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INTERNAL COMBUSTION ENGINE

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Fig. 1.

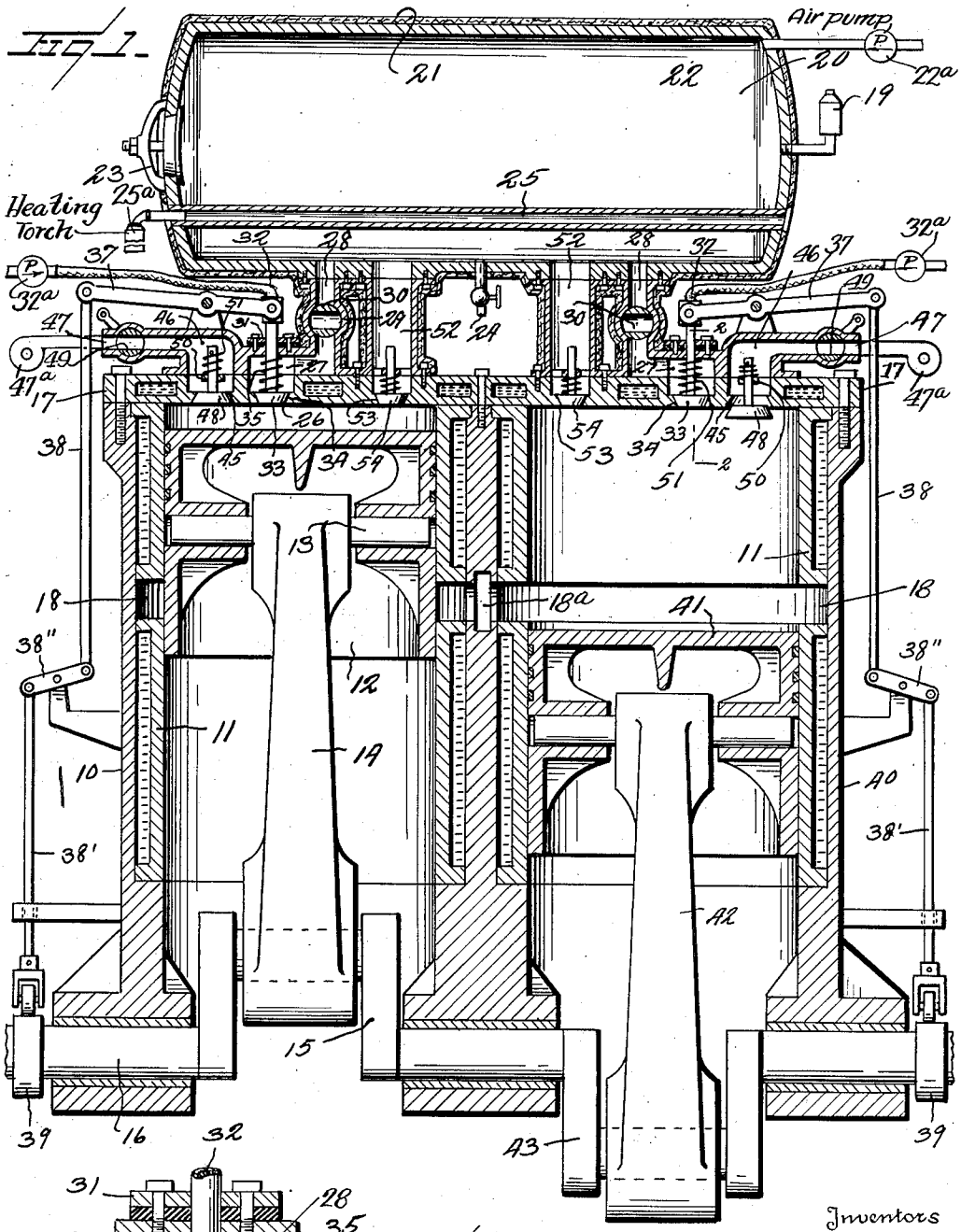


Fig. 2.

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INTERNAL COMBUSTION ENGINE

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This invention relates to internal combustion engines of the constant pressure combustion type, and particularly to variable speed engines of a type which can produce work diagrams similar to the flexible cut-off range of steam engine.

The general object of this invention is to provide in connection with the working cylinders of such engines, means whereby liquid fuel may be forced solidly, in contradistinction to fuel in an atomized state, simultaneously with high-pressure and high-temperature air, into the interior of the working cylinders at or immediately after the end of the compression stroke during variable degrees of crank travel.

A further object of this invention is to provide means whereby the air and fuel shall be supplied at a predetermined ratio relative to each other regardless of the length of time of their simultaneous admission, the fuel being under control and discharged into the cylinders from a fuel pump and the air being discharged into the cylinders, under control of the valve gear, from an insulated high-pressure high-temperature reservoir wherein the air is maintained at a constant high temperature and pressure.

A further object in this connection is to provide means whereby air in said cylinders, on the crank stroke of the pistons, is compressed to the degree of pressure constantly kept in the reservoir and then delivered from the cylinders into the reservoir, by virtue of the small cylinder clearances, in the same thermal condition as the air already in said reservoir, the power for so feeding the reservoir, that is, for so compressing the air in the cylinders, coming from the previous combustion and expansion in the cylinders themselves.

A further object is to provide an engine of this type which can be started under full load from a dead stop and which will continue to function under any varying rate of speed within its capacity, thus allowing the engine to be directly connected to a locomotive driving axle and start and accelerate a train without the necessity of using electrical generators or motors or any kind of clutch or transmission mechanism, the engine being capable of developing a sustained tractive and torque characteristic similar to a steam locomotive, such an engine being also adapted to marine, stationary, and automotive fields. And further in this connection to provide an engine in which conditions can be maintained for starting the engine from a dead stop by holding a supply of high-temperature and high-pressure air in an insulated heat storage compressed air reservoir so that upon starting the engine from a dead stop combustion can be realized upon the first stroke of the piston, which is ordinarily a suction stroke, without the necessity of spinning the engine or starting it by an external supply of compressed air or by an auxiliary engine or motor, as is common with known engines of the internal combustion type, and it is to be understood in this connection that one of our objects is to provide an engine which does not start by simply compressed air, but by combustion of the fuel and air, and which will permit a long period of admission for the fuel and air, thus securing a steady and constant force upon the pistons for a considerable portion of the piston strokes.

A further object is to provide means whereby fuel may be admitted to the working cylinder in the form of a fine spray and simultaneously mixed intimately in the cylinders themselves with incoming air, thus avoiding the difficulties of insufficient turbulence and insufficient mixing, such difficulties being present in oil engines known to-day, and a further object in this connection is to admit air and fuel simultaneously but to admit the air and fuel from independent sources, the air used for combustion being admitted simultaneously with the fuel but this air being at a high temperature but not at a greater pressure than the previous terminal pressure of compression.

A further object of the invention is to provide means whereby a definite predetermined air-fuel ratio is maintained regardless of the point of cut-off and time of admission, thus departing wholly from known "solid" or air injection oil engines; and further in this connection to provide means whereby the large weights and masses of air used per cycle are mixed progressively and simultaneously so as to get complete constant pressure combustion.

Another object of our invention is to provide a structure whereby variable scavenging and supercharging can be secured, one of the elements necessary for this object being the use of a relatively large capacity, high-temperature, high-pressure reservoir, the use of this large capacity reservoir with respect to the combined volume of the cylinders resulting in the delivery of the air with no appreciable pressure rise, thus securing with complete combustion a longer cut-off than is possible with any oil engine operating on any of the known cycles.

Other objects will appear in the course of the following description.

Our invention is illustrated in the accompanying drawing, wherein:—

Figure 1 is a vertical sectional view of our improved internal combustion engine;

Figure 2 is an enlarged detailed view of the fuel and air inlet valve.

Referring to the drawing, 10 and 40 designate working cylinders each having the usual lining 11 and the usual piston. The piston 12 of the cylinder 10 is, of course, connected by the wrist pin 13 with the connecting rod 14 which is in turn connected with the crank 15 of a shaft 16. The cylinders are each provided with a head 17. The cylinder walls below the upper end of the cylinders are provided each with an exhaust port designated 18 through which the products of combustion are blown when the pistons have descended to a point below the port 44.

Disposed in connection with the working cylinders 10 and 40 is an air tank or reservoir 20 containing compressed air kept at a constant state of compression, as, for instance, at a pressure of 500 lbs. and kept at a constant temperature of 1000° F. The reservoir is covered with lagging 21 and is connected at 22 with means such as an air pump 22^a, whereby compressed air may be initially forced into the reservoir and to a pressure of 500 lbs. per square inch. One end of the reservoir is provided with the manhead designated generally 23 for the purpose of entering and inspecting the tank or reservoir. A blow-off or drain outlet 24 is provided in the reservoir. A safety valve 19 may be connected with the vessel in any suitable manner to permit the pressure to blow off when it is higher than a predetermined amount.

Extending longitudinally through the reservoir or tank 20 is a tube 25 whereby the flame from a torch 25^a may be discharged into the interior of the tube through the open ends thereof for the purpose of warming up the compressed air in the vessel before starting the engine.

While we have illustrated a single tube 25 for this purpose, it will be understood that a plurality of tubes might be used and we do not wish to be limited to the use of any particular heating means for warming up the air in this vessel or tank 20. Gas jets may be used for this purpose discharging into the tube 25 or electrical heating means may be used for this purpose. It is within the purview of our invention to use any means for initially heating the air in this tank up to the required point of 1000° F. before the engine is started.

We will first describe the construction of the cylinder 10 specifically, it being understood that the cylinder 40 has the same general construction. The head 17 is provided with a central opening 26 which opens into a chamber 27, this chamber in turn having a passage 28 leading into the interior of the tank 20. The walls of the passage 28 are formed to provide a valve casing 29 within which any suitable throttle valve 30 may be disposed which may be manually operated to cut off the passage of compressed air from the tank 20 into the cylinder or permit said passage.

The chamber 27 is closed by a gland and cap 31 and operating through this gland and cap is a tubular valve stem 32 carrying a valve 33 at its lower end which engages with the seat 34 surrounding the opening 26. A spring 35 may be used to urge the valve to a closed position.

Extending downward through the tubular valve stem 32 is a very small channel 36 which terminates at its lower end in a number of downwardly diverging passages opening upon the lower face of the valve 33 and through which fuel can be injected solidly into the engine cylinder in the direct path of the incoming air passing down around the downwardly beveled face of the valve 33. The shape of the seat 34 and the valve is such that the air coming from the reservoir 20 is discharged downward and centrally while the fuel from the passage 36 is discharged downwardly and outwardly. This throws the fuel into the direct path of the incoming air and atomizes the fuel and thoroughly mixes it with the air as the fuel passes into the upper end of the cylinder 11. Combustion occurs in the clearance space above the piston and forces the piston downward on its power stroke. The combustion of the fuel and air lasts while the valve is held open by the valve gearing. This valve is controlled by any suitable valve gearing and we have shown for this purpose, purely for illustration, a rocker 37, a reach rod composed of sections 38 and 38′, an intermediate rocker 38″ and a cam 39 mounted upon the shaft 16. It is to be understood, however, that we do not wish to be limited to any particular gearing for operating the valve 33.

The tubular valve stem 32 is connected to any suitable form of fuel pump 32^a which controls the feed of the injection of the fuel. There are many different forms on the market and the fuel pump itself forms no part of our invention.

The cylinder 40 is of the same construction as the cylinder 10. Within this cylinder 40 is the piston 41 connected by the connecting rod 42 to a crank 43 on shaft 16. Formed in connection with the cylinder 40 and the cylinder 10 is a common exhaust port 18^a, that is, a port common to both cylinders.

As illustrated, the cylinder 40 and the cylinder 10 are formed in one integral block, though we do not wish to be limited to this and the head 17 extends over the cylinder 10 as well as over the cylinder 40.

In the head of each cylinder 10 and 40, there is formed a scavenging and supercharging air inlet opening 45 which opens into a chamber 46 having an inlet 47 which is adapted to be connected to a pump or blower 47^a or any means whereby the air may be forced into the chamber 46 and forced into the cylinder 10 through opening 45. Passage through the opening 45 is controlled by means of a downwardly opening valve 48, the stem of which extends upward into a guide 50. A spring 51 urges this valve to a closed position. In order to control the amount and pressure of the inlet scavenging air, we have provided a valve 49 in the scavenging air inlet 47, this valve being provided with a handle so that it may be shifted manually to thereby control the amount of pressure of the scavenging air.

Leading from the upper end of each cylinder 10 and 40 is a passage 52 which communicates with the interior of the tank or reservoir 20. The lower end of this passage is formed with a valve seat 53 and coacting with this seat is a downwardly tapered valve 54. When this valve is forced upward, air compressed within the upper end of either cylinder above the piston thereof will be forced into the tank 20. The cylinder 10 is provided, as before stated, with an exhaust port 18—18^a which may extend circumferentially around the cylinders 10 and 40 and which is disposed just above the lowest position of both pistons so that when either piston descends and

passes the exhaust port 18—18a, the burned gases may be discharged from the exhaust port in the manner of a two-cycle engine.

The cylinder 40 is also provided with a fuel inlet valve 33 constructed in the same manner as the fuel inlet valve for the cylinder 10 and having a tubular duct 36 communicating with a source of liquid fuel.

In the drawing, we have illustrated a pair of cylinders, though any number of sets of these cylinders can be used in one engine or upon one crank shaft.

The cranks 15 and 43 are shown as disposed 180° apart and this is the most satisfactory position for the cranks in order to secure the best operation for this engine but the cranks may be disposed at any relative angle without affecting the principle of this invention and obviously we do not wish to be limited to this setting of the cranks.

It is to be understood that not only is the tank 20 lagged with heat insulating material but that the connections between the tank 20 and the cylinders 10 and 40 are also lagged or heat-insulated.

The operation of the form of our invention illustrated in Figure 1 is as follows:—

It is assumed that the tank or reservoir 20 has been filled with air to a predetermined high pressure, as, for instance, 500 lbs. per square inch and that this air is heated to a temperature of 1000° F. This is the constant working condition for this vessel or tank which serves as an enlarged common clearance for all cylinders of a unit. This previous compression of the air is secured, of course, by the use of any desired air compressor connected to the tank through the opening 22 and the heating of the tank to a 1000° F. may be secured by any suitable means as before stated.

When the engine is to be started, the valves 30 are opened and heated compressed air passes into the corresponding chamber 27. When the valve 33 of the corresponding cylinder is opened, which occurs when the piston of this cylinder has at least reached the uppern ost point of its stroke and the air in front of the piston is very highly compressed, the charge of highly atomized fuel and compressed air flows into the upper end of the corresponding cylinder and because of the compression, immediately ignites, and while the piston is receding, constant pressure combustion occurs and the piston of this cylinder is forced down on its power stroke. When the piston has reached the lower portion of its stroke, the valve 33 is, of course, closed and the exhaust port is uncovered by the piston and low pressure scavenging air is admitted through the valve 48, thus scavenging and supercharging the cylinder of most of the burned gases, which are carried out through the port 18—18a. The piston then returns on its upward stroke, compressing the fresh air ahead of it along a nearly adiabatic compression curve until the constant pressure of the cycle is reached. Pressure of the air compressed in the upper portion of each cylinder causes the opening of the valve 54 and a substantial portion of the air compressed within the upper end of the cylinder is forced and delivered into the tank 20 by virtue of the very small cylinder clearance at top dead center. Thus the return of the piston maintains the constant pressure of the cycle and delivers air into tank 20.

It is to be understood that the combustion of fuel oil and air lasts while the valve 33 is held open by the valve gearing and that this may occur during only a short part of the outward movement of the piston or during a large part of the outward movement. The amount of work done in the cylinders 10 and 40 is in proportion to the time or length of opening of the respective valves 33 and the amount of fuel injected, these two factors being under the control of the valve gear which can be obviously set for any desired point of cut off. The action in one cylinder is duplicated by the action in the other cylinder but as the piston 12 moves downward, the piston 41 moves upward so that while one piston is on its working stroke, the other piston is on its compression stroke.

Due to the lagging between the chamber 20 and the cylinders 40 and 10 and the lagging around the chamber 20 or tank and around the passage 28, very little heat loss occurs and the temperature of the air admitted to the cylinders is practically the same as the air leaving the cylinders upon the delivery at the termination of compression.

It will be seen that the engine so far described is a two stroke or two-cycle engine, but it is to be understood that the same principles of variable supercharging and variable cut-off and method of simultaneous fuel and air ratio and burning can be used for a four-cycle engine.

It is again reiterated that the amount of work done in the cylinders 10 and 40 is in proportion to the time or length of opening of the valves 33 and the amount of fuel injected, these two factors being under the control of the valve gear which, of course, can variously be set for any desired point of cut-off.

As the piston 12 moves downward, the piston 41 moves upward. The pressure of the air compressed in the upper portion of the cylinders 40 and 10 causes the opening of the valve 54 and a substantial portion of the air compressed within the upper end of the cylinder is forced and delivered into the tank 20. Due to the lagging between the chamber 20 and the cylinders 40 and 10 and due to the lagging around the chamber 20 or tank and around the passage 28, very little heat loss occurs and the temperature of the air admitted to the cylinder 10 is practically the same as the air leaving the cylinder 40 upon the delivery at the termination of compression.

It will be seen that the cylinders 40 and 10 both have for their purpose on the compression stroke the feeding of reservoir 20 with compressed air in the same thermal condition as the air compressed for combustion in the cylinders themselves, on the compression stroke and that the power for so feeding the reservoir or tank 20 comes from the expansion in the cylinders. Therefore, the cylinders act as combination compressors and expanders functioning self-sustaining when furnished with scavenging air from an external scavenging blower or pump not integral with the engine and not shown.

A further result of the operation of this engine and a further advantage is as follows:—

After the engine has attained some speed or has overcome its load to a certain degree, the work of compression required being less, the cylinders take on a style of operation similar to normal Diesel engine cylinders under medium and light loads.

The principal advantage of an engine constructed in accordance with our invention lies in the fact that it can be started under load from a dead stop and continue to function under full load

capacity provided that before starting, the external reservoir or tank is filled with high pressure, high temperature air. It will further be seen that this engine is a variable speed engine and that this variable speed is entirely independent of the load within the capacity of the engine and that variable cut-off is attended with variable efficiency.

While a multi-cylinder requires no fly wheel, yet a fly wheel can be used, if desired for engines having only one or two cylinders. The engine can be connected directly to the driving axle of a locomotive and may be readily controlled to handle and accelerate or decelerate a train without the aid of electric generators or motors and without the aid of any power gear transmission, though obviously gearing may be used, if desired. The particular manner in which the fuel is admitted through the tubular valve stem provides a means by which a fine spray of fuel is mixed directly with the flow of incoming air, thus avoiding the difficulty of inefficient turbulence and mixing in present oil engines. The mixing in our engine is progressive. The cylinder head clearances have very low values permitting efficient delivery to the reservoir.

An engine constructed in accordance with our invention, under full load conditions, produces a steady torque similar to the work diagram of a steam engine in full gear cut off.

It is to be understood that when the piston rises and reaches nearly the end of its compression stroke, it forces open the valve **54** of that cylinder, and air which is in front of the piston and which is at a pressure greater than 500 pounds to the square inch, is forced into tank **20**. After the piston has reached its highest point and has gained its power stroke, the valve **33** is opened. There is always a pressure drop or pressure difference between the pressure in the air tank **20** and the cylinder after the piston has reached the top of dead center and before valve **33** is opened. This is due to the wire-drawing past valve **33** and also to the increasing volume due to the descent of the piston. Air thus flows from the tank **20** through port **34** into the cylinder carrying with it the fuel oil in the form of fine sprays intimately mixing with the air. The heat of compression at this time is such that the charge is ignited and burns for a predetermined time.

It is to be particularly understood that there is no pressure rise within the cylinder due to combustion because the rate of fuel injection is so predetermined (by proper adjustment or proportioning of the fuel pump) that a constant combustion is secured,—that is, that only enough fuel is injected as will be sufficient for constant combustion but at a pressure slightly lower throughout the working stroke than the pressure in the tank. This constant flow therefore of air from the tank and fuel from the pump, is secured by accurate control of fuel injection. There is no explosion cycle with our engine but a slow combustion cycle, and actual tests and trials have demonstrated that fuel and air can be burned in this engine at constant pressure while the movement of the piston creates an ever-increasing capacity within the cylinder, always provided, however, that the fuel and air ratio are properly proportioned.

The constant pressure combustion which is present in our engine means that combustion takes place in constantly changing volume but at a constant pressure. Constant pressure and combustion in this engine causes a nearly constant pressure combustion line up to the cut-off of fuel and air.

If fuel oil were injected into the cylinder ahead of the dead center position or ahead of the uppermost point of the piston stroke, then the fuel would ignite and the flaming gases would be pushed up into the tank **20** past valve **54**, but in our engine fuel (compressed in highly heated air and liquid oil) is never injected until the piston has reached its uppermost point and begins to move downward. It is stressed at this point that the fuel oil is injected "solidly". This is well understood in the art to mean that the fuel pump pumps the oil as a liquid directly into the cylinder and that the oil is not sprayed into the cylinder in the form of a fine mist. While the oil is atomized by the air stream, it is not atomized before it is discharged into the cylinder around the valve **33**. The air from the tank does not force the fuel into the cylinder. The liquid oil is pumped in by the fuel pump and passes into the cylinder with the air stream, constituting a continuous flow of a burning charge with torch-like effect.

Now the liquid fuel injection rate is figured with the piston speed so that the ratio of fuel and air does not form an explosive charge but a charge which burns at a constant pressure, while the volume or displacement is increased by the downward movement of the piston. Ignition, followed by explosion, never takes place but slow burning does take place.

We have heretofore referred to the necessity of mixing the liquid fuel and air "progressively". This means that the fuel and air are admitted simultaneously but continue to flow into the working cylinder at a definite and predetermined ratio throughout all of the combustion period. The feed is "progressive" because it continues to flow into the cylinder from a point just beyond dead center until the point of cut-off, for which cam **39** is set, is reached. In present or normal engines, the fuel is injected for a certain number of degrees of crank travel, but must confine its contact with molecules of air by whirls and not by progressive mixing upon entering the cylinder.

It is to be noted that this engine is supercharged by the entrance of scavenging air through the pipes **46**, and the pressure of this scavenging and supercharging air is predetermined for the particular engine and particularly for the amount of cut-off.

We have provided a structure whereby variable scavenging and supercharging can be secured which is due largely to the "flexibility" of the relatively large tank or reservoir **20**. We mean by this that the tank has a very large capacity relative to the combined volumes of all the cylinders and thus a tank for a medium-sized engine will have a capacity of about one hundred cubic feet and the maximum volume of air at five hundred pounds pressure to be delivered per compression stroke per cylinder, will only be about .14 cubic feet, and thus it is obvious that there will be no noticeable rise or fall of pressure in a tank of this size either when air is being taken out or air is being put into the tank by the cylinders in rapid succession. Thus when a cubic foot of air is compressed and delivered into the tank by one cylinder, another cylinder is withdrawing that same amount of air, and thus assuming that the engine has eight cylinders with cranks at forty-five degree angles, there will be almost a

steady stream or flow of air into and out of the tank and the pressure will be practically constant in the tank. If the volume of the tank relative to the cylinders was small, there would be considerable rise and fall of pressure.

In our engine the scavenging air pipes **46** are connected to a supercharging pump or auxiliary blower (not shown). It is well known to those experienced in this art, that to increase the scavenging or supercharging pressure with a definite clearance, results in a rise in the terminal pressure of compression. In increasing the pressure of the scavenging and supercharging air, the masses and weights of air to be delivered per cycle to the tank or reservoir will increase. By raising the supercharging pressure we can get a terminal pressure of 500 pounds to the square inch with a lower compression ratio than when we start compressing from atmospheric pressure.

The final temperature of compression, when following the nearly adiabatic curve as used in any Diesel engine, depends upon the compression ratio. Therefore in order to get a final constant temperature along with a constant terminal pressure, the temperature of the supercharging air must be initially raised. This, however, is secured automatically since the air delivered by the supercharging pump is raised in temperature due to its being compressed. It will be seen that this compression of air is secured in two stages. The first stage is the compression of the air by the auxiliary blower or pump which takes atmospheric air at atmospheric temperature and compresses it up to, for instance, twenty pounds, with a temperature of approximately 175°. Then the piston compresses this air in a second stage to 500 pounds and gives it approximately 1000° temperature. The compression ratio diminishes as the initial compression air is raised in pressure and by virtue of its higher temperature, lower constant pressure and temperature of the cycle is maintained within the tank.

There is always confusion between the three common internal combustion cycles, namely, the Diesel, the Dual, and the Otto. The Otto and the Dual cycles experience considerable pressure rise at the instant of combustion but it is reiterated that this is not experienced with a cycle such as is present in our engine. There is never a pressure rise of a greater value than the constant pressure in the tank **20**. If there is never any greater pressure within the cylinders than the pressure within the tank **20**, it is impossible to have a back flow into the tank **20**. The simultaneous admission of a predetermined proportion of fuel and air results in a very accurate and close control of the constant pressure combustion.

It will be seen that we have provided an engine therefore which is capable of starting under load, which can secure a long cut-off, and which has provided for variable scavenging and variable supercharging, that is, which has provided for introducing variably supercharged air.

We claim:—

1. In an internal combustion engine, a plurality of cylinders, pistons therein operating at different crank angles, a thermally insulated compressed air reservoir acting as a common clearance for all the cylinders of the engine and having a greater capacity than the combined volumes of all the cylinders of the engine, means for compressing the air within said reservoir to a pressure equal to that required for starting the engine under load, means for raising the temperature of the air within the reservoir to a degree equal to the compression temperature of the cycle, means for admitting air to each cylinder at the end of the power stroke of the piston thereof, whereby said air is compressed upon the next succeeding compression stroke, means permitting the passage of air so compressed into the reservoir at the end of the compression stroke of each piston, a thermally insulated passage connecting the reservoir with the head end of each cylinder, a valve controlling the flow of air from said passage into the head end of each cylinder, means for opening the said valve immediately that the pressure within the cylinder decreases below the pressure within the reservoir due to the movement of the piston on its power stroke, and means for injecting liquid fuel directly into each cylinder on each power stroke of the piston thereof regardless of the position of said valve and regardless of the engine speed.

2. In an internal combustion engine, a plurality of cylinders, pistons operating therein at different crank angles, a thermally insulated compressed air reservoir of a capacity greater than the combined volumes of all the cylinders of the engine and constituting an external clearance, means operable at any time for compressing the air within said reservoir to a pressure equal to the compression pressure of the cycle whereby to start the pistons upon their power strokes, means operable at any time for raising and maintaining the temperature of the air within the reservoir to a temperature at least equal to the compression temperature of the cycle, means for admitting air in a predetermined amount to each cylinder at the end of the power stroke of the piston thereof whereby said air will be compressed upon the next succeeding compression stroke, a valved connection between the head end of each cylinder and the reservoir permitting the air so compressed to be delivered into said reservoir at the end of the compression stroke, an inlet connection between each cylinder and the reservoir, a valve in said connection, engine operated means for opening each valve immediately that the piston of the corresponding cylinder starts to move upon its power stroke and pressure in that cylinder is thus reduced below the pressure in the reservoir whereby to permit the flow of air from the reservoir to the cylinder, said means holding the valve open for a predetermined time, and means for injecting liquid fuel directly into the cylinder regardless of the position of the compressed air admission valve and regardless of the engine speed.

3. In an internal combustion engine, a plurality of engine cylinders, a piston operating in each cylinder, a reservoir having a capacity substantially greater than the clearance volume of all said cylinders for storing air at a temperature and pressure substantially equal to the temperature and pressure of the air at the end of the compression stroke in each such cylinder, means for delivering air under substantially such pressure to said reservoir, means for maintaining the air within said reservoir at substantially such temperature, separate means for establishing communication between each such cylinder and said reservoir, each such means including a chamber in communication with said reservoir, and having a port communicating with said cylinder, a valve for controlling said port, means for operating said valve in synchronism with the operation of the piston within the associated cylinder to deliver air from said reservoir to said

cylinder during the initial portion of each power stroke of such piston, means for delivering liquid fuel to said cylinder during such portion of said power stroke, and means for shutting off communication between said cylinder and said reservoir independently of the functioning of said valve.

4. In an internal combustion engine, a plurality of cylinders, a piston operating in each such cylinder, a reservoir for air under pressure having a capacity greater than the combined clearance volume of all said cylinders, a separate passage for establishing communication between said reservoir and each such cylinder, a valve controlling said passage, means operating in synchronism with the associated piston for moving said valve to establish communication between said reservoir and such cylinder during the initial portion of each power stroke of such piston, means operating independently of said valve for delivering liquid fuel to such cylinder during the initial portion of each power stroke of such piston, means for delivering compressed air from said cylinder to said reservoir at the end of the compression stroke therein, and means for maintaining the air within said reservoir at a temperature and pressure substantially equal to the temperature and pressure of the air in each such cylinder at the end of the compression stroke thereof.

5. In an internal combustion engine, a plurality of cylinders each provided with a piston controlled exhaust port, a piston operating in each such cylinder, a reservoir for compressed air having a capacity greater than the combined clearance volume of all said cylinders, means for delivering air under pressure to said reservoir and for maintaining the air pressure therein substantially equal to the compression pressure within such cylinders, means for maintaining the temperature of such air within such reservoir at a temperature substantially equal to the compression temperature within such cylinders, a separate passage for establishing communication between each such cylinder and said reservoir, a separate valve in each such passage, means operating synchronously with the piston of the associated cylinder for actuating such valve to deliver air under pressure from said reservoir to said cylinder during the initial portion of the power stroke of such piston, means operating independently of said valve and in synchronism with the operation of such piston for delivering liquid fuel to such cylinder during the initial portion of the power stroke of such piston, means for delivering scavenging air to said cylinder while the exhaust port thereof is open, means for delivering air compressed within such cylinder to said reservoir at the end of the compression stroke, and separate manually controlled means within each such passage for shutting off communication between said reservoir and each said cylinder.

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