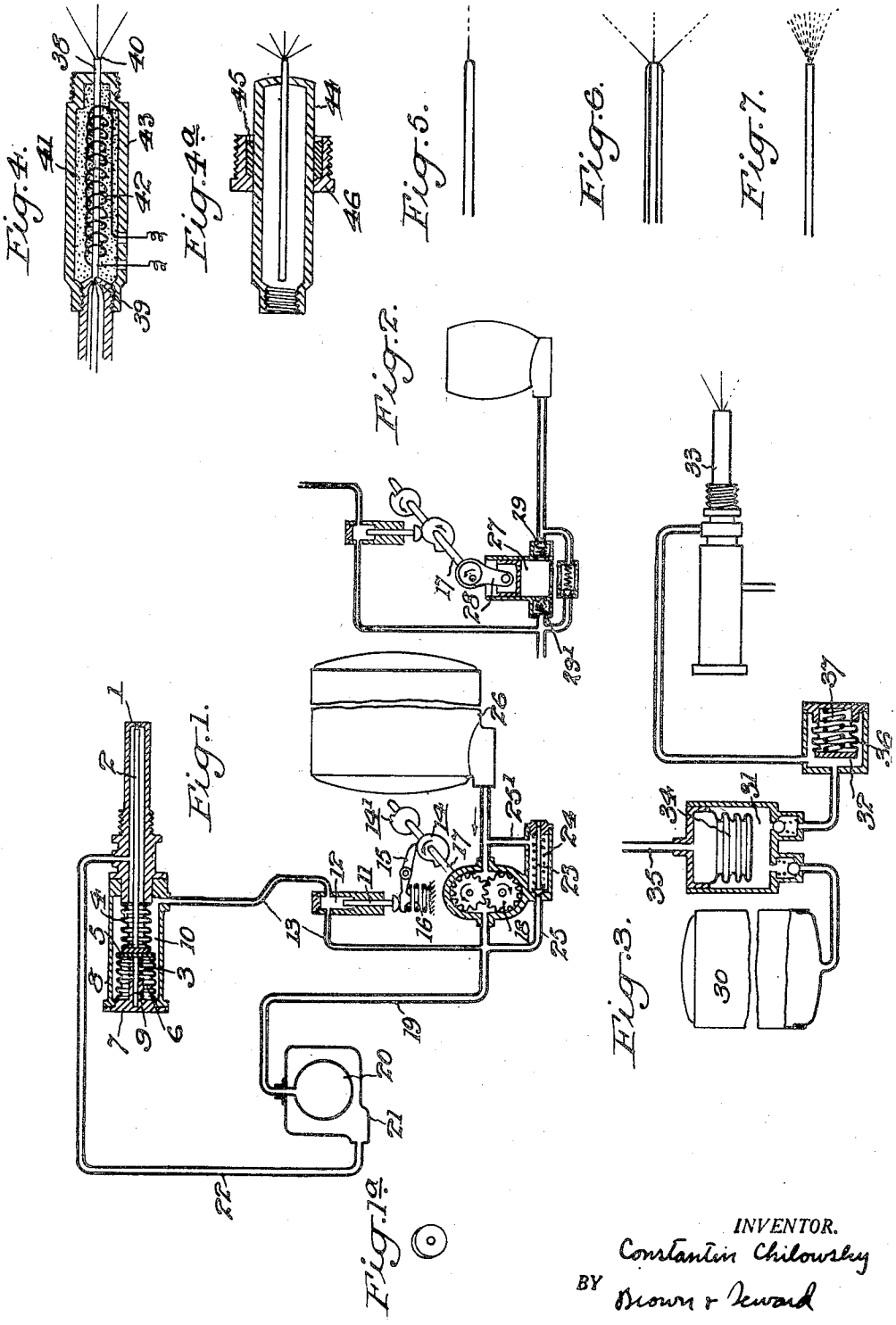
April 11, 1950 C. CHILOWSKY 2,503,472

PYROPHORIC IGNITION

Filed June 2, 1945 3 Sheets-Sheet 1

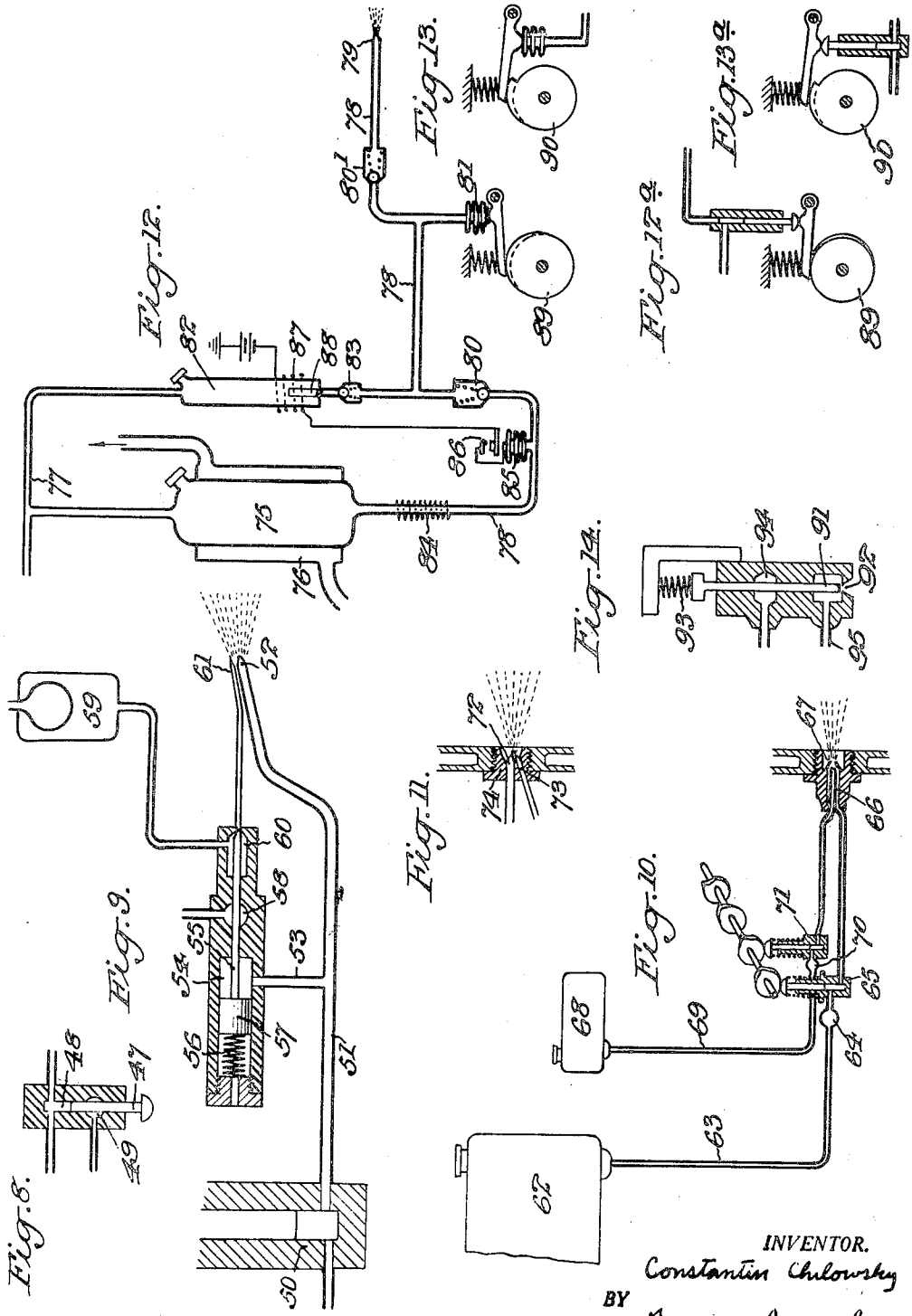


INVENTOR.
Constantin Chilowsky
BY Brown & Seward
ATTORNEYS

April 11, 1950 C. CHILOWSKY 2,503,472

PYROPHORIC IGNITION

Filed June 2, 1945 3 Sheets-Sheet 2



INVENTOR.
Constantin Chilowsky
BY
Brown & Seward
ATTORNEYS

April 11, 1950 C. CHILOWSKY 2,503,472

PYROPHORIC IGNITION

Filed June 2, 1945 3 Sheets-Sheet 3

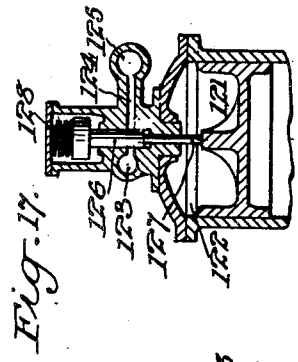


Fig. 17.

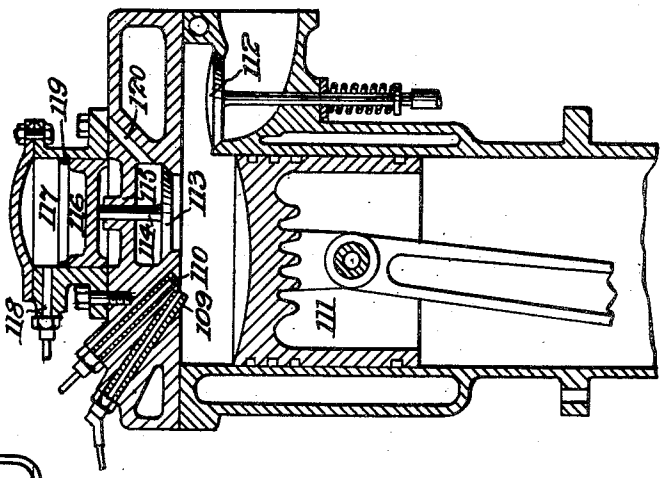


Fig. 16.

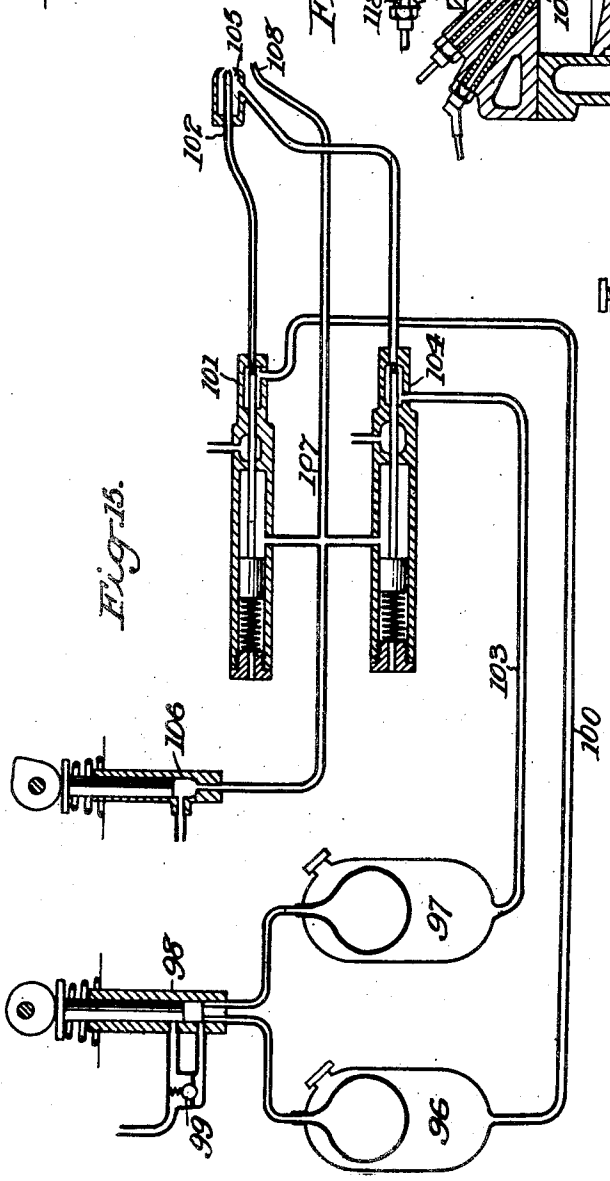


Fig. 15.

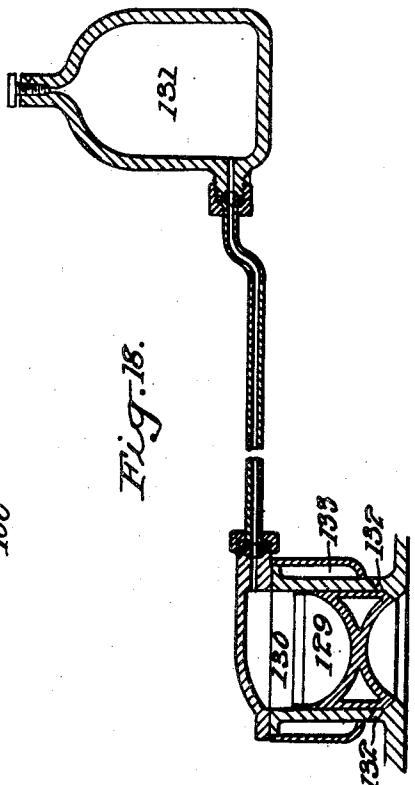


Fig. 18.

INVENTOR.
Constantin Chilowsky
BY
Brown & Seward
ATTORNEYS

Patented Apr. 11, 1950 2,503,472

UNITED STATES PATENT OFFICE

2,503,472

PYROPHORIC IGNITION

Constantin Chilowsky, New York, N. Y.

Application June 2, 1945, Serial No. 597,319

25 Claims. (Cl. 123—1)

1

This invention relates to a method and means for control of combustion in explosion and internal combustion engines.

It is an object of the invention to provide such a method and means in which small quantities of pyrophoric material are supplied to the space where combustion of the fuel is to take place, the combustion being started and controlled by the pyrophoric action of said material. This general object may be attained in a variety of specifically different ways, examples of which are set forth herein.

Ignition of explosive mixtures by electric sparks in internal combustion engines affords certain disadvantages. Thus, in airplane engines, conduits and mechanisms for such ignition must be shielded to suppress the interference with radio apparatus. Moreover, at high altitudes it is necessary to maintain an artificial air pressure within such shields so as to compensate for the reduced insulating properties of the rarified air at such altitudes.

On the other hand, in explosion engines with spark ignition, the spark occurs in only one or two places in the explosive mixture, and the effectiveness of the ignition and the following explosion presupposes sufficiently perfect carburetion by suitable carburetors, and sufficiently rapid propagation of the combustion. Any deviation from such ideal conditions, either through imperfect carburetion or through an improper combustible mixture, may result in serious troubles, which cannot be remedied in any way by the ignition alone. As a result, the range of suitable combustible mixtures for use with spark ignition is very narrow, and faulty operation under certain conditions becomes inevitable.

Internal combustion engines of Diesel type and others, in which the ignition of injected fuel is effected by simple contact with the air heated by adiabatic compression to the temperature of ignition, show a low flexibility in their operation, resulting from the influence of the operation of the engine on the conditions of ignition and internal combustion of injected fuels. In particular, operation at high velocity is impossible for these engines.

With respect to engines of an intermediate type such as semi-Diesels or engines with gasoline injection, operating under intermediate compression, such engines often possess disadvantages of both systems.

The present invention has for its object to remedy such inconveniences.

According to this invention, ignition of combustible mixtures supplied by carburetors, as well as the ignition of injected and pulverized fuels in Diesel engines (or other mentioned engines) is assured by the injection in such motors of small quantities of combustible pyrophoric substances, i. e. substances which are spontaneously ignited by contact with the air.

2

As such pyrophoric substances, it is provided to use sodium, alloys of sodium and potassium which are liquid at room temperatures, or potassium. In certain cases, yellow phosphorus (or red phosphorus under special conditions) may be used.

Metallic combustibles (sodium and/or potassium) will preferably be used in internal combustion and explosion engines. The use in these engines of phosphorus is also possible, but would necessitate the provision of internal liners of unoxidizable material, in order to avoid destructive acid reactions. The metallic pyrophoric substance (or "pyrophore") is injected in such motors in the form of a liquid metal or alloy, suitably subdivided or pulverized.

In an important modification of this process, instead of injecting a liquid metal as such, a suspension of such liquid metal in a suitable non-pyrophoric liquid is used, the liquid being preferably a combustible oil (such as paraffin or similar oil) which may be soluble in the fuel with which it is used.

In the internal combustion engines the pyrophore or liquid pyrophore is injected into the engine at a proper moment for igniting the combustible mixture. Such an injection assures efficient ignition for producing an explosion (instead of or, if necessary, supplementing an electric ignition). Such injection, however, can produce ignition of a combustible mixture not only at the point of the injection, but in a multiplicity of points within the compressed mixture, or along lines traversing different parts of the combustion chamber or in the entire mixture, according to the method of injection. Thus it is possible not only to ignite the mixture very efficiently, but also to increase very favorably the velocity and completeness of the combustion.

The injection can be effected under a very high pressure to assure a rapid penetration and passage across the mixture of incandescent particles in a state of intense combustion with the oxygen of the air. These burning pyrophoric droplets cause, along their trajectories, an instantaneous ignition of the combustible mixture.

The rapidity of such penetration of the droplets may be substantially greater than the velocity of the normal propagation of combustion in the

mixture and may assure a shorter time of combustion of explosion. If necessary (particularly in the case of large cylinders), the pyrophoric liquid can be injected simultaneously through several nozzles from different directions. This will make it possible in practice to obtain rapid explosions of mixtures, otherwise poorly explosive. A more rapid cycle of operation of an engine can be obtained in this manner, and the advance of the ignition can be reduced.

It is understood that the term "explosion" here used, does not denote an exposion with detonation, determined by the velocity of propagation of a wave of explosion, but a rapid process of combustion of a mixture, starting from a point or points of ignition. In fact, in "explosion engines," it is desired to avoid detonating explosions and to make use only of the phenomena of rapid propagation of the combustion. The pyrophoric injections permit the control and the acceleration of this combustion.

Generally, droplets of a pyrophoric metal are spontaneously ignited and burn when brought in contact with air heated by compression. However, for obtaining the best pyrophoric effect, the pyrophores can be injected in a highly preheated state, thereby assuring a very high rapidity of their ignition in contact with the air (largely independently of the temperature of this air) as well as a very rapid combustion of the pyrophoric droplets, and consequently a perfect and rapid ignition of the combustible mixture.

Such heating can be obtained initially by electric current and then it can be maintained by the heat developed in the cylinders. According to the operating conditions, the temperature of such preheating can be varied within wide limits, between the temperature of fusion or melting temperature and the evaporation temperature of the pyrophoric metal. Under certain conditions, however, the heating may even exceed the evaporation temperature so that at least a portion of the metal can be injected in the form of incandescent metallic vapors. In a case of injection of an emulsion of a suspension of a metal, the heating will not materially exceed the evaporation temperature of the oil containing the suspension (such a liquid will be called "supporting liquid").

Depending on operating conditions and the desired results, the amount of the injected pyrophore may vary within wide limits, for instance, of the order of from .1% to several percent of the total amount of the liquid fuel used. But in certain special applications, for instance, for motors of high velocity, or for unusually small cylinders of special motors of great speed, the proportion of injected pyrophoric substance can be much greater and would be only limited by the necessity to produce by combustion of ordinary fuel a sufficient amount of water or water vapor in order to avoid solid deposits of the products of sodium combustion.

Another method for obtaining a desirable pyrophoric effect and for assuring a very rapid ignition and combustion in the cylinders, of the droplets of sodium or potassium (or their alloys), consists in the action on these droplets of water or of water vapor, which will be decomposed by the contact with such metals, liberating hydrogen, according to the chemical formula:

$$2Na+2H_2O=2NaOH+H_2$$

The liberated hydrogen will be spontaneously ignited and will produce water by combining with the oxygen of the air. Such an activation of the combustion of the droplets of sodium and potassium can be obtained by various methods.

There may be provided, for instance, a combined injection into the cylinders of water or water vapor through a pulverizer or atomizer having two concentric orifices, one for water or water vapor, and the other for the metallic liquid. The water vapor can, if desired, serve to assure the pulverization of the metallic liquid. Or two separate pulverizing orifices can be used, one close to the other, mixing their products near the outlets of the orifices. It is also provided that the pulverization of water and of metallic liquid can be effected by the same pulverizing orifice, the liquids being mixed just before coming out from the orifice.

The above methods can be also applied to the pulverization of a metallic suspension in a supporting liquid. It should be noted that the liquid metal, or melted alloy, can be in all such cases preheated, as explained above.

Another method of activating the ignition and combustion of the droplets of the fine particles of sodium and potassium consists in the introduction of water or its vapor into the air of the engine, the metallic particles being ignited more rapidly in the air containing water vapor. Such humidification of the air can be effected either by the introduction of the water or its vapor by suction, or by injection and pulverization, directly into the cylinder during the suction stroke, or during compression, by known devices. Such preliminary humidification of the air can be especially convenient and effective when the pyrophoric metal is injected in the form of a suspension with a large amount of combustible oil, the oil with its suspension being finely pulverized by the same pulverizing orifice. In such a case very fine particles of metal will find everywhere the activating action of water vapor.

If a suspension or emulsion of a metal in a liquid or in oil is used, such an emulsion should be as rich as possible in metal. It can contain, for instance, as an order of magnitude, from 10% to 30% of metal suspended in liquid. The proportion of the oil, however, may be substantially greater in order to facilitate the injection. It is desirable to select for the liquid, used as a liquid support for a metallic suspension, a liquid of such a density which will be equal or approaching the density of the metal in suspension, and of sufficient viscosity to assure a stable state of suspension. It is possible, for instance, to use for this purpose paraffin or Vaseline oils, and even certain greases, or vegetable, animal or mineral oils and fuels.

Conditions of the injection and pulverization, and the fineness of the metallic particles or droplets depend on the conditions of operation and on the desired objects, as well as on the preheating which may be employed in the process.

For ignition in explosion engines it is preferred to employ a not very fine pulverization so as to assure an effective penetration of the particles into the mixture and a great force of the instantaneous ignition. In other cases the pulverization may be finer. Depending on the type of installation, the jets from the injectors may be straight and concentrated, or diffused and large. In general, for engines working by explosion an almost instantaneous or very rapid injection will be used.

In case of an application to internal combustion engines of Diesel type, or other engines em-

ploying injection under pressure of heavy or light fuels, the length of time of the injection will be preferably proportioned to the length of time of the injection of the large mass of ordinary non-pyrophoric fuel.

It is possible to make both injections simultaneously, by separate injectors, placed very close to each other, in such a manner that the cones of the two injections may be fused, the two cones penetrating each other from the opposite directions or at a certain angle. Separate injections can preferably be used when it is desired to preserve for the pyrophoric droplets relatively larger sizes than for the droplets of the ordinary fuel, which generally should be very fine.

It is also provided, however, that the injection of both liquids can take place through the same pulverizing orifice. In such a case, preferably, the pyrophoric substances can be introduced into the combustible liquid prior to, or at the moment of its pulverization. The pyrophores also can be injected into the conduit for combustible liquids near the pulverizing nozzle. Such an injection can take place simultaneously with the pulverization of the ordinary liquid, and in phase therewith, so that the two liquids can be injected and pulverized in the motor by the same pulverizing or atomizing nozzle.

Injection of such small quantities of the pyrophoric liquid can be effected by a system of pumps similar to the pumps used for the injection of the main liquid fuel but with a much smaller output. (It may be noted that the dosage of the pyrophoric combustible does not require the same precision as the dosage of the ordinary fuel.)

Another method of introducing the pyrophores into the cylinder of a motor consists in the preliminary incorporation of such pyrophores in the principal fuel in the form of a suspension, sufficiently stable and very thin or even colloidal. It is thus possible to obtain a fuel, enriched and activated by a very small percentage of the pyrophoric suspension; but the storage and preservation of such pyrophoric fuel in large quantities may present serious difficulties.

According to the invention, however, and as was mentioned above, the suspension of such pyrophoric substances can be made very dense, in a very viscous substance, the supporting substance being soluble in the fuels used in the motor. The liquid with such a dense suspension is mixed with the fuel prior to its used. After the supporting liquid with its suspension is dissolved in the engine fuel, the latter will be enriched and activated by the pyrophoric suspension. It is also provided that the supporting material of the suspension can be, at the room temperature, in a solid or pasty state, being then dissolved in the engine fuel.

The introduction, as specified, of small quantities of the pyrophoric substances into the cylinders, of the internal combustion engines offers important advantages.

In Diesel engines, such pyrophoric injection, which may take place during the entire phase of the fuel injection (or during a portion of such injection), assures a permanent ignition during the entire phase of the injection. Such an ignition, if desired, may embrace the entire space of the combustion chamber and will extend to all its corners.

Such continuous and complete ignition can assure and maintain the combustion of the main mixture, independent, to a large extent, of the temperature reached by the air at the end of the compression. If such temperature is dangerously lowered during a low period of the engine operation, at a slow speed, or with reduced admission of the air, the pyrophoric injection will compensate such deficiency and will assure for such difficult periods the combustion of a desirable quality and rapidity.

Moreover, the introduction of the pyrophores enables Diesel engines to operate at much higher speed, by assuring proper ignition and by "catalyzing" the combustion of the main fuel, so as to provide a much more rapid combustion rate as compared with the ordinary methods. This is particularly important in the case of Diesel engines used in aviation, making it possible to build faster engines of a lower weight per horse power. The introduction of pyrophores will make Diesel engines comparable in their flexibility to gasoline engines.

The use of pyrophores makes the internal combustion and the operation of the motor largely independent of the degree of compression and, to a certain extent, of the kind of fuel employed. It also favorably affects all the intermediate types of engines, semi-Diesels, aviation engines with fuel injection, etc.

In summation, for all internal combustion engines, the introduction of the pyrophoric injection will produce:

(*a*) Greater flexibility of the engines with respect to slow and rapid rotation.

(*b*) Greater range of the usable fuels, permitting, in particular, the use of heavier fuels or fuels more difficult to ignite.

(*c*) Engines of greater speed and, consequently, of a lighter weight per horsepower.

(*d*) Internal combustion engines of improved types, particularly of lower compression than Diesel engines.

The above refers to the injection and pulverization of the pyrophoric substances, as well as to the introduction of fine suspensions of pyrophoric substances, in one form or another, with the main fuel.

In "explosion" engines, with preliminary carburetion, the pyrophoric injection will assure for a poor mixture (with excess of air) a combustion (or so-called "explosion") as rapid as desired, permitting therefore to obtain more economical operation with greater output. It will also make it possible to use a greater range of speeds, by closing the dangerous "gaps" in the carburetion, caused by poor mixtures, which are otherwise often inevitable.

For a carbureted mixture which possesses a slow and insufficient velocity of flame propagation, pyrophoric injection will make possible any desired velocities of combustion. The pyrophoric combustion imposes its own velocity of combustion in place of the "natural" velocity of the mixture. This will permit the use, by known methods, of combustible mixture of slow or difficult combustion, excluding detonations, making such mixtures burn very rapidly by the application of the pyrophoric injection.

The introduction of small quantities of sodium or potassium in Diesel engines or in explosion engines will not cause any damage to such engines. The alkalis (NaOH or KOH), formed in the process, will not attack the metals. On the other hand, such alkalis, in minimal quantities, remain at high temperatures in the form of fine suspended droplets which are removed through the valves; and at lower temperatures such particles, in the presence of large quantities of water

vapors produced by the combustion, will be dissolved, forming a weak alkali solution.

As was mentioned, an alloy of sodium with potassium which is liquid at room temperature will preferably be used (the eutectic proportions being 24% sodium to 76% potassium for a melting point of —12.6°, which may be lower than required). But each of these metals can also be used separately, particularly sodium, which is cheaper. In this case it is provided that the conduits, injectors, and even pumping devices for sodium shall preferably be heated electrically to a temperature assuring complete melting of the metal. The receptacle of a fuel with sodium can be heated by the exhaust gases, in which case the operation can be started with the liquid alloy of sodium and potassium.

It is also possible to use white phosphorus as a pyrophoric substance, under different forms specified above for sodium and potassium. The phosphoric acid formed in the process can be neutralized by small quantities of alkalis (or by the simultaneous use of alkali metals and phosphorus as pyrophoric substances). The use in the engines of stainless steel, or liners of stainless steel, or of alloys resistant to the phosphoric acid, will make it possible to use white phosphorus without any inconvenience in place of sodium and potassium.

The use of pyrophoric substances in the form of very fine or colloidal suspensions in supporting liquids, or in the principal liquid fuel, while requiring a higher proportion, will afford advantages in handling and pumping. It is particularly provided that in case of the use of a very fine or colloidal suspension, such suspensions can remain in the form of solid particles. The liquid supporting such particles can be stored, pumped and injected without any special heating of the pumping devices or conduits. This will make it possible to use sodium alone, white phosphorus, and even, in certain cases, red phosphorus, without preheating, in the form of a very fine or colloidal suspension.

One of the main causes of greater weight of Diesel engines as compared to the explosion engines, resides in the fact that, once in a while, violent explosions take place in the engines instead of progressive combustion. This makes it necessary to build Diesel engines of much greater strength and almost three times as heavy as would otherwise be possible. Such explosions are of two different natures. One is an unseasonable explosion of the injected oil, when the oil, injected before the peak of the compression, instead of burning progressively, forms an explosive mixture which, under the maximal compression, explodes with violent excess of pressure. This cause of explosions is automatically suppressed by the injection of a pyrophoric substance, simultaneously with the injection of the main fuel.

Every explosion presupposes a preliminary formation, to some extent, of an explosive mixture. However, in the presence of a continuous ignition accompanying the injection from its beginning (for instance, in the entire volume of the injected charge, or in the entire explosion chamber) the formation of an explosive mixture will be impossible, since any contact of the injected oil and pyrophore with the air is immediately accompanied by ignition and combustion.

The second cause of unseasonable detonation is the formation in the cylinder, very rarely and accidentally, of an accumulation of vapors of the lubricating oil and of remnants of unburned gases from the previous cycle, forming an explosive mixture with the air which detonates at the moment of the maximum compression by the piston. A judicious use of the pyrophoric ignition described herein will make it possible to suppress also this second form of detonation, making it possible to build much lighter Diesel engines.

For this purpose the engine cylinders are provided with pyrophoric ignition of a "preventive" character, according to which the liquid pyrophore is injected into the cylinder substantially before the piston reaches the position of the highest compression ratio. Thus, for instance, the injection can take place when the piston has effected compression to a ratio of 4 or 5 (instead of, for instance, a maximum of 14 to 17), and such preventive injection can, if desired, continue until the end of the piston stroke, i. e. up to the moment of injection of a fuel into the cylinder. Thus in the rare instances when an exceptional accumulation of residues and/or of oil vapors forms an explosive mixture with the air, such mixture will be ignited by the pyrophoric injection at a moment when such an explosion will not yet cause any harm to the engine.

By way of example, if by the preventive ignition such a premature explosion takes place at a moment when the compression ratio has reached the value of 5, the pressure, resulting from this explosion, even in case of detonation, will not substantially exceed (and will even be lower than) the maximum working pressure obtained by normal combustion of fuel at the maximum compression ratio of 17 which maximum pressure is generally of the order of 55 to 70 kg./cm.^{2}. Without such premature ignition, however, the same accidentally formed explosive mixture will be inevitably ignited, when the compression ratio reaches 14 to 17, and the pressure developed at that moment by an explosive detonation can reach the order of 300 kg./cm.^{2}.

In the case of such a "preventive" explosion, the engine piston, continuing its movement until the compression ratio reaches it maximum, can compress the products of such a preventive explosion to a high pressure, approaching the above mentioned value of 300 kg./cm.^{2}, and therefore very dangerous. But the essential difference lies in the fact that the increase of pressure after the "preventive" explosion will be progressive, and will increase gradually with the displacement of the piston. Therefore, the length of time for establishing such high pressure will be incomparably longer than when such explosion is produced almost instantaneously at the peak of compression. Advantage is taken of such time of establishment of the pressure by combination of the preventive explosion and of a safety valve, mounted in the cylinders of a Diesel engine, these valves being regulated so as to open automatically when the pressure in the cylinders, caused by the preventive explosion, and by the subsequent advance of the piston, reaches a critical value, compatible with the mechanical resistance of the engine.

A Diesel engine can be built in such a case without any excess of mechanical resistance and weight, which are needed in ordinary Diesel engines for taking care of the high pressures resulting from explosive detonations.

Heretofore it has been impossible to eliminate the described danger by means of safety valves on the cylinders, and it was necessary to increase the mechanical resistance and the weight of the engine, because the explosion of the strongly com-

pressed gaseous mixture is almost instantaneous, and the enormous pressure of such an explosion is developed so rapidly that even a very light safety valve does not have enough time to open sufficiently for releasing the pressure (the movement of a valve under action of a given pressure being proportional to the square of the available time).

In the case of a preventive explosion, the products of the explosion, after their pressure under action of subsequent compression by the piston has reached a determined value, have all the time necessary for opening the valves and for allowing gradual escape of the gases under pressure. Thus, for instance, in a high speed Diesel engine, of a two cycle type, 1200 R. P. M., the establishment of the maximal pressure after the preventive explosion will take a time of the order of $1/100$ to $1/150$ of a second, and without such a preventive explosion the same pressure will be established in a time of the order of 10^{-4} sec.

In a practical application of the pyrophoric ignition, which is a "durable" or continuing ignition, the latter can be started at a moment when the piston has completed, for instance, $4/5$ of its compression stroke and can be stopped, for instance, when the piston completes $9/10$ of its stroke.

It is particularly provided, however, that two actions and two injections of the pyrophoric ignition may be combined; one starting at the moment of injection of a fuel into the engine and continuing during such an injection (or during a portion thereof), resulting in flexible operation of the engine and other advantages; and another, starting, for instance, at approximately $4/5$ of the piston stroke and prolonged, if desired, almost to the end of the stroke.

In such a manner, in an internal combustion engine in which pyrophoric ignition is installed, it will be sufficient to extend the time of ignition for a relatively short period prior to the injection of the fuel, in order to obtain complete safety against accidental premature explosions with the resulting possibility to reduce approximately three times the weight of the engine (assuming also the provision of a safety valve, as explained above).

Pyrophoric ignition may thus provide a solution for the technical problems which have heretofore prevented the use of Diesel engines for aviation, such as: flexibility of operation, high speed, light weight, and absence of danger of explosions.

Although the preventive pyrophoric ignition is generally compatible with the use of ordinary relatively heavy safety valves, with steel springs, it will also be possible to use very light valves, for increasing the safety of operation, and for allowing the valve to function effectively even in the event of an explosion, occurring when the piston is at a short distance from the end of its compression stroke. Such a valve is characterized by the fact that, instead of a spring acting on the valve, there is equivalent action of a fluid under high pressure, and especially of a highly compressed gas or air, or, in certain cases, of water or its vapor, or of oil under pressure. Special steps are taken to assure perfect tightness of the piston forming the valve, or transmitting the gas pressure to the valve. For assuring such a pressure, there is provided a receptacle for a gas, for instance, air under high pressure, serving as a collector, the valves of the different cylinders being connected by suitable pipes with this collector whose pressure is maintained constant, and continuously controllable. The pressure in the collector is maintained at a desired level (preferably automatically) by a suitable mechanism, such as a bottle with compressed air with an automatic controlling valve.

Practical embodiments of the invention are shown in the accompanying drawings, in which

Fig. 1 represents, diagrammatically and partly in section, an assembly of parts for supplying and injecting a liquid pyrophore, the injection being remote-controlled by means of oil under pressure;

Fig. 1*a* represents, in side elevation, a modified form of cam;

Fig. 2 represents, diagrammatically and partly in section, a modified form of pump and valves, to be substituted for corresponding elements in the assembly of Fig. 1;

Fig. 3 represents, diagrammatically and partly in section, a further modified arrangement of parts for supplying and injecting the liquid pyrophore;

Fig. 4 represents, in longitudinal section, an electrically heated injection nozzle;

Fig. 4*a* represents, in longitudinal section, a modified form and mounting of an injection nozzle similar to that of Fig. 4;

Figs. 5, 6 and 7 represent diagrammatically three types of injection jets or sprays;

Fig. 8 represents, in section, a modified form of pump using a piston instead of the bellows shown in Figs. 1 and 3;

Fig. 9 represents, diagrammatically and partly in section, an assembly of parts for supplying and injecting simultaneously a liquid pyrophore and a liquid fuel;

Fig. 10 represents a modified assembly of parts similar to the arrangement shown in Fig. 9;

Fig. 11 represents a detail section of an injection nozzle mounting, suitable for use with the assembly of Fig. 9 or instead of the arrangement of Fig. 10;

Fig. 12 represents diagrammatically an assembly of parts for supplying and injecting a liquid pyrophore, with provision of means for preheating said pyrophore;

Fig. 13 represents a modified form of pump to be substituted for the pump of Fig. 12 under certain circumstances;

Figs. 12*a* and 13*a* represent further modified forms of pumps corresponding to those shown in Figs. 12 and 13 but using pistons instead of bellows;

Fig. 14 represents a detail section of a type of valve suitable for use in case of injection under constant pressure;

Fig. 15 represents, diagrammatically and partly in section, an assembly of parts for supplying and injecting a liquid pyrophore combined with water or water vapor;

Fig. 16 represents, in vertical section, a Diesel engine cylinder with injectors, valve, safety valve and related parts;

Fig. 17 represents a detail vertical section of a fuel-bypass valve adapted for association with a safety valve, and

Fig. 18 represents in section an assembly of parts constituting a fluid-pressure-controlled safety valve.

Referring to Fig. 1, an injector nozzle 1 is shown as provided with a needle valve 2 urged toward nozzle-closing position by a spring 3. A metal bellows 4 assures hermetic sealing of the needle while permitting movement of the needle and

of the plate 5 which is mounted on the needle. A second somewhat larger metal bellows 6 extends from the plate 5 to the head 7 of the casing 8, forming a chamber which contains the spring 3 and the drilled lug 9 in which the end of the needle is slidably supported, and hermetically sealing the chamber 10 against the escape of oil under pressure. An increase of pressure in the chamber 10 will open the needle valve, due to the difference in size and displacement of the bellows 4 and 6, and a decrease of pressure will permit the valve to be closed by the spring 3. Such variations of pressure may result from the operation of a piston 11, reciprocated in and out of a chamber 12 in the oil line 13 by a cam 14, rocker arm 15 and spring 16.

The cam shaft 17 is understood to be suitably geared to the crank shaft of the engine (not shown) and operates, in addition to the cams 14, 14', etc. (for each cylinder), the gear pump 18 which forces oil under sufficiently high pressure through the pipe 19 into an expansible bag 20 within the tank 21 containing pyrophoric liquid. Such liquid is accordingly supplied under similar pressure, through the pipe 22, to the injector nozzle 1. The pressure on the delivery side of the pump 18 is regulated by the return valve 23, held seated by a spring 24, which permits oil to return through the pipes 25, 25' to the oil tank 26 when the pump has built up the desired pressure in the lines 13 and 19.

The cam 14, having a sharp drop, operates the piston 11 to cause a momentary excess of pressure in the line 13, thus opening the needle valve to permit instantaneous injection of the pyrophoric liquid from the nozzle 1 into the combustion chamber of the cylinder with which it is understood to be associated. Such instantaneous injection is suitable for explosion type engines (gasoline) and in this case the oil tank 26 may be of a size comparable to that of the tank 21 containing the pyrophore (as shown in Fig. 2). In connection with Diesel type engines the tank 26 may be large enough to carry the main fuel supply, and the cams 14, 14' may have a profile approximately as indicated in Fig. 1a so that the opening and closing of the needle valve will be less rapid.

Fig. 2 shows a modified detail in that the gear pump 18 of Fig. 1 has been replaced by a piston pump 27 operated by the crank arm 28 eccentrically driven by the shaft 17, the chamber of the pump having automatic closing inlet and outlet valves 29, 29' of any customary type.

In Fig. 3 is shown an arrangement in which the tank 30 containing the liquid pyrophore is not under pressure, a pump 31 serving to supply the liquid to a pressure accumulator 32 from which it is fed to the injector 33. The pump 31 may conveniently comprise a bellows piston 34 actuated mechanically or by means of oil supplied under fluctuating pressure through the pipe 35. The accumulator 32 contains a bellows 36 which is compressible against the action of a spring 37, as the equivalent of a chamber containing a compressible gas.

Fig. 4 shows means for electrically heating the liquid pyrophore to a high temperature after it passes through the needle valve and before it is injected into the combustion chamber. The heating means includes a tube 38 extending from the needle valve opening 39 to the point of injection 40 where the tube terminates in one or more orifices adapted to spray or pulverize the injected liquid. The tube is surrounded by a body of thermal insulating material 41 and by a heating coil 42, all contained within a casing 43 suitably designed for association with a wall of a combustion chamber. A modified form of heater is shown in Fig. 4a where a casing 44 is surrounded by a refractory sleeve 45 within a threaded bushing 46, the tube 38 extending through the casing as before. In this form a substantial part of the casing extends within the combustion chamber where it is heated during operation by contact with the hot gases and in turn heats the tube 38 by conduction and radiation.

The form in which the pyrophoric liquid emerges in the combustion chamber may vary as indicated in Figs. 5, 6 and 7 showing tubes representing the nozzle 1 of Fig. 1, the nozzle 33 of Fig. 3 or the tube 38 of Figs. 4 and 4a. In Fig. 5 the liquid emerges as a linear jet which breaks up into globules or droplets. In Fig. 6 the liquid emerges from a plurality of orifices in diverging directions. In Fig. 7 the liquid is sprayed out of a single orifice.

While metal bellows devices are shown in numerous instances herein, it will be understood that pistons and the like may be substituted in some cases, particularly where a dense suspension of the pyrophore in a viscous fuel oil is used. In other cases certain moving parts may be sealed by means of an oil-filled groove, as shown in Fig. 8 where the piston 47 works in and out of a cylinder 48 (constituting, for instance, a pump for pyrophoric liquid) the piston being surrounded by an annular chamber 49 filled with oil under pressure.

Fig. 9 represents, largely diagrammatically, an arrangement for the automatic simultaneous injection of fuel oil and pyrophoric liquid. A fuel oil pump 50 (having suitable valves, not shown) forces the fuel oil through the pipe 51 at timed intervals, to the injector nozzle 52. A pipe 53 communicates the oil pressure to the chamber 54 of the housing for a needle valve 55 which is held closed by the spring 56 except when the pressure in the chamber 54 acts on the piston 57 to overcome the spring pressure. The needle valve is sealed at 58 by means of an oil seal such as that shown in Fig. 8. The pyrophoric liquid is fed under pressure from a tank 59 to the valve chamber 60, from which it passes to the injection nozzle 61 (adjacent the oil nozzle 52) when the needle valve is opened. The proportions in which the fuel and pyrophore are injected may be determined by the size of the nozzles, by the pressure in the tank 59, by the pressure of the spring 56, or in other suitable manners.

In the arrangement shown in Fig. 10 the two liquids (a small quantity of pyrophoric liquid and relatively large quantity of combustible liquid, such as fuel oil) are mixed immediately before being sprayed together into the combustion chamber. In this figure the fuel oil flows from the tank 62, through the pipe 63 and collector 64 to a pump 65, by which it is pumped to the mixing chamber 66 having an injection nozzle 67. The pyrophoric liquid (which may be oil with a suspension of pyrophoric material) flows from the tank 68, through the pipe 69 and collector 70 to the pump 71, by which it is pumped to a point in the mixing chamber 66 which may be adjacent the nozzle 67 or may be spaced therefrom to permit more thorough mixing with the fuel. The pumps 65 and 71 may be cam-operated as shown, and the relative quantities of the liquids supplied to the chamber 66 will correspond, in general, to the relative piston displacement of

the pumps. Check valves and the like may be provided if necessary.

A modified form of injection nozzle is shown in Fig. 11, the fuel and pyrophoric liquid being injected through separate but adjacent nozzles **72** and **73**, respectively, mounted in the recessed bushing **74**.

As noted above, the sodium-potassium alloy which remains liquid down to −12° C. will generally and preferably be used as the pyrophoric liquid in order to avoid the necessity for preheating. If desired, however, either metal (preferably sodium) may be used alone with the provision of a suitable heating arrangement, as shown in Fig. 12.

In Fig. 12 the sodium tank **75** is arranged to be heated to 100° C. by the passage of exhaust gases through the jacket **76**, the melted sodium being kept under pressure by a gas or liquid in the pressure pipe **77** and being conducted through the feed pipe **78** to the injection nozzle **79**. Check valves **80** and **80'** are provided in the line of the pipe **78** and an injection pump **81** (shown as a cam-operated bellows pump) is connected to the line between the check valves. A secondary tank **82** contains sodium-potassium alloy (liquid at normal temperatures), for starting the motor and operating it until the sodium in tank **75** is melted, the tank **82** being connected to the pressure pipe **77** and, through the valve **83**, to the feed pipe **78**. The several elements of the feed line can be electrically heated without difficulty since they are of small mass, a section of a heating coil for this purpose being shown at **84**; similar heaters may be provided along the line as required.

A small bellows **85** is connected to the pipe **78** and is arranged to operate the electrical contacts **86** in the circuit of a solenoid **87** which has as its core the needle valve **88** in the tank **82**. Pressure in the bellows **85** opens the contacts **86** and permits the valve **88** to close, while reduction of pressure in the bellows will close the contacts and open the valve. When the sodium in the tank **75** is not melted the pressure in the bellows **85** will be low or absent so that the valve **88** will open to permit the alloy in the tank **82** to be pumped to the injection nozzle. When the motor has run long enough for its exhaust gases to melt the sodium, the valve **88** will be closed and sodium alone will be used for continued operation of the motor.

The cam **89** (Fig. 12) is suitable for use in motors where the injection is somewhat prolonged: in explosion type engines the cam **90**, shown in Fig. 13, may be used to give a rapid and sharp injection. Figs. 12*a* and 13*a* show piston pumps which may be substituted, respectively, for the bellows pumps shown in Figs. 12 and 13.

It will be understood that the injection of pyrophoric liquid according to Fig. 12 is coordinated with the injection of fuel in any suitable manner, including the use of the various injection nozzle arrangements described herein.

The modified form of injection valve shown in Fig. 14 may be used for injection under constant pressure, the "needle" **91** having a flat end adapted to close and open the nozzle orifice **92**, and being urged toward closed position by the spring **93**. The valve stem is oil sealed at **94** and the pyrophoric liquid is supplied through the pipe **95** from an injection pump.

Fig. 15 shows, largely diagrammatically, an arrangement in which water or water vapor is injected with the pyrophoric liquid and fuel, parts of the structure being similar to the parts shown in Fig. 9. In Fig. 15 the tank **96** contains pyrophoric liquid and the tank **97** contains water, both being maintained under high pressure by means of expansible bags fed by a fluid pressure pump **98** having a pressure-controlling spring-closed ball valve **99**. The pyrophoric liquid from tank **96** passes through the pipe **100** to the needle valve **101** which controls its injection through the nozzle **102**. The water (or its vapor) from tank **97** passes through pipe **103** to valve **104** controlling its injection through nozzle **105** surrounding concentrically the nozzle **102**. The fuel is fed by a pump **106** to the fuel line **107** terminating in the injection nozzle **108**, the line **107** being connected also to the valves **101** and **104** so that the fuel injection impulse will automatically and simultaneously open said valves, as explained in connection with Fig. 9, and permit the injection of pyrophoric liquid and water under the high pressure developed in their respective tanks.

The use of the pyrophoric materials described herein makes it possible to control very accurately the ignition and combustion of fuel in engines of the Diesel type, with a minimum of danger from destructive detonations. Such detonations as may still unavoidably occur can be provided for by the use of suitable safety valves without the need for increasing the weight and strength of other parts of the engine, examples of such safety valves being given in Figs. 16, 17 and 18.

Fig. 16 shows, somewhat diagrammatically, a cylinder of a Diesel type engine having mounted in its head an injection nozzle **109** for fuel and an injection nozzle **110** for pyrophoric liquid, corresponding, for instance, to the nozzles **52** and **61** in Fig. 9. The cylinder has a piston **111** and exhaust or air inlet valve **112** of customary form. In the head of the cylinder is a valve **113**, seated to open outwardly, having a stem **114** slidably mounted in the guide **115** and connected to a light piston **116** in the small cylinder **117**, to which gas under pressure is supplied through the duct **118**. The tight sealing of the piston **116** in its cylinder may be effected by means of a thin brass lip **119**, as the equivalent of the packing leather in a pump. The valve **113** opens into a chamber which communicates with the outside through one or more escape vents **120**.

Fig. 17 represents a modification of the piston **116** and cylinder **117** shown in Fig. 16, in order that the injection of fuel may be prevented when there has been an explosion of sufficient strength to actuate the safety valve. An explosion such as the "preventive explosion" provided for herein would consume a large part of the oxygen in the combustion chamber so that fuel injected immediately thereafter could not burn and would remain to cause trouble on the next cycle. In Fig. 17 the piston **121** corresponds to the piston **116** of Fig. 16 and the cylinder **122** corresponds to the cylinder **117**. The fuel injection line for the engine cylinder is arranged to include a section **123** which communicates, through a by-pass **124**, with a pipe **125** leading back to the fuel tank. The by-pass is normally closed by a slide valve **126** having a stem **127** bearing on the piston **121**, so that when the piston is raised (as by the valve stem **114**, Fig. 16) the by-pass is opened and the charge of fuel is diverted to the pipe **125** instead of being injected in the combustion chamber.

The resistance to opening of the safety valve depends primarily on the gas pressure in the cylinder **122** (as in the cylinder **117**). The inertia of the piston **121** is low and preferably less than the inertia of the slide valve **126**, while the spring

128 may exert relatively light pressure on the valve compared to the gas pressure in cylinder 122; the relationship being such that the safety valve will open and close in response to the creation and release of excess pressure in the combustion chamber, the slide valve opening at the same time and remaining open somewhat longer due to the differences in inertia and in the respective closing forces.

Fig. 18 shows a modified form of safety valve in which the free piston 129 fits within a cylinder 130 to which fluid under pressure is supplied from the container 131. The piston is exposed to the pressure in the combustion chamber and when this pressure rises abnormally the piston is forced up sufficiently to open the ports or vents 132 for the escape of gases of combustion. The container 131 may supply fluid under pressure to the safety valves of a plurality of cylinders, and suitable pipes may be provided to permit circulation of the fluid in a closed system for cooling the safety valves, or water jackets may be provided as indicated at 133. The fluid may be air or other gas, or may be water which will be vaporized in the cylinder 130.

Complete security against accidental destructive explosions is afforded by the combination of "preventive" pyrophoric ignition (extended in time and space in the combustion chamber) with a safety valve, for instance, of the type shown herein. Desirable, if not perfect, results may, however, be obtained by the use of pyrophoric ignition alone, or by the use of ordinary igniting means with the safety valves described. In a well designed Diesel engine premature explosions are rare; furthermore, pyrophoric ignition (because of its simplicity) will very rarely misfire. The combination of these probabilities thus leads to the conclusion that conditions conducive to premature explosion will coincide with misfiring of the pyrophoric ignition only at infinitely rare intervals, so that complete safety may be assumed.

While the principle of pyrophoric ignition has been described primarily with reference to its use in liquid fuel combustion engines, it is evidently equally adaptable to the ignition and control of combustion of fuels for other purposes including jet propulsion devices, or to the ignition and combustion control of gas fuels.

According to the conditions of use of the pyrophoric ignition, the pyrophoric materials may merely initiate the combustion without substantial subsequent control thereof, or may both initiate and control the combustion; or may merely control combustion which has been otherwise initiated (as by an electric spark); the action in each case being comprehended within the scope of the expression "effecting combustion."

It will be understood that various changes may be made in the form, construction and arrangement of the several parts, without departing from the spirit and scope of my invention, and hence I do not intend to be limited to the details herein shown and described, except as they may be included in the claims.

What I claim is:

1. The method of effecting and controlling combustion of a combustible fluid which includes, providing a quantity of combustible fluid in condition for combustion, and injecting through said fluid in a predetermined direction and with controlled and predetermined velocity a quantity of pyrophoric material in finely divided form and in condition for spontaneous self-ignition.

2. The method according to claim 1 in which the pyrophoric material is preheated to a selected definite temperature.

3. The method of effecting combustion of a combustible fluid which includes, providing a quantity of combustible fluid in condition for combustion, and applying thereto a quantity of pyrophoric material in condition for spontaneous self-ignition, said material being in finely divided form and selected from the group consisting of sodium, potassium, an alloy of sodium and potassium, and yellow phosphorus.

4. The method of effecting combustion of a combustible fluid which includes, providing a quantity of combustible fluid mixed with a combustion-supporting medium, and applying thereto a quantity of pyrophoric material in condition for spontaneous ignition upon contact with said medium, said material being in finely divided form and selected from the group consisting of sodium, potassium, an alloy of sodium and potassium, and yellow phosphorus.

5. The method of effecting combustion of a combustible fluid which includes, providing a quantity of combustible fluid in finely divided form in a combustion-supporting medium, and applying thereto a quantity of pyrophoric material in condition for spontaneous ignition upon contact with said medium, said material being in finely divided form and selected from the group consisting of sodium, potassium, an alloy of sodium and potassium, and yellow phosphorus.

6. The method of effecting combustion of a combustible fluid which includes, injecting a quantity of combustible fluid in a finely divided form into a combustion chamber containing a combustion-supporting medium, and injecting into said chamber a quantity of pyrophoric material adapted for spontaneous ignition upon contact with said medium, said material being in finely divided form and selected from the group consisting of sodium, potassium, an alloy of sodium and potassium, and yellow phosphorus.

7. The method of effecting combustion of a combustible fluid which includes, providing a quantity of combustible fluid in condition for combustion, and applying thereto a quantity of pyrophoric material in condition for spontaneous self-ignition together with a quantity of water or water vapor, whereby the pyrophoric properties of said material are increased.

8. The method of effecting combustion of a combustible fluid which includes, injecting a quantity of combustible fluid in a finely divided form into a combustion chamber containing a combustion-supporting medium, injecting into said chamber a quantity of pyrophoric material adapted for spontaneous ignition upon contact with said medium, and injecting simultaneously and intimately with said material a quantity of water or water vapor, whereby the pyrophoric properties of said material are increased.

9. The method of effecting combustion of a combustible fluid which includes, injecting a quantity of combustible fluid in a finely divided form into a combustion chamber containing a combustion-supporting medium and water vapor, and injecting into said chamber a quantity of pyrophoric material adapted for spontaneous ignition upon contact with said medium and vapor.

10. The method acording to claim 7 in which the pyrophoric material is selected from the group consisting of sodium, potassium and an alloy of sodium and potassium.

11. The method according to claim 8 in which the pyrophoric material is selected from the group

consisting of sodium, potassium and an alloy of sodium and potassium.

12. The method according to claim 9 in which the pyrophoric material is selected from the group consisting of sodium, potassium and an alloy of sodium and potassium.

13. The method of effecting combustion of a combustible fluid which includes, injecting a quantity of combustible fluid in a finely divided form into a combustion chamber containing a combustion-supporting medium, and injecting into said chamber a quantity of pyrophoric material adapted for spontaneous ignition upon contact with said medium, said material being in the form of a fine suspension of pyrophoric particles in a small quantity of viscous liquid.

14. The method of effecting combustion of a combustible fluid which includes, injecting a quantity of combustible fluid in a finely divided form into a combustion chamber containing a combustion-supporting medium, and injecting to said chamber a quantity of pyrophoric material adapted for spontaneous ignition upon contact with said medium, said material being in the form of a fine suspension of pyrophoric particles in the combustible fluid.

15. The method of effecting combustion of a combustible fluid which includes, injecting a quantity of combustible fluid in a finely divided form into a combustion chamber containing a combustion-supporting medium, and injecting into said chamber a quantity of pyrophoric material adapted for spontaneous ignition upon contact with said medium, said material being injected at a velocity sufficient to ensure its passage across a substantial part of the chamber, whereby ignition at a multiplicity of points is assured.

16. The method of effecting combustion of a combustible fluid which includes, injecting a quantity of combustible fluid in a finely divided form into a combustion chamber containing a combustion-supporting medium, and injecting into said chamber a quantity of pyrophoric material adapted for spontaneous ignition upon contact with said medium, said material being injected in the form of a spray at a velocity sufficient to ensure its passage throughout a substantial part of the chamber, whereby ignition at a multiplicity of points is assured.

17. The method of effecting combustion in an internal combustion engine which includes, injecting fuel into a cylinder of said engine at a normal part of the cycle of operation, and injecting into said cylinder before the injection of fuel a quantity of pyrophoric material adapted for spontaneous ignition upon contact with any unburned combustible residue in the cylinder, whereby destructive detonation of an excessive charge in the cylinder is prevented.

18. The method of effecting combustion of a combustible fluid which includes, providing a quantity of pyrophoric material adapted for spontaneous self-ignition, forming a concentrated suspension of said material in a fuel-soluble supporting vehicle, distributing said suspension uniformly in a combustible fluid fuel, dissolving said vehicle in said fuel, and introducing said fuel and pyrophoric material into a combustion-supporting medium.

19. The method of effecting combustion in an internal combustion engine which includes, providing a quantity of pyrophoric material adapted for spontaneous self-ignition, forming a concentrated suspension of said material in a fuel-soluble supporting vehicle, distributing said suspension uniformly in a combustible fluid fuel, dissolving said vehicle in said fuel, and injecting said fuel and pyrophoric material into a cylinder of said engine containing a combustion-supporting medium.

20. A pyrophoric ignition device comprising, a combustion chamber, means for injecting into said chamber a quantity of combustible fluid, and means for injecting into said chamber in a predetermined direction and with controlled and predetermined velocity a small quantity of pyrophoric material adapted for spontaneous ignition in said chamber.

21. A pyrophoric ignition device comprising, a combustion chamber, means for injecting into said chamber a quantity of combustible fluid, means for injecting into said chamber in a predetermined direction and with controlled and predetermined velocity a small quantity of pyrophoric material adapted for spontaneous ignition in said chamber, and means for actuating both said injecting means in timed relation such that said injections take place at least in part simultaneously.

22. A pyrophoric ignition device comprising, a combustion chamber, means for injecting into said chamber a quantity of combustible fluid, means for injecting into said chamber in a predetermined direction and with controlled and predetermined velocity a small quantity of pyrophoric material adapted for spontaneous ignition in said chamber, and means for actuating both said injecting means in timed relation such that the pyrophoric material injecting means is actuated for a shorter time than the combustible fluid injecting means.

23. A pyrophoric ignition device comprising, an internal combustion engine cylinder and a piston therein, means for injecting fuel into said cylinder at a normal part of the stroke of said piston, means for injecting pyrophoric material adapted for spontaneous ignition in said cylinder at an earlier part of said stroke, and a safety valve in a wall of the cylinder adjusted to remain closed during normal operation of the engine and to open in response to the excess pressure of an explosive detonation.

24. A pyrophoric ignition device according to claim 23 in which the safety valve includes a piston held in valve-closing position by fluid pressure.

25. A pyrophoric ignition device according to claim 23 which includes means responsive to the excess pressure of an explosive detonation for rendering inoperative the fuel injection means.

CONSTANTIN CHILOWSKY.

REFERENCES CITED

The following references are of record in the file of this patent:

UNITED STATES PATENTS

Number	Name	Date
1,274,941	Sanchez	Aug. 6, 1918
1,506,322	O'Neill	Aug. 26, 1924
1,506,323	O'Neill	Aug. 26, 1924
1,532,930	O'Neill	Apr. 7, 1925
2,394,608	Hansley	Feb. 12, 1946

FOREIGN PATENTS

Number	Country	Date
22,531	Great Britain	Oct. 19, 1903
559,348	Great Britain	Feb. 15, 1944