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BY A. P. C.

P. L'ORANGE

FORMATION OF THE COMBUSTIBLE MIXTURE IN INTERNAL COMBUSTION ENGINES

Filed Oct. 19, 1938

Serial No. 235,881

4 Sheets-Sheet 1

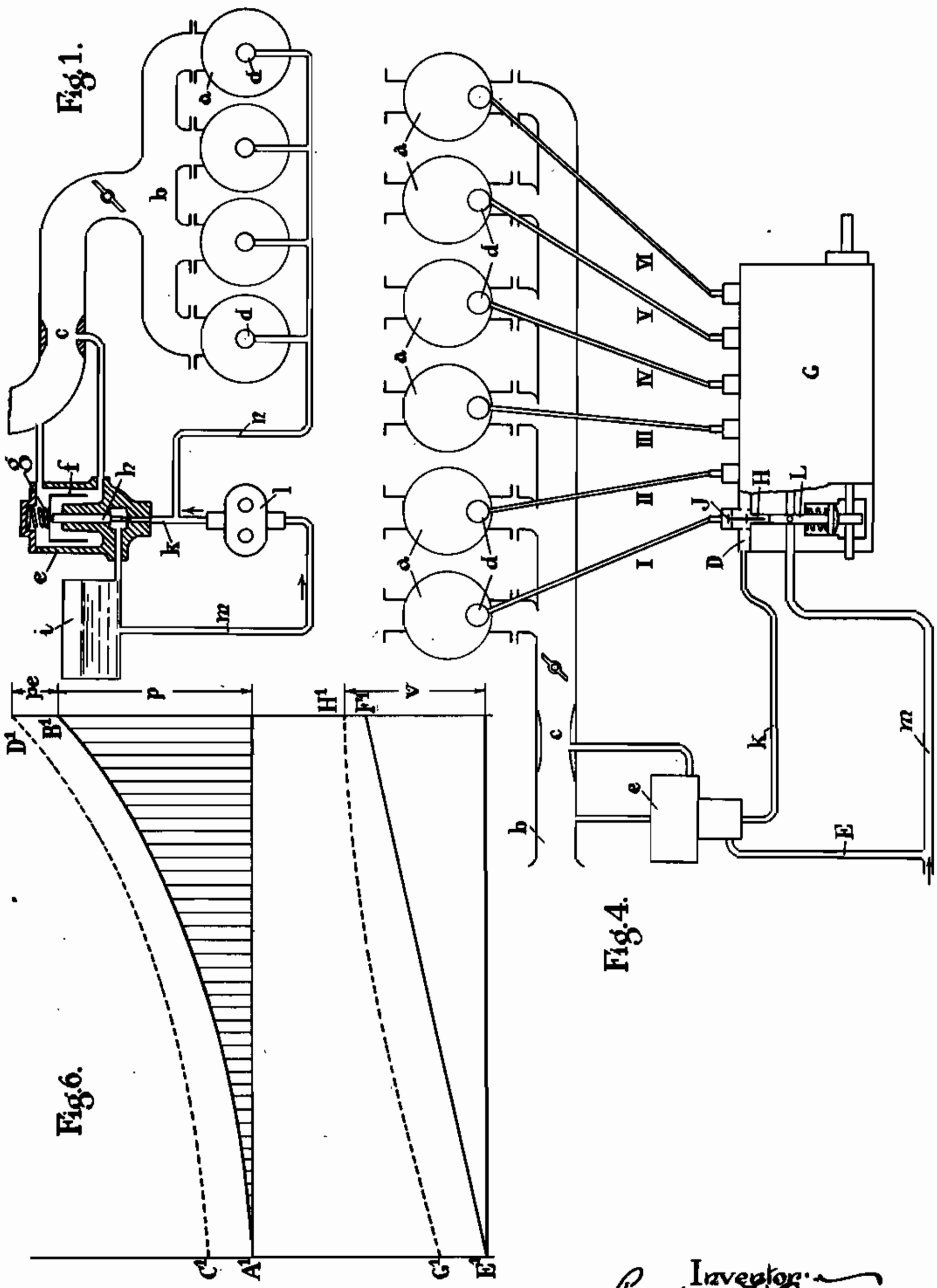


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Fig.5.

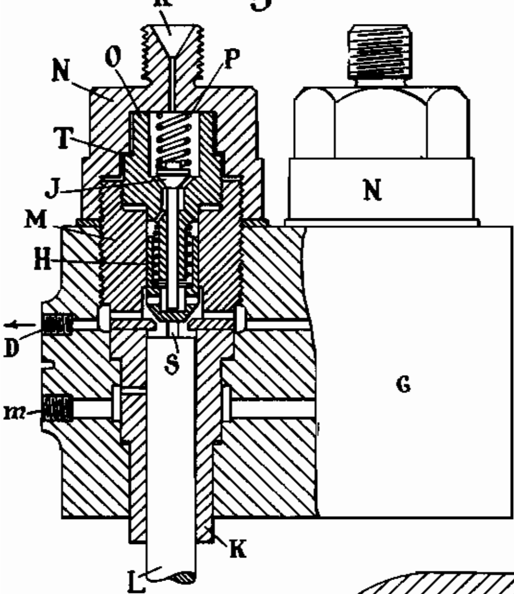



Fig.2.

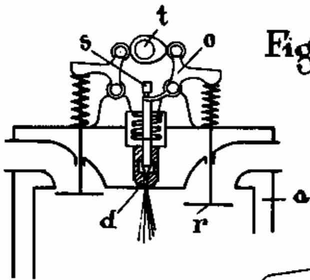
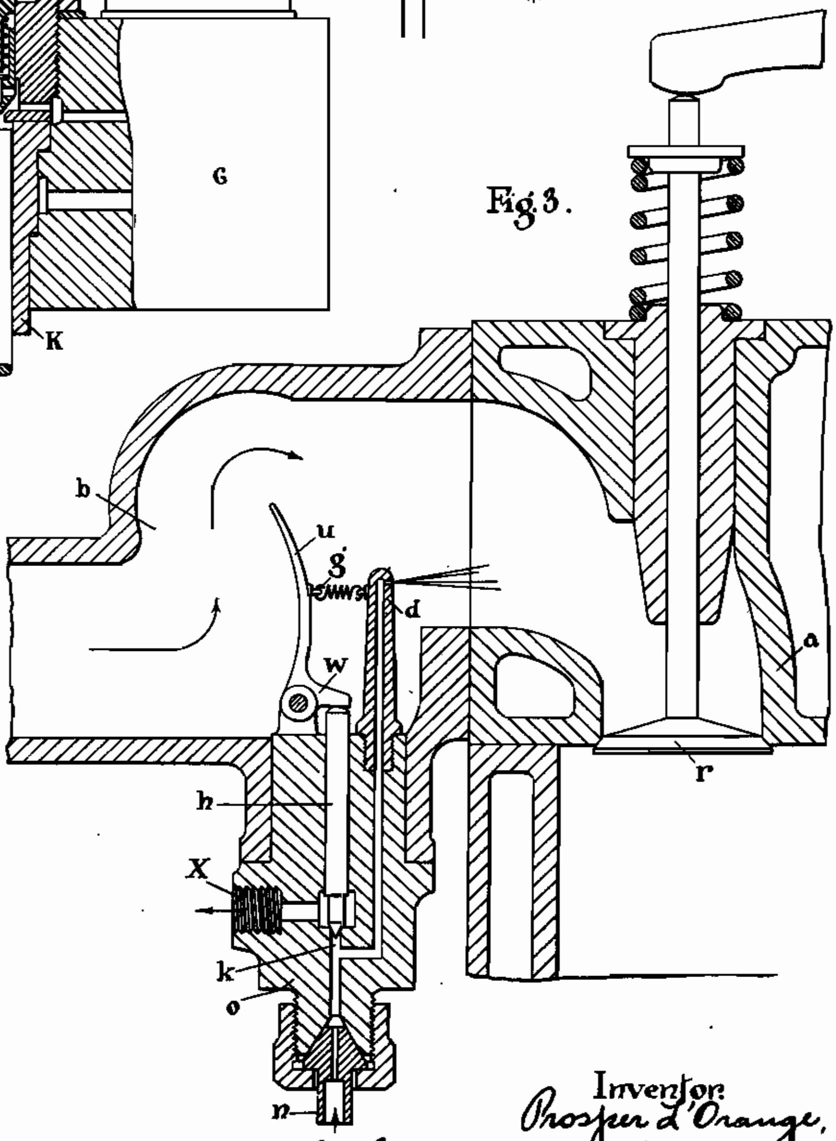



Fig.3.

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4 Sheets-Sheet 3

Fig. 7.

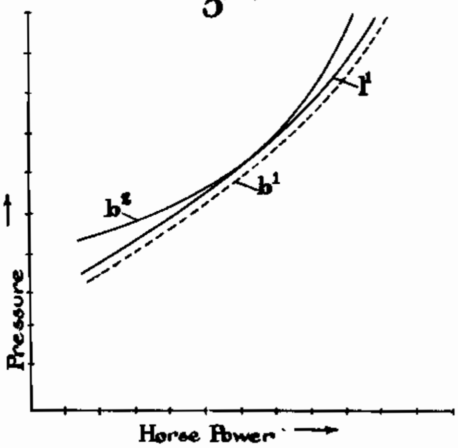



Fig. 8.

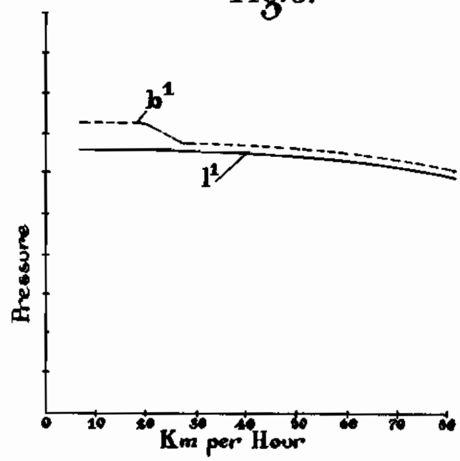



Fig. 9.

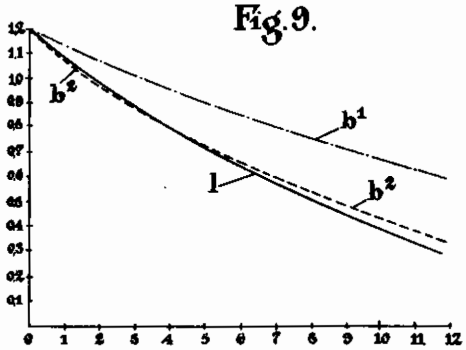
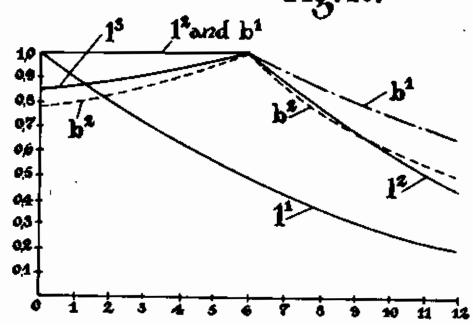



Fig. 10.

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4 Sheets—Sheet 4

Fig. 11.

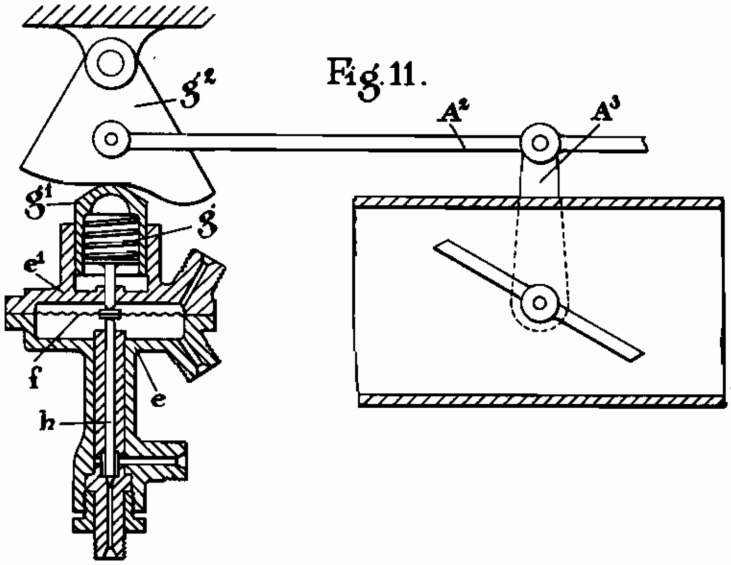



Fig. 13.

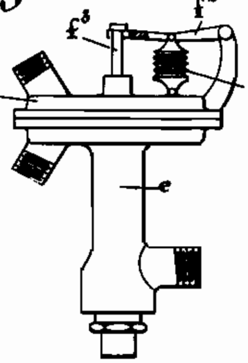



Fig. 14.

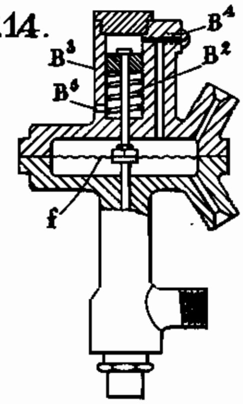
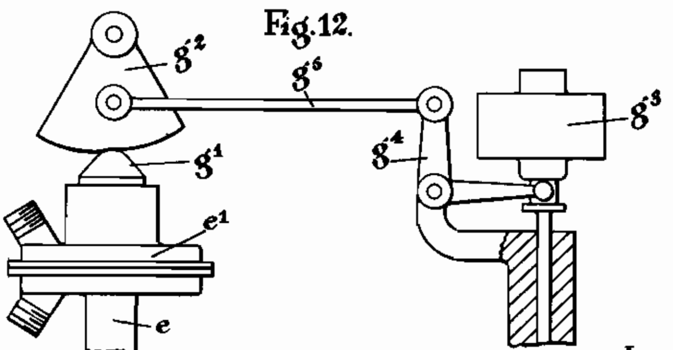



Fig. 12.

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# ALIEN PROPERTY CUSTODIAN

## FORMATION OF THE COMBUSTIBLE MIXTURE IN INTERNAL COMBUSTION ENGINES

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Application filed October 19, 1938

This invention relates to a method of and apparatus for the formation of the combustible mixture in internal combustion engines.

The formation of the combustible mixture in internal combustion engines by means of carburettors has the advantage that the quantity of fuel is adapted directly to the quantity of air supplied, but suffers on the other hand from the drawbacks that the fuel surface is exposed, that the carburettor is sensitive to position, and that the mixture is liable to be too rich at high speeds. The fuel pressures produced are also too low to effect sufficient atomisation, particularly if the fuel is injected into the interior of the cylinder.

With a view to retaining the above-mentioned advantages whilst avoiding the disadvantages it has been proposed to employ fuel pumps designed to give a variable supply and regulated by means of apparatus influenced by the pressure of the suction air supply. Such regulation cannot, however, be carried out sufficiently simply and sensitively.

According to the present invention the energy of flow of the air being supplied to a cylinder, which is also effective with a carburettor, is caused to act upon an overflow valve of a supply of fuel delivered in excess to a fuel injection nozzle, so as to maintain the fuel supply at a pressure proportional to the square of the velocity of the air supply, whereby the quantity of fuel ejected per unit of time from the nozzle at a constant value thereon is directly proportional to the quantity of air being supplied per unit of time.

In carrying the invention into effect the energy of flow of the air supply may be caused to act either directly upon, or by producing a partial vacuum upon, a piston or a diaphragm surface so arranged that the force acting thereon influences the loading of an overflow valve in the fuel pipe by which fuel is supplied to an injection nozzle or nozzles.

The speed of flow of the air increases in direct proportion to the quantity of air drawn into the engine per unit of time, but the air pressure thereby produced increases as the square of the speed of flow. Consequently, the load on the overflow valve, and therefore the pressure in the fuel supply pipe, increases as the square of the air speed. The injection velocity of the fuel, however, corresponds to the square root of the pressure of the supply thereof and thus is proportional to the speed of flow of the air.

The formation of the mixture in accordance with the invention can be effected whilst using either pumps with a uniform rate of delivery, for example, gear pumps, or piston pumps having a separate piston for each nozzle to be supplied. In the first case, a decisive factor in the design is whether a carburettor delivering a uniform flow of mixture to a plurality of cylinders is to be replaced, or whether the fuel is to be delivered to each cylinder individually just before or just after the inlet valve, in which event the injection valves must be controlled, but only one overflow valve is necessary for each pump. In the second case, no control of the injection valves need take place if a special overflow valve is provided for each nozzle. On the other hand, if it is desired to use a multiple cylinder pump with only one overflow valve, control of the injection valves is necessary. Such a control is frequently difficult to provide for, however, particularly when the invention is to be applied to existing types of engines.

According to a further feature of the invention, therefore, when a multiple piston pump is employed with only one overflow valve, the control of the injection nozzles is effected by the pump itself.

In order to effect such control in a simple manner and, in particular, to avoid as far as possible externally operated control members producing condensation, the piston of each pumping unit is utilised to control the communication between a pump delivery space common to all the pumping units, and a nozzle corresponding to the said piston. In this case a given piston does not operate to convey the charge delivered thereby to the corresponding nozzle, but actuates a control member which establishes a connection between the nozzle and the pump delivery space into which all the pumping units deliver, so that on the one hand a portion of the discharge of the other pumping units passes through the opened nozzle and, on the other hand, the total discharge of the piston actually operating does not pass through the said nozzle.

The quantity of fuel supplied through an open nozzle is determined by the regulated pressure common to all the pump delivery spaces and by the cross-sections of the nozzle supply passage and the injection aperture.

The overflow valve loaded by the pressure of flow can, in principle, be designed in two different ways.

Thus, according to one constructional embodiment of the invention a constriction may be provided in the suction pipe, for example by means of a so-called venturi tube, and a connection made between the position therein at which the air has its maximum velocity and lowest pressure and the lower side of a piston or diaphragm regulating the overflow valve, the upper side of which piston is exposed to the pressure of the air in the suction pipe before reaching the constriction.

The overflow valve is thus loaded by a resultant pressure which, if necessary, may be increased by the pressure of a spring for the purposes hereafter described; the valve will therefore open as soon as the pressure of the liquid multiplied by the cross-section of the valve is greater than the resultant pressure acting on the regulating piston multiplied by the cross-section of the latter, plus the force of the spring.

The pressure of the liquid thus always remains proportional to the difference of pressure of the flowing air at the two points in the suction pipe to which the valve regulating device is connected, and this ratio can easily be made very large, as for example a thousand to one, so that a fluctuation of the air pressure produced by a variation in the velocity of the air and amounting to a few-one-hundredths of an atmosphere will cause an excess pressure in the fuel pipe amounting to several atmospheres.

The overflowing liquid is carried back into the supply tank or into the pump suction pipe.

In an alternative construction, in order to avoid the necessity for any air-sealing member, the load on the overflow valve is obtained by placing in the air-stream an obstacle, for example a plate or other deflection surface, by which the current of air is deflected.

Such an arrangement can readily be so formed that there is no considerable loss of air velocity. It can also be conveniently designed to oscillate about a pivot and be made to act upon the overflow valve through a transmission mechanism.

The injection nozzle, when it is controlled, can be closed by a valve opening inwardly or outwardly. When the nozzle is not controlled it can, particularly when the injection takes place in the cylinder, be closed by an outwardly opening needle or by a spring-loaded check valve opening inwardly. The nozzle, however, can also be quite open, especially when it discharges into the suction pipe leading to the inlet valve.

If a controlled injection nozzle is used in conjunction with a pump having a uniform output, the control may be effected by means of a mechanical control derived from the cam shaft, and conveniently from the existing control of the inlet valve.

In addition to effecting a control of the fuel supply in the manner already described it may be necessary or desirable to effect a correction of the richness of the mixture, the nature of the correction depending upon the particular circumstances or requirements, and further features of the invention are concerned with such corrections. Thus it is sometimes found that the quanttiy of fuel at higher engine speeds becomes too great as a consequence of the air attenuation then taking place, so that the mixture becomes too rich. In order to obviate this difficulty according to a further feature of the invention, the overflow valve, in addition to being loaded in accordance with the pressure of the air flow, is also loaded with an approximately constant additional force, for example by means of a spring. It is possible in this way to maintain the proportions of the mixture substantially constant.

On the other hand, in many cases, particularly in the case of aircraft engines, it may not be desired to maintain a constant mixture for all speeds and, consequently degrees of loading but to vary the mixture so as, for example, to be richer with light or full load than with intermediate loads. This variation is effected, according to the invention, by loading the overflow valve with a variable force, additional to that depending upon the pressure of the air flow, and supplied, for example, by a spring the tension of which is varied with the load. For this purpose the tension of the spring may be varied simultaneously with the adjustment of the throttle regulating the output, so that an additional initial tension is imparted to the spring when the throttle is slightly open and when it is fully open, but the tension is relieved in the intermediate position of the throttle corresponding for example, to the stage between sixty per cent and eighty per cent of the full load.

In still other cases, notably in the case of heavy motor vehicles, it may be desired that the mixture should be particularly rich at a certain speed, for example at the speed at which gear-changing takes place, and should become weaker with increasing speed. In such cases, according to another feature of the invention, the fuel curve is corrected for example, by employing the inertia of a centrifugal regulator, by loading the overflow valve with a force, additional to that depending upon the pressure of the air flow, which is influenced by the speed and increases or decreases therewith. In this way, a mixture can be produced which is richer at low speed and at maximum speed, but poor at intermediate speeds, or which is richest at any given speed.

Another feature of the invention relates to the correction of the mixture proportions to compensate for variations of the altitude at which the engine is operating. The method of mixture formation already described ensures that the quanttiy of fuel supplied in a given time shall be in direct proportion to the quantity of air supplied in the same time, subject to any of the previously described corrections that may be applied, and provided that the density of the air remains constant. The proportions of the mixture would not, however, remain constant with variations in the altitude at which the engine is operating, since, although the fuel pressure is reduced in direct proportion to the fall in air density, the quantity of fuel supplied per unit of time varies as the square root of the air density. The quantity of fuel supplied is therefore not reduced to the same extent as the air density and the mixture thus becomes relatively richer with increasing altitude. In accordance with the invention, this fault is corrected by reducing the force loading the overflow valve as the altitude increases. This may be effected by applying an additional force having a negative action, the said force being provided, for example, by a diaphragm chamber, filled with air at normal atmospheric pressure so as to expand as the altitude increases, and arranged to reduce the load on the overflow valve when such increase takes place. If a supercharging blower is provided, the difference between the blower pressure and the external pressure may be employed to produce the variation in loading of the overflow valve, the said difference in pressure being compensated for by a spring as is more fully described hereafter.

In order that the invention may be clearly understood and readily carried into effect reference will now be made to the accompanying drawings, in which:

Figure 1 illustrates diagrammatically an engine having a fuel supply installation according to the invention which embodies controlled injection nozzles and a fuel supply pump with a uniform output;

Figure 2 illustrates an arrangement for controlling the injection nozzles;

Figure 3 illustrates an alternative arrangement for the regulation of the overflow valve in which an uncontrolled injection nozzle is used in conjunction with an intermittently discharging piston pump;

Figure 4 illustrates a modification of the invention in which several injection nozzles are supplied separately from the pumping units of a multiple piston pump and the operation of the nozzles is controlled by the pump pistons;

Figure 5 illustrates in detail a construction of a pumping unit and injection-valve control suitable for use in the embodiment illustrated in Figure 4.

Figure 6 is a diagram illustrating the operation of a fuel supply installation constructed in accordance with the invention, and one way in which the mixture proportions may be corrected.

Figures 7 to 10 are further diagrams illustrating the correction of the mixture proportions to take account of different circumstances and conditions, and Figures 11, 12, 13 and 14 illustrate various modifications of an apparatus constructed according to the invention, designed to effect the corrections illustrated respectively in Figures 7, 8, 9 and 10.

Referring to the construction illustrated in Figure 1 of the drawings, the four controlled injection valves *d* of an engine *a* are supplied with fuel from a pump *l* having a uniform rate of delivery, by means of a pipe *n* connected in parallel with the four injection valves *d*. The pipe *n* is connected to an overflow pipe *k*, controlled by an overflow valve *h*, and leading to the supply tank and thence back to the suction side of the pump *l*.

There is inserted in the air suction pipe *b* of the engine *a* a constriction *c* from the narrowest point of which a connection is made with the underside of a regular piston *f* which works in a cylinder *e* and is thus subjected on its underside to the reduced pressure resulting from the partial vacuum at the point *c* in the pipe *b*. The upper end of the cylinder *e* is connected to the pipe at a point on the inlet side of the constriction *c*. The piston *f* is thus loaded in accordance with the difference in the pressures in the pipe *b* at the point *c* and on the inlet side thereof. In addition the piston *f* is loaded by a spring *g* for effecting a correction of the fuel delivery curve in a manner more fully described hereafter in connection with Figure 6 of the drawings. These loads are applied to the overflow valve *h* which is made as a needle and closes the pipe *k* from the pump *l* until the pressure in the pipe *n* is sufficient to lift the valve *h*, whereupon a portion of the liquid flows back to the fuel tank *i* and subsequently, by way of the pipe *m*, to the suction side of the pump *l*.

The manner in which this construction operates is illustrated in Figure 6 of the drawings, in which the full line curve A', B' illustrates the increase of the fuel pressure *p* with the engine and air supply speeds, at a constant position of the air throttle. By taking the square roots of the values for the pressure *p* given by the curve A', B', a curve E', F' corresponding to the fuel injection velocity *v* is obtained. This curve, as can be seen, is in the form of a straight line, indicating that the fuel injection velocity increases proportionally to the engine speed.

Figure 2 illustrates one manner of controlling the injection valves *d* illustrated in Figure 1. In this construction, the valve is moved by the lever *o* of the cylinder inlet valve, so that it is open during the whole or a portion of the suction period. By shifting a collar *s*, the period of opening and the height of the opening movement of the valve *d* can be adjusted. The injection valve could equally well be controlled directly from the cam shaft *t* by means of cams and double armed levers. The adjustment of the valve during working (for example, to obtain a weak or a rich mixture) could then take place, for example, by adjusting the lever pin which in this case would be eccentric.

In the modification illustrated in Figure 3, the energy of the air flowing in the suction passage acts on a blade-like deflection surface *u* which, by means of a small lever arm *w*, bears upon the needle *h* of the overflow valve. The needle *h* closes a passage *k* communicating with the passage *n* through which fuel is supplied to an uncontrolled injection nozzle *d*.

The fuel is supplied by a piston pump (not shown) which supplies periodically and to excess during the corresponding suction stroke, so that there arises in the passage *n* a pressure proportional to the square of the air velocity. When the fuel exceeds this value the valve *h* opens to permit the overflow of fuel to pass by the passage *x* back to the suction side of the pump, whilst the remainder of the fuel is injected into the passage *b* through the nozzle *d*, which has a small bore directed towards the inlet valve *r* in the cylinder *a*.

The entire overflow valve and regulating device is mounted in and on a body *o* which is so fitted in a socket in the suction pipe *b* at an enlarged portion thereof that the current of air deflected by the blade *u* is caused to follow an S-shaped path.

In use, the pump is so adjusted as to commence its delivery stroke shortly after the commencement of the suction in the passage o and to end its delivery stroke slightly before the moment when the suction in the passage *b* ceases. During the delivery stroke of the pump, therefore, the overflow valve *h* is continuously loaded proportionally to the square of the quantity of air passing the blade *u* per unit of time.

A spring *g* is provided in this case also to effect a correction of the fuel delivery curve as described hereafter with reference to Figure 6.

The rebound surface *u* may also be made round and act directly on the needle *h*.

The nozzle opening may also be closed by an automatic valve, especially when the injection takes place in the cylinder itself.

In addition to effecting the correction described with reference to Figure 6, the spring *g* may be used to provide a supplementary load in order to compensate for a constant resistance in the injection pipe *n* or the nozzle *d*, for example, the resistance of a spring-loaded valve therein. The fuel pressure necessary for the opening of such a valve would then be determined by the spring *g* which would have to be designed to provide a force corresponding to that pressure, in addition to the force required for effecting the correction of the mixture proportions.

In the modification illustrated in Figure 4 the air suction pipe *b* of a six-cylinder engine *a* is connected to a regulating device *e*, for example of the form illustrated in Figure 1. The pressure of the fuel supply to the injection nozzles is produced by a multiple piston pump G, all the units of which discharge into the same delivery space D which is connected by a pipe *k* to the overflow valve of the device *e*. The pressure in the delivery space of the pump G is thus kept at a level corresponding to the quantity of air supplied per unit of time. The outflow of the excess fuel from the device *e* takes place through the pipe E to the pump suction pipe *m*.

The pistons L of the pump G are so adjusted that each piston reaches the end of its discharge stroke approximately at the mid point of the injection period of the corresponding injection valve.

During the compression stroke of a given piston L a pressure valve H opens, but the stroke of the said valve H is limited by a valve J, which is held on its seat by a strong spring. At the end of the compression stroke, however, the piston L positively engages the valve H and thus lifts it and the valve J by a small amount, so that during this period the pressure space D is connected to one of the pipes, I, II, III, IV, V, or VI supplying the injection nozzles *d*.

The construction of one of the pumping units diagrammatically illustrated in Figure 4 is more clearly illustrated in Figure 5. In this construction the pump housing G contains a piston guide K in which the piston L slides. In the position shown, the piston L is at the upper end of its stroke and has lifted, by means of an extension S, the pump discharge valve H and with it the control valve J, so that the passage in the union R is connected to the pump delivery space D and with the overflow valve of the regulating device *e*. The valve J is moved against the pressure of a strong spring P, so dimensioned as to maintain the valve J closed against the highest fluid pressure arising beneath it.

The delivery valve H is fitted in a screw-threaded body M which bears upon the piston guide K and is closed at the top by a cap B. The control valve J moves in a guide member O which is tightly screwed into the cap N. The height of opening of the control valve J can be determined by the thickness of a packing T.

In place of a control valve J of the form illustrated, a ground slide valve may be employed.

In each of the constructions described, since the loading of the overflow valve is derived solely from the energy of flow, the connections for utilising that energy can be made in front of or behind the air throttle. Similarly, the injection nozzle, when fitted in front of the air inlet valve, can be inserted at any position in the suction passage in front of or behind the air throttle.

As has already been pointed out, it may be necessary or desirable to correct the proportions of the mixture to take account of different circumstances. Thus, it may be found that the quantity of fuel at higher engine speeds becomes too great as a consequence of the air attenuation then taking place, so that the mixture becomes too rich. This difficulty is met by the provision of the spring *g* illustrated in Figures 1 and 3, which acts to apply an approximately constant load to the overflow valve *h* additional to the load derived from the pressure of the air flow. The effect of such additional load can be seen from Figure 6, in which the addition of the load *p, e* produces the final fuel pressure curve indicated by the broken line C′, D′. By taking the square roots of the values given for the pressure $(p+p, e)$ by the curve C′, D′, the curve G′, H′ is obtained which, as can be seen from the drawing, has a downward curve, in contradistinction to the straight line curve E′, F′, that is, the rate of increase of the fuel injection velocity is not directly proportional to the engine speed but decreases somewhat as the engine speed increases. It is easy by the choice of a spring of appropriate strength so to adjust this relative decrease of the fuel injection velocity as to permit the maintenance of a mixture of uniform proportions at all engine speeds.

Figure 7 illustrates a case in which the mixture proportions are corrected so that the mixture is richer with light and full load than with intermediate loads, as may be required, for example, in an aircraft engine. In the figure the continuous curve $l^1$ represents the variation of air pressure behind the throttle and, consequently, of the approximate air density in the cylinder, with variations in load. The curve $b^1$ represents the variation of the fuel supply pressure when no correction is applied, and curve $b^1$ being proportional to the curve $l^1$. The supply should, however, comply with the curve $b^2$, that is to say, the mixture should be richer with no load and with full load than with intermediate loads.

This may be achieved, for example, by the apparatus illustrated in Figure 11, which comprises a regulator *e*, operating similarly to the regulator illustrated in Figure 1, and having an overflow needle *h* loaded by a diaphragm *f*, the upper side of which is connected to a region of high pressure in the air supply passage, while the lower side thereof is connected to a region of lower pressure.

The said diaphragm *f* is further loaded by a spring *g*, the upper abutment of which is formed by the displaceable piston $g^1$ in the casing cover $e^1$. The piston $g^1$ is displaced by a cam disc $g^2$ and the spring *g* is tensioned as soon as the cam disc, which is connected to the throttle valve A by a connecting rod $A^2$ and a lever $A^3$, moves upon opening the throttle. As is illustrated, the cam $g^2$ is designed to correct the supply curve in the desired manner.

If desired, instead of employing the mechanism $A^2$, $A^3$, the correction may be effected by actuating the cam disc $g^2$ by means of a piston which is loaded on one side by the pressure of the air supply in front of the throttle and on the other side by a spring and by the negative pressure behind the throttle.

Figure 8 illustrates a correction which is suitable, for example, for the engines of heavy motor vehicles. In this case, the additional output and consequently the increase in the supply is provided, as indicated at $b^1$, at a road speed at which gear-changing takes place after which a rapid increase in the torque is necessary. The correction indicated in Figure 8 may be obtained by means of the apparatus illustrated in Figure 12 which comprises a centrifugal regulator $g^3$ which actuates a cam disc $g^2$ through a lever $g^4$ and connecting rod $g^5$ in a manner similar to that illustrated in Figure 11. When the regulator $g^3$ rises owing to an increase in the speed, the cam disc $g^2$ is thereby displaced to the left and so reduces the spring tension. When the regulator $g^3$ descends, the cam increases the tension of the spring and consequently the supply of fuel.

If the engine is to be used at considerably varying altitudes it is desirable to effect a correction to compensate for the change in the air density, the reduction of which from a very low altitude up to an altitude of 12 kilometres is indicated by the curve $l$ in Figure 9. The reduction in pressure of the fuel supply, however, follows the curve $b^1$ if no correction is applied, and thus differs increasingly from the air pressure with increasing altitude. The present invention provides a correction of the fuel pressure whereby the curve $b^2$ is obtained, which provides a sufficient approximation of the fuel pressure variation to the air density variation.

A device suitable for this correction is illustrated in Figure 13, in which a diaphragm chamber $f^1$ is mounted on the cover $e^1$ of a regulator casing $e$ of the form already described, the said diaphragm chamber $f^1$ acting, through a lever $f^2$ and a connecting rod $f^3$ on the regulator diaphragm and expanding with increasing altitude, due to the decreasing air density, so as to reduce the load on said regulator diaphragm.

When the engine is supercharged the correction to compensate for variations in altitude requires to be modified, and the manner in which the correction is effected is illustrated in Figure 10, in which the curve $l^1$ represents the reduction in the external air pressure from a very low altitude up to an altitude of 12 kilometres. By adjustment of the supercharger it is usually possible to maintain the air supply substantially at atmospheric pressure curve $l^2$ and $b^1$ until a given maximum altitude (indicated in the figure as 6 kilometres) is reached. Subsequently the pressure of the air supply decreases substantially in the same proportion as the external air pressure, as indicated by curve $l^2$. The device illustrated in Figure 1 of the drawings would provide a mixture of the correct proportions up to the said maximum altitude, (curve $l^2$ and $b^1$) but as indicated by the curve $b^1$ would then produce the same deviation as is indicated in Figure 9. If, at this point, the action of the diaphragm chamber $e$ is replaced by that of a small piston which is loaded on one side by the external air pressure and on the other side by the pressure of the air supply, an effect can be obtained which is similar to that produced by the diaphragm chamber $f^1$ illustrated in Figure 13, so that the fuel curve $b^1$ is corrected at its right hand end to the form of the curve $b^2$. This result is obtained if the correcting piston is rendered operative, for example by means of the charging regulator, only when the given maximum altitude of 6 kilometres has been exceeded. However, it is advantageous for this correction also to be rendered effective before the said altitude has been attained as in indicated in Figure 10. This is due to the fact that if the air supply pressure is maintained constant up to the said maximum altitude, the quantity of fresh air charged does not remain constant, but is increased by an amount varying from approximately 20% until the said altitude is reached, owing to the influence of residual gas and temperature. By applying the correction referred to, however, the air supply pressure curve and the fuel supply curve are corrected to the form of the curve $l_3$ and the left hand end of the curve $b_2$.

Since the differential pressure increases when descending from the said maximum altitude, that is to say from 6 kilometres in this case, the arrangement also produces the correction when descending from that altitude.

An apparatus suitable for effecting the correction illustrated in Figure 10 is illustrated in Figure 14, in which a piston B and spring $B^2$, which are both enclosed in a cylinder $B^3$, act on a regulator diaphragm $f$, such as is illustrated in Figure 11, through a connecting rod C.

The space above the piston B communicates through a passage $B^4$ with the space above the regulator diaphragm $f$ and thus with the air supply pipe in front of the throttle. The space below the piston B is in communication with the external air through apertures $B^6$.

At very low altitudes, no differential pressure is produced on the piston B and the spring tension effects a maximum reduction of the load on the regulator diaphragm $f$. At the given maximum altitude of 6 kilometres the differential pressure is at a maximum and nullifies the spring pressure. Upon a further increase of altitude, however, the spring pressure again becomes effective.

The different corrections described can be employed simultaneously; for example, the correction illustrated by Figure 7 may be employed simultaneously with the altitude correction illustrated by Figure 10. In such a case, in addition to the piston B loaded with the differential pressure, there would be a spring of variable tension acting on the regulator diaphragm and controlled as in Figure 11. Alternatively the tension of the spring $B^2$ below the piston B would be controlled to produce the correction indicated in Figure 7.

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