air velocity is steady, but both fluctuate violently, the so-called "mean velocity" figure has no relation to reality, but is a convenient convention to employ as a basis for calculations. The figure of 300 ft./sec. is considerably higher than that usually quoted in works dealing with multi-cylinder engines, probably because the total time during which the inlet valve is open is much longer than the time of the induction stroke, which lowers the actual velocity in the case of a single or twin, but does not do so in the case of a single-carburetter "four" or "six" in which the inlet-valve opening periods overlap.

If an engine with a very large-bore carburetter is held on open throttle while the speed is progressively reduced by climbing a steep hill, obviously the air velocity through the choke will become progressively less until a point is reached where the carburetter cannot deliver a burnable mixture and the engine will stall; though if the throttle is gradually closed the "variable choke" effect exercised by it will enable power to be maintained down to a lower speed. However, the gas velocity in the tract between the throttle and the inlet valve will still be too low to ensure effective vaporization of the fuel, so for engines which require good low-speed pulling powers, small-bore induction pipes and carburetters are needed.

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For maintenance of power at high r.p.m. a straight, smooth, circular bore is the ideal. It is partly attained through elimination of the butterfly throttle which, however thin or streamlined it is made, is bound to obstruct the flow to some extent.

In needle-type instruments, the small-diameter needle and the projecting tip of the spray-tube are the only real obstructions, and even the former can be moved out of the stream by attaching it to one side of the throttle-slide, as is done in the remote-needle and G.P. Amals.

The air-passing ability can be still further enhanced by the addition of a long, tapering extension with a curved edge to lead the air smoothly in; such an extension is also of value when very large-bore instruments are used because its presence increases the suction applied to the jet. Also, under certain conditions a considerable amount of fuel may be blown back through the mouth of the carburetter. While this may be entirely lost if the intake is short, a large proportion may be retained and fed back into the engine again if the bell-mouth is long and of perceptible volume, with beneficial effects on fuel consumption, which may be quite as important to a racer in saving a pit-stop as it is to a workaday rider in saving his pennies.

Whilst the theoretical air-fuel ratio for complete combustion of petrol is 15 : 1 it is impossible to ensure that every particle of fuel is vaporized and consumed at the correct time. Some, inevitably, escapes the fire or is burnt too late in the cycle to be effective. Maximum power, therefore, is developed with a mixture-ratio of 13 or even 12 : 1, depending upon the characteristics of the engine.

Since the latter figure is beginning to approach the borderline of misfiring through over-richness, any slight increase of enrichment caused by float-chamber flooding may curtail the speed or hold it just below the figure at which vibration of float or float-bowl in resonance with the engine causes the flooding to commence. To overcome this trouble, it is common practice to protect the float-bowl from high-frequency vibration by mounting it remotely on rubber or hanging it from a rubber support, with a flexible pipe to convey fuel to the jet-block on the carburetter body.

Alternatively, the whole carburetter may be insulated by inserting a section of rubber hose in the induction pipe, a device which also acts as a heat break and assists in obtaining a cold charge. It must not be overlooked, however, that the flow between float-bowl and jet is not steady, but pulsating, and it is therefore advisable to keep the connecting pipe from the float-bowl short but of large diameter, otherwise the mixture may weaken-off at high speeds for a reason which is not clearly apparent.

Correct carburation is dependent upon the difference in pressure existing on the fuel in the float-chamber and that at the jet. This is only very slight. Consequently stray air currents blowing across or into the air-intake, or a difference between the pressure at the air-intake and that at the float chamber such as may be caused by eddy-currents set up by the tank, may easily upset the mixture strength, usually by making it momentarily weaker and causing a hesitation. For that reason, carburetters are best placed in still air; and though facing the intake forward appears to offer a minor increase in power, in practice it is a thing to be avoided, for unless the intake is shielded from a direct blast it is extremely difficult to achieve correct carburation at all times.

NEXT WEEK: Two-stroke Power