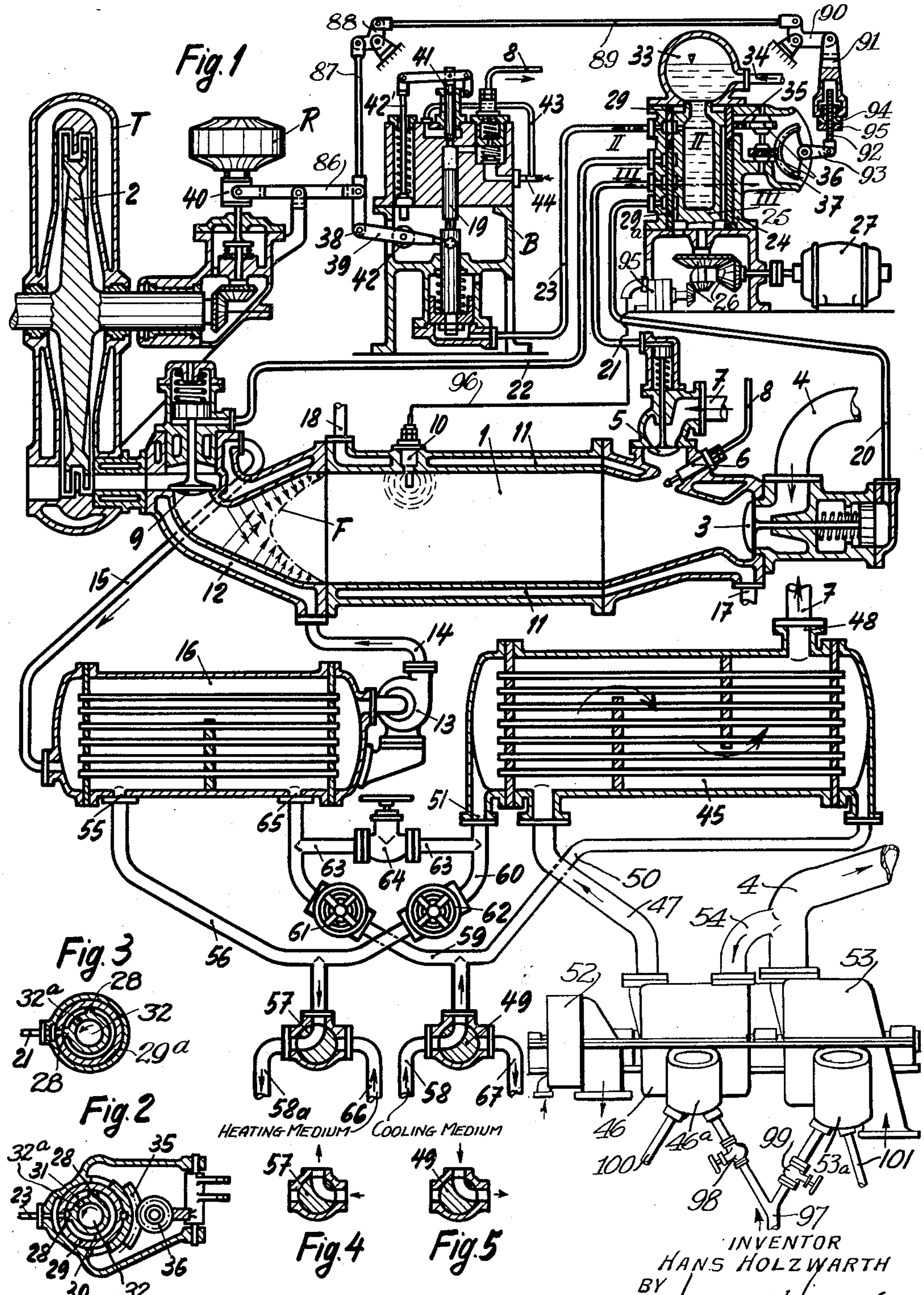
June 18, 1935. H. HOLZWARTH 2,004,945

METHOD AND APPARATUS FOR IGNITING EXPLOSIVE CHARGES

Filed April 25, 1933 4 Sheets-Sheet 1



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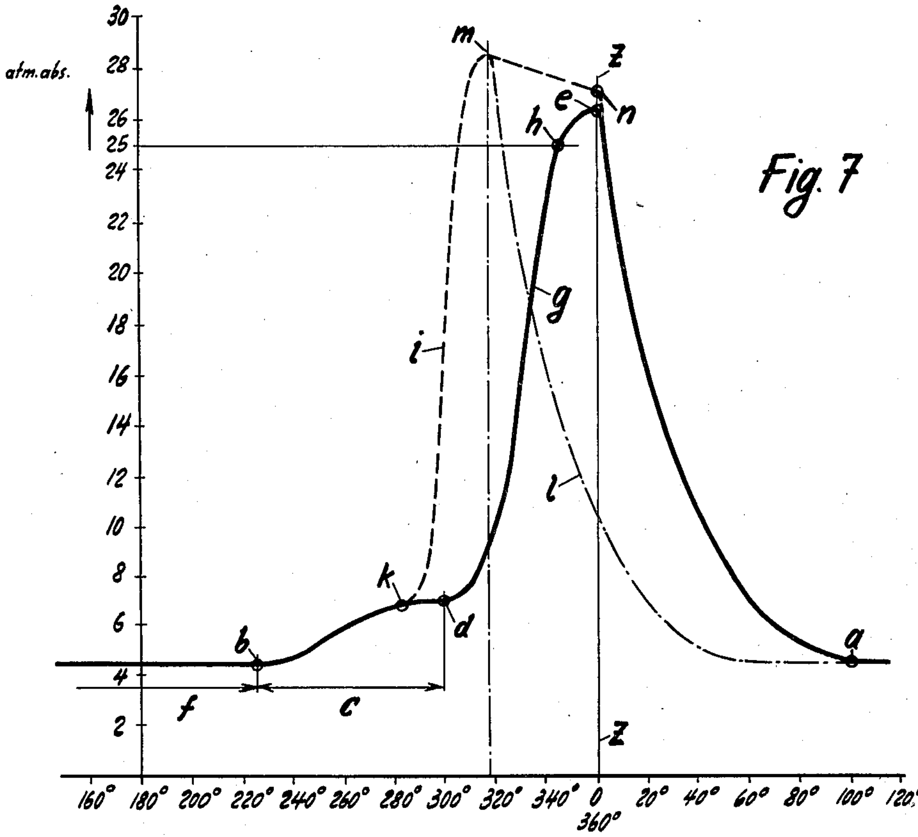

Fig. 7

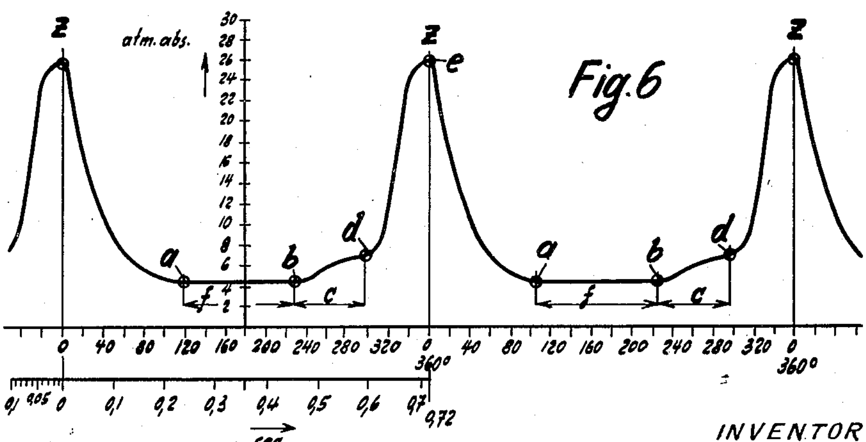

Fig. 6

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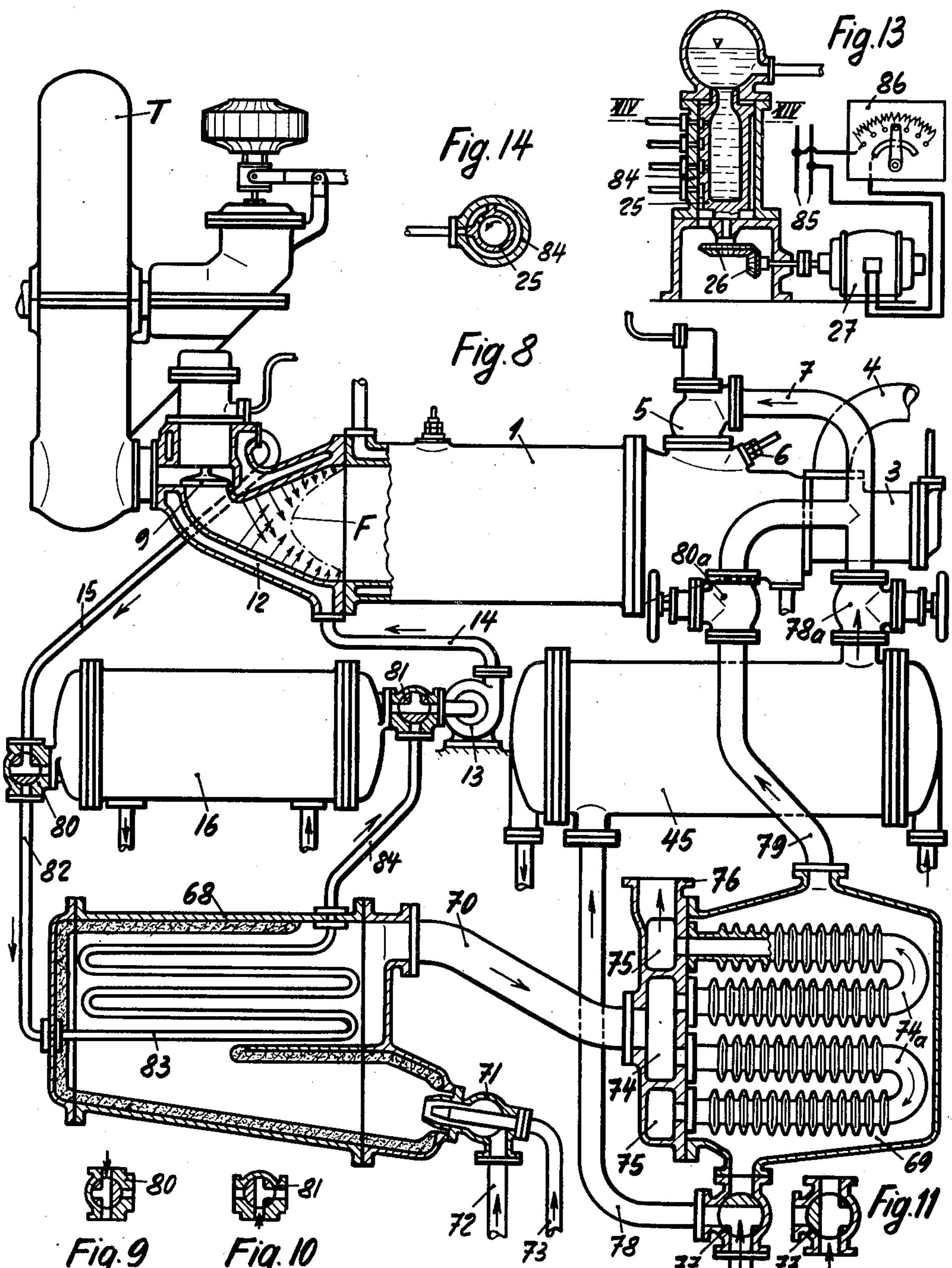

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METHOD AND APPARATUS FOR IGNITING EXPLOSIVE CHARGES

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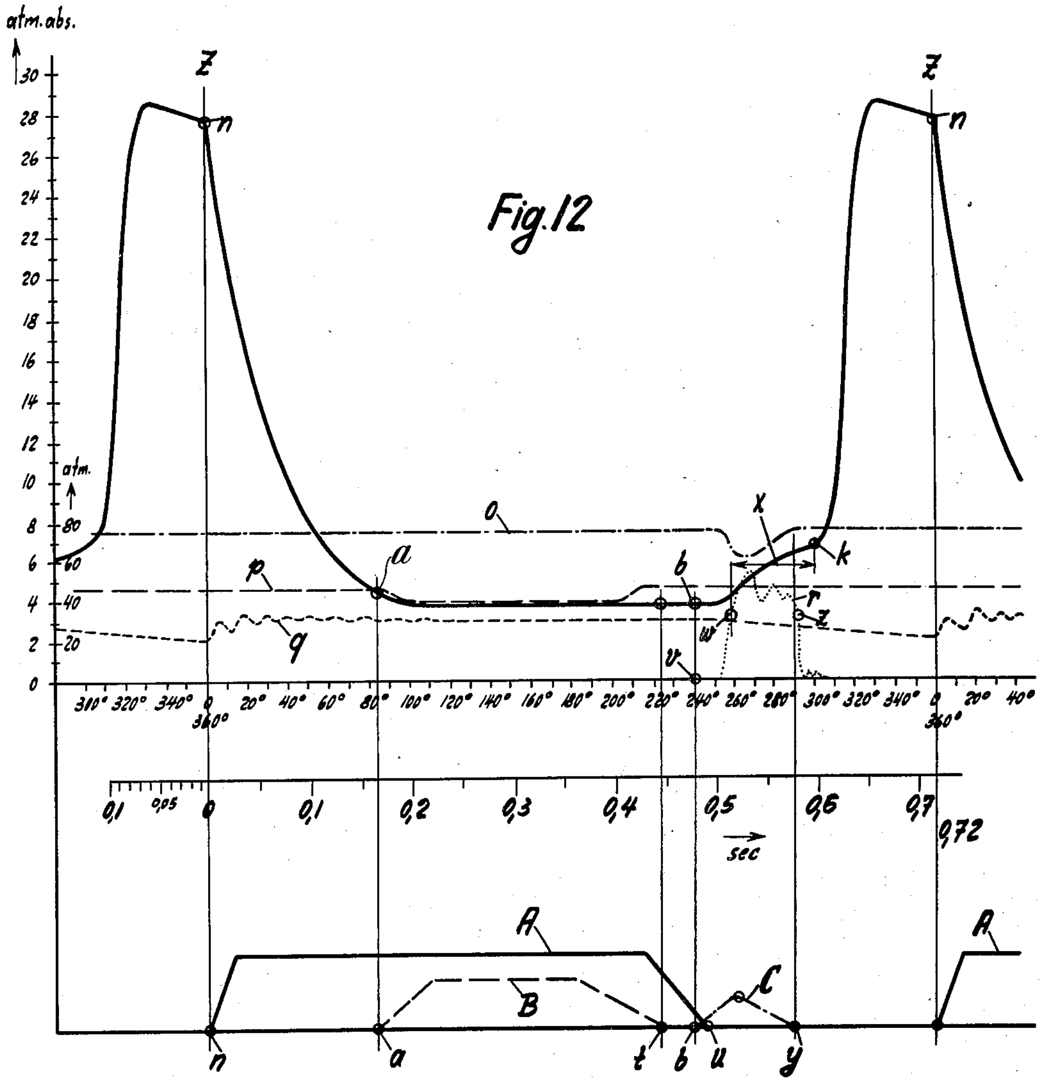

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2,004,945

METHOD AND APPARATUS FOR IGNITING EXPLOSIVE CHARGES

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In Germany April 27, 1932

21 Claims. (Cl. 60—41)

The present invention relates to an improved method of accomplishing the periodic ignition of combustible charges of fuel and air intermittently introduced into an explosion chamber, whereby more rapid and complete combustion of such charges is obtained.

Briefly described, my invention involves the ignition of a charge of fuel and air along the extensive dividing plane or zone between the ignitable mixture comprising the new charge and a body of hot gas, which may be either scavenging air or residual gases or both, confined or trapped at the outlet end section of the explosion chamber, and maintained at or raised to a temperature sufficient to effect ignition of the combustible mixture in the manner described more fully hereinbelow.

The invention relates in particular to the operation of elongated explosion chambers, and particularly of elongated constant volume explosion chambers employed in explosion turbines, provided with air and fuel inlet members at one end thereof, and outlet mechanism at the opposite end thereof, in which chambers preferably gaseous or liquid, but if desired also solid fuel is burned by explosion, the resulting explosion gases being then discharged from the chamber and all of their available energy utilized outside such chamber.

The invention has for its primary object to accelerate the ignition and the course of combustion of the fuel and air mixture in explosion chambers of the type indicated as contrasted with known processes. It is also an object of the invention to make it possible to determine the instant of ignition in the most exact manner and to control the instant of ignition, that is, to make such ignition controllable in such manner that the ignition of the fuel and air mixture occurs with certainty only after the charging of the explosion chamber with the materials that support the combustion is completed.

I have found that the usual method of ignition of a fuel-air mixture with the aid of an electric spark has two fundamental disadvantages, both of which are attributable to the very small igniting surface presented by the electric spark. Investigation has shown that, in the first place, there is no assurance that, even when the fuel has been homogeneously distributed through the air charge, the fuel and air mixture will become ignited directly, that is, immediately, after the appearance of the spark, because there is no absolute certainty that the instant when the spark is struck an ignitable part of the mixture is directly in contact with the comparatively minute spark. Moreover, the surface of the spark is extremely small in comparison with the size of the charge in the chamber. The combustion of the mixture in the chamber thus proceeds from this small surface of the igniting spark as a sheet of flame which takes the form of a spherical shell of constantly increasing radius having its center at the point of ignition, in a manner similar to that in which sound waves, when unobstructed, spread out in air from the source of the sound in concentric spherical surfaces. The burning surface developing in the fuel and air mixture thus enlarges as the combustion proceeds. From this it follows that a combustion process initiated by ignition at a point requires a great deal of time because of the originally very small igniting surface of this ignition point. If the fuel mixture, furthermore, contains difficultly burning fuel which must be decomposed or dry-distilled before the ignition, the combustion process lasts even longer because the enlargement of the burning area, proceeding from the igniting spark, occurs comparatively slowly. There is therefore required a certain time interval before a sufficiently large and effective igniting area forms in the combustible mixture. Where liquid fuels are employed, the quantity of heat required for vaporizing and gasifying the fuel must be abstracted from the interior of the already burning portion of the charge and transferred by radiation to the still unburned part of the charge, which of course is very large at the beginning of the combustion. In this way there is withdrawn from the just-mentioned burning portion of the charge, so large a quantity of heat that its temperature falls considerably. This temperature reduction leads to slow and incomplete combustion. To determine the magnitude of the heat withdrawal involved, a mixture consisting of liquid benzol and air in the ratio of 1:32.5 was investigated and it was found by calculation that by the evaporation alone of the liquid benzol its surroundings were cooled by more than 20° C. With some ordinary fuels a further cooling occurred due to the endothermic chemical breaking up of the fuel particles prior to the combustion of the mixture. If further, the fuel and air mixture is ignited, as is usual, by means of a spark, in which the ignition surface, as above explained, assumes the form of a burning spherical shell which grows constantly larger as the combustion proceeds and by which the fuel surrounding the same on all sides must be evaporated and decomposed, the resulting cooling is increased many fold.

The present invention provides a new and improved process for the ignition of mixtures containing liquid, gaseous or even powdered fuels, whereby the disadvantages of the known processes are overcome and the combustion process very materially improved. My improved process is preferably carried out in elongated, constant volume explosion chambers and consists essentially in confining or trapping, between the outlet member of the explosion chamber and the fresh fuel and air mixture introduced into the chamber for the next charge, a body of gases of such a temperature that the mixture of fuel and air ignites along the surface of the gases facing the same, that is, along the plane of contact between such trapped gases and said mixture. The gases serving for the ignition of the fuel and air mixture may, for example, consist of residual explosion gases which have been retained in the chamber from the preceding explosion cycle of the explosion chamber, and may have been mixed, if desired, with air; such gases may however also consist of air which has been highly heated by radiation and by the direct transfer of heat by conduction. My improved method of operation has above all the great advantage that a comparatively large igniting surface is presented right from the beginning by the trapped igniting gases to the fresh mixture of fuel and air introduced into the chamber, such igniting surface being practically perpendicular or nearly so to the longitudinal axis of the chamber when the latter is of elongated cylindrical form, the surface being capable of being itself curved.

My novel process can of course be aided to a considerable degree by a high temperature in the parts located in the region of the igniting gases and especially in the wall itself of the explosion chamber which is heated in any suitable manner. A high temperature at such parts is not only valuable for effecting a high degree of heat radiation into the igniting gases located at such place and thereby insuring their igniting temperature, but these parts represent a sort of heat storage apparatus which is capable of yielding that quantity of heat which is necessary with certain fuels for the vaporization and decomposition of their constituents before the ignition. In this way a measure is provided which guards against the withdrawal of the whole quantity of heat required for the vaporization and decomposition of the fuel particles from the combustion process itself. In other words, the atmosphere surrounding the fuel particles is prevented from becoming too cool.

As already indicated, my improved process can best be carried out in an elongated explosion chamber which is as nearly cylindrical as possible, such as had already been proposed by me for constant volume explosion turbines, the inlet members for the operating media (the fuel and air) being located at one end of the explosion chamber and the outlet member or members at the other end. By such arrangement of the inlet and outlet members, the result is obtained that the inlet end through which the comparatively cool operating media forming the combustible mixture enter remains cool, while the outlet end, through which the hot gases escape after the explosion of the mixture, becomes strongly heated. The ends of the explosion chamber are preferably made of conical form to the end that the residual combustion gases, after the explosion and expansion are completed, may be displaced by the air subsequently entering the chamber in the manner of a piston. By the conical formation of the outlet end of the chamber the transverse cross-section of the chamber continuously diminishes with the result that such a high velocity is imparted to the combustion gases upon opening of the outlet member that the heat transfer at the outlet end of the chamber is gradually increased. The gases which are to serve for the ignition of the fuel and air mixture, and which are located at the outlet end of the chamber between the outlet valve and the incoming body of air, are preferably provided in such quantity that they fill as completely as possible the rear or outlet conical end of the chamber, so that the dividing surface (the igniting surface) between the igniting gases and the fuel and air mixture is located, upon the initiation of the ignition, in the neighborhood of the connection between the outlet conical end and the middle, elongated cylindrical portion of the chamber. In this way the result is attained that the kindling of the mixture from here on proceeds at all points of the ignition surface linearly toward the chamber inlet end, whereby a heat transfer from the burning core of the contents of the chamber to the mixture to be burned occurs only at the surface of the burning core, facing the mixture to be burned, the area of which latter surface is limited by the circumference of the elongated portion of the chamber, and is very small in comparison with such core, in contrast with the known type of ignition by means of an electric spark, in which the spherically shaped igniting surface, which grows continually larger as the combustion proceeds, is materially larger than the igniting means itself.

For heating the igniting gas confined at the outlet end of the chamber a certain amount of combustion gas residue may be with advantage retained at such end, such gases being trapped at the outlet end of the chamber, during the expulsion of the residual combustion gases during the scavenging of the explosion chamber while the outlet member is open, by advancing the moment of closing of the latter. My improved process is carried out with particular advantage both when the explosion chamber is of considerably elongated form, and much time is provided for scavenging the chamber of the residual gases except the portion thereof which is to serve for igniting the next charge. Under these conditions there will occur, even during the scavenging step, a strong radiation of heat from the combustion gases into the adjoining portion of scavenging or super-charging air advancing from the inlet side of the chamber.

My novel process affords certain and complete combustion in every particular of any mixture of fuel and air in a preferably elongated explosion chamber, as the mixture in the chamber comes into contact from the beginning of the ignition on, with an extraordinarily large igniting surface of a temperature sufficient to effect ignition, such temperature being increased, if desired, by additional radiation of heat. Because of the large available igniting surface, the ignition of the mixture occurs with great rapidity and rapid combustion of the whole contents of the chamber is accomplished. My new process makes it possible to burn fuels so completely (which fuels can be burned, for example, in Diesel motors only with difficulty and very incompletely) that it is not possible, even with chemical means, to detect any unburned constituents of the mixture after the combustion in the chamber. In particular, even those fuels can be burned completely without odor which in known combustion processes burn only incompletely and consequently, as is known, produce gases having an unpleasant odor.

In the application of my new process to explosion chambers for power plants, as for example, explosion turbines, in which, because the load and speed of such plants may change greatly and frequently, the charging conditions of the explosion chamber may change suddenly and abruptly, there may be arranged additional igniters in the chamber, such as, for example, constantly glowing parts, or, still better, controlled electric spark devices whereby failure of ignition is avoided with certainty. Such auxiliary igniters may with advantage be employed for starting the explosion chamber from the cold condition. Where positively controlled electric spark plugs are employed as auxiliary igniters, they are preferably controlled in such manner that they are fired after the instant at which ignition is to be effected, in the normal operation of the chamber, by the igniting gases confined therein. Such controllable auxiliary igniters cannot disturb the normal ignition by the confined igniting gases, but they insure the ignition of the mixture in the event that the normal ignition by the igniting gases fails for any reason.

The use of auxiliary igniters does not, however, always suffice to produce a disturbance-free starting operation with difficultly ignitible fuel, In such case the condition of the mixture at the instant of ignition must, during the starting operation, be made to approach as closely as possible to the condition during normal operation. This result can be secured by the use of the process and means provided with the present invention whereby the outlet end of the chamber is artificially pre-heated and in this way the temperature of the body of gas (air and/or residual gases) confined thereat is increased by radiation, or else by heating the scavenging and charging air before its entry into the explosion chamber.

In a further development of the inventive idea, my improved process may be carried out by making the time interval, during which the fuel mixture advances from the inlet end of the chamber toward the outlet end, that is, toward the igniting surface, controllable at will in such a manner that the instant at which the ignition of the mixture occurs can be exactly predetermined. By this measure the ignition of the mixture is prevented before the charging of the chamber with a combustible mixture of proper quantity and composition is completed. Should the ignition of the mixture occur before the inlet members of the chamber are closed, the pressure gases generated by the explosion would be forced into the conduits in advance of the inlet members and displace the operating media (e. g. fuel and air) contained therein. Should this occur, there would be charged into the chamber during the next cycle, at least at first, uncombustible constituents originating from the combustion gases, or combustion supporting air mixed with combustion gases, so that an incomplete and unsatisfactory mixture would be formed in the chamber and proper operation of the chamber would be rendered impossible.

Moreover, when combustion gases frequently backfire into the inlet valves and feeding conduits, the inlet end of the combustion chamber becomes so strongly heated that the new fuel and air mixture forming at the beginning of a charge becomes ignited at such inlet end, so that the combustion is initiated even more prematurely than before and the whole process is completely deranged.

These disadvantages can be overcome by various measures in accordance with the further development of the present invention. One possibility of avoiding the difficulties resides in the proper measurement of the velocity of the vehicle which carries fuel, such vehicle being usually air. This measure can be carried out in a satisfactory manner by displacing the beginning of the fuel introduction into the chamber with reference to the introduction of the air. This procedure is based upon the observation that the highest air velocity in the chamber is attained right at the beginning of the air admission into the chamber, that is, shortly after the opening of the air inlet valve, since upon opening of such valve the difference between the pressure of the incoming air and the back pressure in the chamber is greatest. The back pressure becomes gradually higher as the charging of the chamber proceeds, so that the velocity of the incoming air falls proportionally. Hence, upon coincidence of the beginning of the introduction of fuel and air, the fuel meets air of the highest velocity in the chamber, the fuel particles first entering the chamber being thus carried by the air at very high velocity toward the chamber outlet, that is, toward the igniting place. If, now the fuel is introduced into the chamber a certain time interval after the beginning of the opening of the air inlet member, it follows from the above stated considerations that the fuel meets in the chamber a current of air whose velocity is smaller than its initial velocity. Hence, the later the admission of fuel is begun with reference to the instant at which the air introduction begins, the smaller will be the air velocity which the fuel particles first entering the chamber will meet, and therefore the longer will be the time required before such fuel particles traverse the distance between the mouth of the fuel inlet member and the igniting place at the outlet end of the chamber; that is, the greater will be the time interval available prior to ignition for terminating the introduction of air and fuel into the chamber and closing the corresponding inlet members at the proper time before the ignition actually takes place.

By the increase of the time interval between the beginning of the fuel injection and the ignition by retarding the beginning of the injection, it is however possible for the injection to begin only after the charging of the explosion chamber with air has proceeded too far, so that the velocity of the air, because of the increase of the back pressure as the charging of the chamber proceeds, has fallen to a value at which proper atomization of the fuel is no longer possible. In such case there can, in accordance with the invention, be selected another simple way of correctly dimensioning the interval from the beginning of the fuel injection to the instant of ignition of the mixture—in the description, following this time interval, will, for the sake of brevity, be called "ignition lag"—by changing, that is increasing or decreasing, the number of working cycles of the explosion chamber per unit of time, whereby the fuel can be injected at the instant at which the air velocity is the most favorable, advantageously upon the opening of the air valve. In this way the duration of the individual control phases of a complete working cycle, as for example the scavenging, the charging, and the discharging of the high pressure combustion gases from the chamber, can be increased or decreased. The absolute duration of the ignition lag can be kept constant at all cycle frequencies by so determining the control conditions that the instant of beginning of the fuel admission is not changed with reference to the instant of beginning of the air admission. In such case the fuel particles first entering the chamber always meet, at the moment they enter the chamber, a current of air at the same favorable velocity at all cycle frequencies, so that the time for conveying the mixture to the igniting place is always the same.

It will be understood that the best conditions of operation for any particular shape or size of explosion chamber can readily be determined by preliminary tests in which the variable factors are adjusted until optimum results are obtained. Thus the necessary velocity of the fuel and air stream could also be attained by correctly dimensioning the cross section of the passage way in the inlet members; aside from that, the pressures of the operating media could naturally also be suitably selected with a view toward attaining a favorable ignition lag. That path which the fuel must traverse in the chamber from the place of admission of the fuel to the ignition place should be made sufficiently long, as far as possible within practical limits, by suitably shaping the chamber, so that the fuel will traverse this distance at a given flow velocity only after the charging of the chamber has been entirely completed and the inlet members for the operating media are again completely closed or very nearly closed. By adequate dimensioning of the length of this path it is further possible to admit the fuel with the air at about the same time, and thus, under certain circumstances, with a small time displacement, between their respective admissions, so that the fuel particles first entering the chamber are carried along toward the ignition place in a current of air of the highest velocity, which, according to experience, is most favorable for producing complete and homogeneous mixture, the fuel being in fact torn along by such air current.

Finally, it is of course essential, in explosion plants in which the ignition lag corresponds at least approximately to the correct operating conditions, to employ one or another of the indicated methods for adjusting the ignition lag (after-regulation).

Several embodiments of apparatus suitable for carrying out my improved ignition process are illustrated by way of example on the accompanying drawings. In said drawings,

Fig. 1 illustrates diagrammatically a section taken through a plant built in accordance with the present invention, such plant operating according to the constant volume explosion process;

Fig. 2 is a horizontal cross section through the control oil distributor of the turbine plant and is taken along the line II—II of Fig. 1;

Fig. 3 is a similar section through the control oil distributor along the line III—III of Fig. 1;

Figs. 4 and 5 illustrate certain of the valves of Fig. 1 in a different position of adjustment;

Fig. 6 is a time-pressure diagram representing the normal course of the pressure curve of a constant volume explosion chamber, the abscissae indicating the time for the control processes in the explosion chamber, expressed both as the angular velocity of a hydraulic control device in degrees and in seconds, and the ordinates indicating the pressure prevailing in the chamber at any moment;

Fig. 7 shows a diagram drawn on a larger scale than that of Fig. 6 and illustrates only that section of the time-pressure curve which is pertinent to the present invention;

Fig. 8 shows a modification of the explosion turbine plant, the same being shown partly in elevation and partly in section;

Figs. 9, 10 and 11 show details of the plant illustrated in Fig. 8 in various positions of adjustment;

Fig. 12 is a diagram illustrating the time-pressure relationships in the explosion chamber which come into consideration upon displacement of the commencement of the fuel injection with reference to the moment of opening of the air charging valve;

Fig. 13 shows by way of example an arrangement for altering the control periods of the hydraulic control device which is adapted for charging the explosion chamber, in dependence upon the motor which drives such control device, the construction being shown for the most part in section; and

Fig. 14 is a section through the control device along the line XIV—XIV of Fig. 13.

The numeral 1 in Fig. 1 indicates an elongated cylindrical explosion chamber of the constant volume explosion type in which explosion gases of high pressure are periodically generated, such gases being then directed against the rotor 2 of the Curtis turbine T which is shown as provided with two rings of blades. The explosion chamber is provided in the usual manner with a scavenging air valve 3 at the conical inlet end of the chamber, the valve being arranged co-axially with the chamber, scavenging air of a pressure above atmospheric being fed to the valve through conduit 4. The air valve 5 which charges air of a still higher pressure is likewise located at the conical inlet end of the chamber, as is also the fuel inlet member 6 in the form of an injection nozzle. Air is charged to the valve 5 under pressure through the conduit 7, while fuel is fed to the injection device 6 by conduit 8 leading from the pressure discharge side of a piston fuel pump B which is hydraulically controlled in known manner. The pump B is connected with the explosion turbine T through a governor R which regulates the quantity of fuel fed. The gases generated by explosion in chamber 1 flow through the outlet or nozzle valve 9 arranged at the outlet end of the chamber which, like the inlet end, is of conical configuration, and are charged against the rotor 2 of the explosion or impulse turbine T. In the cylindrical portion of the explosion chamber 1 there is provided an igniting device 10 which serves primarily only for starting, such device being suitably in the form of a spark plug. The explosion chamber is surrounded over its whole length with two cooling chambers 11 and 12 which are independent of each other. The cooling chamber 12 is the smaller and serves to cool the conical outlet end of the chamber 1, at which end the nozzle valve 9 is located; while the cooling chamber 11 surrounds the remaining and much larger part of the chamber, including the inlet end of the chamber. In the normal operation of the plant, a cooling agent is conducted to the cooling chamber 12 by the pressure pump 13 through conduit 14 and leaves such chamber through the pipe 15 leading into a heat exchanger 16, from which the pressure pump 13 sucks the cooling agent after the latter has given up a certain part of the heat absorbed in the chamber 12, and feed such cooling agent again to the chamber 12. A cooling agent is introduced into the cooling chamber 11 by the conduit 17 and is withdrawn from such chamber by the conduit 18.

The inlet and outlet valves of the explosion chamber and the fuel pump B are controlled hydraulically by mechanism of a known type. To this end, the two air inlet valves 3, 5, the nozzle valve 9 and the fuel pump piston 19 are each provided with a spring-pressed piston into whose cylinder a pressure conduit 20, 21, 22 or 23 opens. These conduits are connected with a pressure medium distributor 24 whose general construction and operation are known, such distributor having a revolving disc or cylinder 25 which is rotated by a motor 27 through a drive 26. The conduits 20 to 23 are controlled by the revolving cylinder according to a definite working cycle in such a manner that each conduit is filled temporarily with a medium under pressure and is then again relieved of pressure. For this purpose, the rotating disc is provided upon its circumference with a number of blocks 28 (see Figs. 2 and 3), each two of which serve to control one of the attached conduits 20, 21, 22 and 23. Each two blocks lying in the same plane, together with the two-part sleeve 29 surrounding the revolving cylinder, form two separate annular chambers 30, 31, the chamber 31 being constantly in communication with the hollow interior 32 of the cylinder through a transverse port 32*a* in the disc. This hollow interior, which may be connected with an air chamber 33, is filled with a compressed medium, such as pressure oil, introduced by the conduit 34. The other chamber 30 is connected with a space of lower pressure or with the atmosphere. Depending upon the position of the rotating cylinder, the conduit 20, 21, 22 or 23 is connected either with the pressure space 31, so that the associated member 3, 5, 9 or 19 is actuated, or with the space 30, at which time it is under reduced or under no pressure.

Fig. 2 shows the condition in which conduit 23 is covered by one of the control blocks 28, so that upon further rotation of the cylinder 25 in the direction indicated by the arrow, it is placed in communication with the pressure space 31, whereupon the pressure stroke of the fuel pump is initiated. Fig. 3 shows a section through the control section of the distributor 24 for the charging air valve 5, the associated conduit 21 being similarly covered by one of the control blocks. Thus if the blocks 28 for the fuel pump and also those for the charging air valve are so adjusted in reference to each other that the two associated oil conduits are simultaneously placed under pressure and again relieved of pressure, the fuel will be injected into the explosion chamber simultaneously or at least nearly simultaneously with the beginning of the charging of chamber 1 with charging air.

The instants of introduction of charging air and fuel may be displaced relatively to each other. To this end, the upper part of the sleeve 29, all of which lies close to the rotating cylinder of the distributor, is arranged to rotate with reference to the lower, immovable section 29*a*. This rotation is accomplished by means of a toothed segment 35 attached to the upper sleeve section, and a drive 36 (see Fig. 2), which in turn is actuated by a segment 37. The latter segment is coupled by suitable connecting means with the speed controlling governor R, as by being connected with the regulating sleeve 40 of the governor through lever 86, link 87, bell-crank lever 88, link 89, bell crank lever 90, link 91, 92 and arm 93, as shown in Fig. 1. The governor regulates also the quantity of fuel fed in known manner, such regulation being effected by adjusting vertically the fulcrum 38 of the lever 39, which at its other end is articulated with the fuel pump piston 19, by shifting of the regulating sleeve 40 of the governor. In this way, depending upon the position of the fulcrum 38, the spring pressed by-pass or return valve 41 is opened sooner or later by the roller 42 acting through the linkage 42', or, when the maximum quantity of fuel is to be fed (when the operation is at full load) such valve is not opened at all. By the opening of the return valve the effective feed stroke of the pump is interrupted to a greater or lesser degree, the fuel which is fed during the further course of the pressure stroke of the piston 19 being forced back into the fuel suction conduit 44 by the pipe 43. The connection between the rotatable upper section of sleeve 29 with the speed governor R may advantageously be accomplished in such manner that such section in certain instances, for example upon adjustment of the instant at which the injection of fuel begins, when the apparatus is under test, can be displaced independently of the governor by hand. This may be done in simple fashion by making one of the elements of the connecting mechanism 86—93 adjustable in length. Thus, as shown in Fig. 1, the link 91, 92 may be formed of two parts, the part 92 being in the form of a threaded rod which is received within a manually rotatable nut 94 which is held against axial movement within the hollow end of the part 91 but is free to rotate relatively to the latter. Rotation of the nut 94 will change the effective length of the link 91, 92, and thus cause adjustment of the upper section 29 of the sleeve 29, 29*a*. The nut 94 may be held in adjusted position by the lock nut 95.

At 45 is shown a second heat exchanger which can be constructed similarly to the heat exchanger 16. The heat exchanger 45 serves in normal operation for re-cooling the compressed super-charging air delivered by the compressor 46, the air flowing to the heat exchanger 45 through the conduit 47, and after traversing such heat exchanger is conveyed to the charging air valve 5 through outlet 48 and conduit 7. The medium for cooling the super-charging air, preferably water, flows to the heat exchanger 45 through the variable valve 49 and conduit 50, and flows off at 51. The super-charging compressor 46 is driven by a turbine 52 or any other suitable driving motor, which at the same time drives the scavenging air compressor 53, from which the compressed air flows in part through pipe 4 to the scavenging air valve 3, and in part to the super-charging compressor 46 through branch 54. Both compressors may be supplied in known manner (see page 895, Figs. 47 and 48, of the handbook "Huette", 25th edition, Vol. II, Berlin 1926, Wilhelm Ernst and Son) with at least one intermediate cooling stage 46*a* or 53*a*, which, when necessary, can be cut out. The cooling agent enters the heat exchanger 16 at 65 and leaves the same at 55 through conduit 56 and variable valve **57**, such heat exchanger in normal operation serving as a re-cooler for the cooling agent of the explosion chamber outlet section.

According to the present invention, various possibilities are provided for feeding the two heat exchangers **16**, **45**, which will be described in detail hereinbelow in connection with the novel and improved mode of operation of the whole explosion turbine plant. The cooling agent feeding conduit **50** is connected with the inlet **65** of the heat exchanger **16** through a branch conduit **59**, and the cooling agent withdrawing conduit **56** is connected with the outlet **51** of the heat exchanger **45** through a branch conduit **60**. The two branch conduits **59** and **60** have each a valve **61** or **62** by which they can be closed. Furthermore, there is provided between the two branch conduits a connecting pipe **63** which likewise contains a valve **64**. By reversing the two variable valves **57**, **49** into the position shown in Figs. 4 and 5, a hot medium instead of a cooling agent may be fed into the heat exchangers. The purpose of such reversal will be described hereinbelow.

The explosion plant so far described is operated in accordance with the invention as follows:

To facilitate the understanding of the inventive idea, the mode of operation of the explosion plant will be explained with the aid of the two diagrams in Figs. 6 and 7, in which the ordinates indicate the pressure course in the explosion chamber during a complete working cycle, while the abscissæ indicate the angular displacement of the rotating cylinder **25** of the oil distributor **24** in degrees, a complete revolution of such cylinder corresponding to a complete working cycle, and being equal to 360 degrees. In Fig. 6, which represents a normal time-pressure diagram of a known constant volume explosion chamber, the time scale is indicated also in seconds for a complete working cycle for the purposes of comparison. The working cycle is arbitrarily assumed to lie between two consecutive ordinate axes *z*—*z*, during which, as stated, the rotating cylinder makes a complete revolution of 360 degrees. At the position 0° the nozzle valve **9** is opened, the oil conduit **22** leading thereto having immediately before been placed under pressure by the pressure oil distributor **24**. The gases generated in the chamber **1** flow to the rotor **2** of the turbine upon opening of the valve **9**. After the pressure of the gases have fallen approximately to the back or exhaust pressure, the scavenging air valve **3** begins to open at the point *a*, its oil conduit **20** having been placed in communication with the oil pressure accumulator space in the cylinder **25**. Fresh air delivered by the conduit **4** from the compressor **53** at a certain superatmospheric pressure is then introduced into the explosion chamber **1** through the open scavenging air valve **3**. The residual combustion gases in the chamber are driven out through the still open nozzle valve **9** by the incoming air which, due in part to the peculiar shape of the chamber, takes the form of a piston, there being no whirls and eddies and thus no appreciable mixing of residual gases and air. When the chamber has been sufficiently scavenged, the scavenging air valve closes, its oil conduit **20** being connected with the low pressure space in the oil distributor **24**. The nozzle valve **9** is closed at the point *b*, its oil pressure conduit **22** having been disconnected from the interior of the cylinder **25**. After nozzle valve has closed at point *b*, the air charging valve **5** and fuel inlet member **6** begin to open, the oil conduits **21** and **23** being placed under pressure. Upon opening of the air charging valve, compressed air delivered by the compressor **46**, after passing through the heat exchanger **45** where heat is abstracted therefrom, is charged into the chamber **1** through conduit **7**, while fuel is injected into the chamber by the pump B through the conduit **8** and fuel valve **6**. The charging of the chamber with air and fuel occurs on the diagram of Fig. 6 along the interval *c* from the point *b* to the point *d*. At the point *d* the mixture is ignited and the explosion is ended at the point *e*, at which the next ordinate axis is located. The expansion of the high pressure explosion gases through the nozzle valve **9** and the individual phases of the working cycle are then repeated in the above item described sequence. It will be understood that the gases may exhaust from the turbine T under pressure, or at only atmospheric pressure, and that the scavenging air pressure is at least slightly higher than such exhaust pressure.

The ignition of the charge in the chamber occurs in the normal operation of the plant, according to the invention, at the highly heated surface F shown in Fig. 1, which is adjusted between the combustible mixture in the chamber to be ignited and the mass of gas or air located in the conical discharge end of the chamber. This ignition surface arises during the scavenging process, which takes place according to Fig. 6 between the points *a* and *b*, and is equal to the interval *f*. During the scavenging, in which the scavenging air displaces the residual combustion gases from one end of the chamber to the other, there occurs a strong heat transfer from the hot residual gases to the advancing, piston-like body of scavenging air. In order that no scavenging air may escape through the nozzle valve **9**, the latter is so controlled by the oil distributor **24** that it closes at the proper instant, preferably at the point in which a certain amount of residual gases still remains in the outlet end of the chamber, such amount of residual gases being retained between the body of scavenging air and the closed nozzle valve. By this trapped quantity of gas the temperature of the adjoining layer of air, which has already taken up some heat during its travel from the inlet end of the chamber through the body of the chamber, is considerably increased. This temperature can, in accordance with the invention, be further increased to a considerable degree by conducting a cooling agent of very high temperature (hot oil, super-heated water, steam, etc.), to the jacket **12** which surrounds the conical outlet of the explosion chamber. This hot medium is circulated by the pump **13**, such cooling medium being only partially recooled in the heat exchanger **16** in order that it may return to the jacket **12** at a definitely high temperature. I have found that the heating of the outlet section of the explosion chamber is favored by giving the same a conical configuration, as due to the gradually decreasing cross section of such outlet end portion of the chamber, the gases discharged from the chamber during the expansion period attain very high velocities. Aided by these high velocities, a very vigorous heat interchange occurs in the wall of the conical outlet of the chamber, so that a large quantity of heat is stored in its walls. During the charging of the chamber **1**, a large part of this stored heat radiates into the rear portion of the chamber and hence into the already hot body of gas or air located at such end, as is indicated in Fig. 1 by the arrows. This heat radiation is transmitted to the surface F directed toward the chamber mixture, which surface probably assumes a concave form. As a result of the radiation, the surface F ultimately reaches a temperature which is sufficient to cause ignition of the mixture in the chamber.

The same object of forming a large igniting surface F is attained according to the invention under certain circumstances even when the residual gases are completely driven out from the chamber. In such cases the heat stored in the walls at the outlet end of the chamber is radiated into the body of air (scavenging air) collecting at such end in exactly the manner described above. A quantity of residual gases is, of course, more effective as an igniting medium, as such gases already have high temperatures from the beginning, so that less time and radiant heat are required for developing the igniting surface F to kindling temperature than when pure air is located at the end of the chamber, the original temperature of such air being far less than that of the combustion gases.

In order to make clearer the action and superiority of the large igniting surface F created in accordance with the invention, as contrasted with the modes of ignition heretofore employed, namely, by means of an electric spark, there are shown circles of different sizes about the spark gap of the igniting device **10** which projects into the interior of the chamber. The function of this spark plug will be described below. These circles indicate how the ignition of the charge proceeds upon a gradually enlarging spherical surface from the originally very small electrical spark produced by the spark plug. Consideration of these circles of increasing size will show clearly that at the moment of the initial ignition the charge in the chamber presents a very small igniting surface. It is considered further that prior to the ignition of the charge a certain amount of heat must be available for evaporating and on occasion for splitting up the fuel, which heat for the greater part is withdrawn from the igniting mass of means, then it will be evident that with such ignition the combustion can proceed only slowly and incompletely. In any case, the igniting surface of a spark plug, which in its original condition presents a punctiform ignition surface, can, due to the heat withdrawal above mentioned, develop only slowly into an effective, large igniting surface. Such an igniting surface, moreover, at least during the first part of the combustion, is exceedingly small in comparison with the surrounding unburned charge.

In accordance with the invention, there is presented to the mixture of fuel and air in the explosion chamber, right from the instant at which ignition is initiated, a very large igniting surface F, which scarcely changes in area from the beginning to the end of the combustion process. Moreover, the igniting area F, in comparison with the core of the ignition mass (consisting of the gas or air located at the outlet end of the chamber) is only very small. In spite of the size of the igniting surface F, however, the quantity of heat radiating therefrom to the mixture to be burned, which heat is necessary for evaporating, atomizing and decomposing the fuel, will be comparatively small, that is, small in comparison with the quantity of heat which is contained in the igniting core. The heat withdrawn from this igniting core for atomization of the fuel is always immediately replaced by the heat radiated from the highly heated walls of the conical outlet of the chamber, so that the igniting surface F retains practically unchanged its original igniting temperature during the whole combustion process. In this way there results a very rapid and complete combustion of the fuel and air mixture enclosed within the explosion chamber.

In Fig. 7, which presents on a larger scale than Fig. 6 only those phases of the working cycle of the explosion chamber which need be considered in connection with the present invention, the effect of my improved mode of ignition is graphically illustrated. The full-line curve indicates again the time-pressure curve of the normay explosion diagram according to Fig. 6, in which the ignition of the combustible mixture in the explosion chamber is effected in known manner with the aid of a point ignition. The reference characters *a*, *b*, *c*, *d*, *e* and *f* for the different phases of the process have the same meaning as in Fig. 6. The point *d* thus again indicates the moment of ignition. From the course of the rising explosion line *g* beginning at this point and ending at the point *e* it will be seen upon simultaneous consideration of the abscissa time scale, that the combustion occurs comparatively slowly; the combustion is particularly slow from the point *h* on, at which instant the pressure in the chamber is about 25 atmospheres absolute. The course of the combustion line *g* from the point *h* to the point *e* leads to the conclusion that the combustion of the mixture is not yet entirely completed at the point *e*, so that during the expansion phase from the point *e* to the point *a* a strong after-combustion takes place.

When, however, the explosion chamber operates according to the method proposed by the present invention, according to which the charge in the chamber is ignited at the large igniting surface F of the air or gas mass located at the outlet end of the chamber, the pressure-line is changed as is indicated on the diagram by the dotted line *i*. The charge is ignited at the instant *k*, the spark plug **10** being connected to a distributor **95** by a cable **96** (Fig. 1) in known manner, the distributor being geared to the motor **27** and thus properly synchronized with the valve controlling mechanism. From the steepness of the line *i* it will be recognized that the combustion takes place considerably more rapidly than is the case with known ignition at a point, represented by the explosion line *g* shown in full lines. The charge is completely burned in my improved igniting process at the instant *m*. This will be clear in the diagram from the fact that the line *i* falls beyond the point *m* down to the point *n*, at which instant the expansion of the explosion gases begins as the nozzle valve commences to open; there occurs during the interval *m*—*n* a definite pressure drop in the chamber due to the transfer of heat to the walls of the explosion chamber. If, now, the opening of the nozzle valve is advanced to the point *m* at which instant the charge is fully burned, the expansion of the explosion gases beginning at such point would proceed according to dot and dash curve *l*. The pressure of the combustion gases at the moment of opening of the nozzle valve amounts to about 28.25 atmos., absolute while in an ignition process involving ignition at a point, the pressure at the instant *e* amounts to only about 26.15 atmos. absolute. These values for the pressure at the beginning of the expansion phase have been established by careful investigation, the air, pressure and other conditions being of course the same, and confirm and support the statements given hereinabove.

From both of these pressure values it follows that the increase in pressure of the combustion gases resulting from the practice of the present invention amounts to about 12% of the pressure obtained with ignition at a point, assuming that the amount of fuel and the ratio of fuel to air are the same in both cases. Corresponding to this increased pressure rise, there is obtained of course a larger energy output from the combustion gases in my improved process. In the investigations conducted by me the improvement in the combustion attained in accordance with the invention was apparent also from the fact that, while the exhaust during the operation with punctiform ignition was always cloudy, which as known is attributable to poor combustion, with combustion according to my novel process the exhaust was completely colorless and odorless.

The above-described novel ignition process makes it necessary to provide special auxiliary measures for the starting of the explosion chamber **1** from the cold condition, as at such time the air entering the explosion chamber can not take up any heat in view of the absence of residual combustion gases and in view also of the low temperature of the walls of the chamber, which remain comparatively cool for quite a number of cycles and can therefore receive no sufficient heat.

If easily ignitable fuel is used in the operation of the explosion chamber, an igniting device **10** in the form of one or more electric spark plugs may be employed for starting. As soon as normal operating conditions prevail in the explosion chamber, these auxiliary igniting devices can again be cut out, so that in the further course of operation of the chamber, that is, after the air or residual gases occupying the outlet end of the chamber during the charging are heated to the necessary igniting temperature by radiation, the ignition of the charges occurs at the ignition surface F. For the sake of insuring ignition, one or more of the above-mentioned igniting devices **10** can be permitted to continue operating during the normal operation of the explosion chamber. Such safety igniters are above all advantageous when the gases generated in the explosion chamber are used for operating a machine whose load and speed vary frequently and widely so that, due to these fluctuations, the charging conditions of the explosion chamber are changed suddenly and very abruptly. If such auxiliary igniters are permitted to operate during the normal functioning of the chamber, they are preferably controlled in such manner that they become active after the normal ignition instant of the surface F, the distributor **95** being made adjustable as is well known in the art. In this way the auxiliary igniters cannot disturb the normal ignition operation by the ignition surface F, but in case of failure of proper functioning of such surface they initiate the ignition.

The starting of the explosion chamber from the cool condition can be favored in accordance with the invention in the case of difficultly ignitable fuel by conducting the charging air into the chamber in a highly heated condition. To this end, the air is passed through a pre-heater before it is admitted into the explosion chamber. If a re-cooler is provided for the normal operation of the plant for re-cooling the compressed charging air in order to obtain a large weight of air per charge, then such re-cooler may with advantage be operated as an air pre-heater during the starting period by conducting a hot medium, such as steam, therethrough. The conditions on starting of the explosion plant are especially favorable when the outlet end of the explosion chamber is artificially pre-heated, so that the temperature of the air confined at such end is raised.

The pre-heating of the charging or scavening air and of the outlet end of the chamber may be accomplished with the apparatus shown by way of example in Fig. 1 by operating the two heat exchangers **16** and **45**, which in the normal operation of the plant function as re-coolers, as pre-heaters during the starting period. In order to obtain such result the two reversing valves **49** and **57** are brought into the position shown in Figs. 4 and 5. Assuming that the two heat exchangers are to operate in series as pre-heater, the valves **61** and **62** are closed while the valve **64** in pipe **63** is opened. In the position of the reversing valve **57** according to Fig. 4, a heating medium, for example steam, flows through the conduit **66** and through the conduit **56** first to the heat exchanger **16** where the steam after giving up a part of its heat to the medium circulated by the pump **13**, flows off at the exit **65** to the heat exchanger **45** through the open conduit **63**. In the latter the steam gives up its residual heat to the air flowing through the exchanger from the compressor **46** and flows finally through the conduit **50** and reversing valve **49** into the discharge conduit **67**.

The temperature of the pre-heated air can, when necessary, be raised by arranging the two heat exchangers in parallel. In such case the valve **64** is closed while the valves **61** and **62** are opened. The heating medium fed by pipe **66** passes through the reversing valve **57** and then flows in part through the conduit **56** into heat exchanger **16** and in part through the conduit **60** into the heat exchanger **45**. Both heat exchangers are thus traversed by a heating medium of the same temperature. The streams of heating agent leaving both heat exchangers meet at the junction of conduits **50** and **59** in advance of the reversing valve **49** and after passing through such valve flow off through the conduit **67**.

Finally, by closing the valves **62** and **64**, the beat exchanger **16** can be used alone as the pre-heater. In such case only the air or gases confined within the outlet end of the explosion chamber are heated, if the heat exchanger **45** is not heated in some other fashion; similarly, only the charging air could be heated during the starting of the plant. The pre-heating of the air can be increased to a considerable extent by cutting out of operation the intermediate cooling stages **46*a*** and **53*a***, respectively, of the two compressors **46** and **53**, or only one of such stages could be cut out, as by arranging suitable valves **98**, **99** in the conduit **97** which supplies the cooling agent, the latter being withdrawn through conduits **100** and **101**.

As soon as the explosion chamber has reached the condition of normal operation, the two valves **49** and **57** are reversed into the positions shown in Fig. 1. There then flows a cooling agent instead of a heating agent into the exchangers, such cooling agent flowing through the conduit **58** and reversing valves **49**, while the heated cooling agent, following the heat interchange, flows off through valve **57** and conduit **58*a*** to be recooled or discharged. The heat exchangers which now operate as re-coolers can be operated in the same way as was described in connection with their operation as pre-heaters by suitable adjustment of the valves 61, 62 and 64. In other words, the heat exchangers can be arranged either in series or in parallel, or the cooling agent delivered by the conduit 58 can be circulated through only one or through both heat exchangers. If the heat exchangers are arranged in series, then the cooling agent, contrary to the operation of the apparatus as preheaters, flows first through heat exchanger 45 for the charging air and subsequently through the heat exchanger 16 for recooling the cooling agent of the outlet end of the explosion chamber. With such mode of operation the requirement that the cooling agent for the chamber outlet end be only partially recooled is met in the most satisfactory manner, so that there remains stored in such cooling agent the necessary radiant heat for the formation of the hot igniting surface F.

The pre-heating of the outlet end of the chamber and of the air introduced into the explosion chamber for starting the plant, can be accomplished in still other ways. Fig. 8 shows one way of bringing about such result in a manner different from that shown in Fig. 1. In Fig. 8 the numeral 1 again indicates the explosion chamber, T the turbine, 3 the scavenging air valve, 5 the charging air valve, 6 the fuel injector valve, 9 the nozzle valve, 16 the heat exchanger for the chamber outlet end, with the interposed circulating pump 13, and 45 the heat exchanger for the charging air. The construction of Fig. 8 differs from that of Fig. 1 only in that for starting, two separate pre-heaters 68, 69 are provided which are arranged in series, for example, by means of the connecting conduit 70. The heat exchangers 16, 45 thus operate only as re-coolers which are cut out of operation during starting. The pre-heater 68 is heated by a burner 71 to which air is fed by conduit 72 and fuel by conduit 73. The hot combustion gases give up a part of their heat in the exchanger 68 and then flow through conduit 70 to the space 74 of the second pre-heater 69 for the charging air, whence they flow in the direction indicated by the arrow through the heating tubes 74a which by way of example are shown as of U-form. The gases leaving the heating tubes reach interconnected collecting spaces 75, which they leave through the discharge pipe 76.

The air delivered by the compressor flows in the normal operation of the plant through the three-way valve 77, conduit 78 into the recooler 45 and subsequently flows through the conduit 7 connected therewith to the charging air valve 5. A check member 78a is positioned in the conduit 7 and is open during normal operation. Upon starting of the plant the valve 77 is brought into the position shown in Fig. 11, so that the passage to the conduit 78 leading to the re-cooler 45 is cut off. The air then flows through the air heater 69 and through the conduit 79 into the conduit 7 to the charging air valve 5. The conduit 79 likewise is provided with a check device 80a which after starting, that is, in normal operation, is closed.

The medium serving for partially cooling the outlet end of the chamber is circulated during the normal operation of the plant with the aid of pump 13 in the circuit containing conduit 14, cooling space 12 of the outlet end of the chamber, discharge conduit 15, valve 80, recooler 16 and valve 81. Upon starting, the recooler 16 is cut out by reversing the valves 80 and 81, as shown in Figs. 9 and 10. In this position of the valves, the medium circulated by the pump 13 is forced through the conduit 82 leading from the valve 80, through the heating coil 83 of the pre-heater 68 and finally through conduit 84 and three-way valve 81 back to the pump 13, whence it is conveyed in strongly heated condition to the chamber outlet end, so that the latter becomes heated. As soon as the explosion chamber has reached its condition of normal operation, the pre-heater 68 is cut out by moving the valves 80 and 81 back to the positions shown in Fig. 8, so that the pump 13 circulates the cooling medium of the cooling space 12 through the re-cooler 16.

The present invention provides also a method of determining the instant of ignition of the fuel and air mixture with reference to the available charging time in such a way that the ignition always begins after the formation of a homogeneous, combustible mixture of fuel and air with avoidance of pre-ignition. In the embodiment of the invention illustrated in Fig. 1, the adjustment of the instant of ignition is accomplished by a time-displacement of the instant of fuel introduction with reference to the instant at which the charging of air is begun. For this purpose, the upper part of the intermediate sleeve 29 of the distributor 24 which has the function of controlling the oil conduit 28 of the fuel pump B is rotated a suitable distance by the toothed segment 37 relatively to the lower, fixed part 29a of the sleeve 29, 29a. This adjustment is made by hand upon starting the explosion plant, while when the plant is in operation such adjustment can be effected also automatically in dependence upon the governor R when the adjusting mechanism 35, 36, 37, of the upper sleeve part is connected with the governor R through a suitable connection as shown in Fig. 1. The time interval necessary for the travel of the fuel from the point of introduction into the chamber toward the ignition place becomes larger the later the fuel pump B begins its effective feeding stroke.

The way in which the control of the instant of ignition affects the time-pressure diagram is shown in Fig. 12. This diagram shows between the ordinate axes Z the course of the pressure curve in the explosion chamber during a complete working cycle with the individual process phases similar to the pressure course illustated by the diagram in Fig. 7, where the ignition of the fuel-air mixture occurs at the instant k and the opening of the nozzle valve at the instant n. The dot-and-dash line o in Fig. 12 indicates the pressure diagram of the super-charging air, and the long dash line p the pressure curve of the scavenging air in advance of the corresponding valves, and the short dash line q the counter pressure behind the nozzle valve. All of these curves are drawn to the scale shown at the left of the ordinate axis in atmospheres absolute. The point line r represents the fuel pressure in the delivery conduit of the fuel pump during the whole pressure stroke, the scale for such curve being indicated in atmospheres absolute at the right of the ordinate axis. The movements of the inlet and outlet valves of the explosion chamber are shown at the bottom of the diagram, the full line A representing the valve lift diagram of the nozzle valve, the dash line B that of the scavenging air valve, and the dot and dash line C that of the super-charging air valve. The abcissa scale is given in angular degrees based on a complete revolution of the oil-distributor which controls all the valves, beginning at zero degrees at the moment of opening of the nozzle valve, and is given also in seconds, it being assumed by way of example that a complete cycle, that is a single complete revolution of the rotating cylinder of the oil distributor requires 0.72 sec. Upon opening of the nozzle valve at the point *n*, the high pressure gases expand out of the explosion chamber down to the point *a*, at which instant the scavenging air valve is opened. The latter is again closed at the instant *t*. Shortly thereafter the nozzle valve also closes, the same being completely closed at the instant *u*. At about the same time, the charging air valve, which supercharges the chamber with air of higher pressure, opens at the instant *b*, so that the high pressure charging air flows at high velocity into the explosion chamber filled with scavenging air of lower pressure. At approximately the beginning of the introduction of the charging air the fuel pump begins its pressure stroke at the instant *v*, in the present case about 120° in advance of the opening of the nozzle valve. The actual injection of the fuel begins at the point *w* when the pressure in the fuel conduit leading to the injection nozzle overcomes the pressure tending to keep such nozzle closed. The fuel injection therefore occurs a certain interval of time after the beginning of the charging air admission, that is, at an instant at which the original high air velocity has fallen to a definite value, as the counter pressure in the explosion chamber rises as the charging proceeds. The fuel thus meets an air stream of lower velocity the later the injection of the fuel begins with reference to the beginning of the air charging. The smaller the air velocity, the longer will be the time consumed before the first fuel particles are carried forward to the ignition point *k* and the ignition is effected. According to the invention, the instant *w* at which the fuel injection begins, is to be so adjusted—in the embodiment shown in Fig. 1 this is accomplished by rotation of the upper sleeve part **29** of the oil distributor **24**—that the instant *y* of closing of the charging air valve and the instant *z* at which the fuel injection is ended come to occur in advance of the ignition point *k*, that is, within the interval *x* (ignition lag). In other words, the ignition of the fuel-air mixture always occurs only after the charging air valve and the fuel valve are again closed, so that the combustion gases cannot penetrate into the conduits leading to such valves.

If, however, it should be desired, with a view to obtaining good atomization of the fuel, to utilize for such atomization the maximum flow velocity of the air which prevails at the beginning of the charging air admission, so that the beginning of the charging air and fuel admission coincide at least approximately, such result can be realized according to a further development of the invention by changing the cycle number of the explosion chamber. As the cycle frequency is fixed by the velocity of the oil distributor, which is equivalent to any other mode or mechanism for control, the rotational speed of the cylinder of the distributor is accordingly altered. In this way the time scale is varied with reference to the degree scale, and hence the length of the ignition lag *x*, which depends only upon the time scale is changed with reference to the other magnitudes (control phases of a working cycle) which vary in point of time with the cycle number, that is with the rotational speed of the oil distributor (control shaft speed); these other magnitudes (control phases) depend only upon the degree scale.

Fig. 13 shows by way of example an arrangement for varying the cycle frequency in the manner above described. The numeral **84** indicates an oil distributor which differs from the distributor **24** shown in Fig. 1 only by the omission of a two part intermediate sleeve **29** arranged between the distributor housing and the rotating cylinder **25** and the actuating mechanism for such sleeve. The rotating cylinder is driven as usual from the electric motor **27** through the drive **26**. Current is supplied to the motor from the line **85** through a regulating resistance **86**. With the aid of this resistance it is possible to vary the rotational speed of the motor and of the distributor cylinder, and thus also the cycle frequency of the explosion chamber, which results in a change of the ignition process in the manner explained above.

It is of course obvious that my improved method of operation and the various details of apparatus are not limited to the specific form of the invention above described and shown on the drawings. Also, the individual features of my improved process need not all be used together, as certain features can be used without others.

I claim:

1. The method of operating elongated constant volume explosion chambers suitable for use in explosion turbines and having air and fuel inlet members arranged at one end thereof, and an outlet member at the opposite end thereof, said method comprising confining a gaseous medium between the outlet member of the chamber and a new charge of air and fuel entering and occupying the chamber, closing the chamber when the charge of air and fuel has been admitted into the chamber, and causing said medium to assume such a temperature that at the surface of contact between such medium and the said charge the ignition temperature of the combustible mixture formed in the chamber prevails and directly initiates the combustion of such mixture.

2. The method according to claim 1, including the steps of displacing the residual gases of a previous explosion with the combustion air of the next cycle, and closing the outlet member of the explosion chamber before it is reached by the new charge of air being introduced into the chamber.

3. The method according to claim 1, including the steps of displacing the residual gases of a previous explosion with the combustion air of the next cycle, and closing the outlet member at an instant at which a certain amount of residual combustion gases is trapped in the chamber at the outlet end section thereof.

4. The method according to claim 1, including the step of cooling the outlet end section of the explosion chamber to so limited an extent that the temperature of the gaseous medium is effectively increased by radiation of heat from the walls of the explosion chamber.

5. The method according to claim 1, including the steps of cooling the outlet end section of the explosion chamber to so limited an extent that the temperature of the gaseous medium is effectively increased by radiation of heat from the walls of the explosion chamber, and likewise cooling the main body of the explosion chamber with a cooling agent, the temperature of the cooling agent for the outlet end section being maintained higher than that of the cooling agent of the main body of the chamber.

6. The method according to claim 1, including

the step of subjecting the combustible charge in the chamber to an additional ignition which becomes effective at an instant after that predetermined for the ignition by the gaseous medium.

7. The method according to claim 1, including the step of conducting external heat to the igniting gaseous medium at the starting of the chamber to develop in such medium the temperature condition at which it effects ignition.

8. The method according to claim 1, including the step of preheating the outlet end section of the chamber with an agent of very high temperature at the starting of the chamber to develop in said gaseous medium the temperature condition at which it effects ignition.

9. The method according to claim 1, including the step of conducting external heat to the igniting gaseous medium at the starting of the chamber to develop in such medium the temperature condition at which it effects ignition, and heating the air prior to its admission into the explosion chamber during the starting of the chamber.

10. The method according to claim 1, including the step of preheating the agent which in normal operation serves to cool the outlet end section of the chamber, and likewise the air, at the starting of the chamber to develop in said gaseous medium the temperature condition at which it effects ignition.

11. The method according to claim 1, including the step of conveying the fuel by air toward the outlet end of the chamber, and dimensioning the interval during which the fuel is conveyed to the ignition place in correspondence with the control time determined by the cycle frequency of the process by suitably adjusting the fuel-carrying air velocity prevailing at the beginning of the formation of the combustible mixture.

12. The method according to claim 1, including the steps of conveying the fuel by air toward the outlet end of the chamber, and dimensioning the interval during which the fuel is conveyed to the ignition place in correspondence with the control time determined by the cycle frequency of the process by suitably adjusting the fuel-carrying air velocity prevailing at the beginning of the formation of the combustible mixture, and so adjusting the velocity of the fuel-carrying air that the ignition occurs when the inlet members close or are closed.

13. The method according to claim 1, including the step of conveying the fuel by air toward the outlet end of the chamber, dimensioning the interval during which the fuel is conveyed to the ignition place in correspondence with the control time determined by the cycle frequency of the process by suitably adjusting the fuel-carrying air velocity prevailing at the beginning of the formation of the combustible mixture, and opening the fuel inlet member later with reference to the instant of opening of the air inlet member according as the moment of ignition is retarded.

14. The method according to claim 1, including the steps of conveying the fuel by air toward the outlet end of the chamber, dimensioning the interval during which the fuel is conveyed to the ignition place in correspondence with the control time determined by the cycle frequency of the process by suitably adjusting the fuel-carrying air velocity prevailing at the beginning of the formation of the combustible mixture, and retarding the instant of ignition by opening the fuel inlet member only when the back pressure in the combustion chamber has reached a predetermined value, as the charging of the air proceeds.

15. The method according to claim 1, including the steps of conveying the fuel by air toward the outlet end of the chamber, dimensioning the interval during which the fuel is conveyed to the ignition place in correspondence with the control time determined by the cycle frequency of the process by suitably adjusting the fuel-carrying air velocity prevailing at the beginning of the formation of the combustible mixture, and operating the chamber at a cycle frequency at which the instant of ignition occurs after the air and fuel inlet members are closed.

16. In an explosion plant, the combination of a constant volume explosion chamber having air and fuel inlet mechanism at one end thereof and outlet mechanism for the explosion gases at the opposite end thereof, timing mechanism for so operating the air inlet and the outlet mechanism that the air inlet mechanism is opened while the outlet mechanism is still open following the expansion of the explosion gases, means for charging fuel under pressure to the fuel inlet mechanism after the charging of air into the chamber has begun, and means whereby the body of gas at the outlet end of the chamber is caused to have such an elevated temperature by the time that the advance portion of fuel reaches such body of gas, that ignition of the fuel and air mixture is effected along the surface of contact between such body of gas and the fuel and air mixture.

17. The combination set forth in claim 16, wherein the last mentioned means comprises a cooling jacket about only the outlet end of the chamber, and a pump for circulating through said jacket a cooling agent having so nearly the temperature of the wall at said outlet end that said end is subjected to a limited degree of cooling.

18. The combination set forth in claim 16, wherein said timing mechanism is constructed to cause closing of the outlet mechanism at such an advanced instant that enough residual gases are trapped at the outlet end section of the chamber to fill such section.

19. The combination set forth in claim 16, wherein the outlet end section of the chamber is of conical configuration, and wherein said timing mechanism is constructed to cause closing of the outlet mechanism at such an advanced instant that enough residual gases are trapped at the outlet end section of the chamber to fill such section.

20. The combination as set forth in claim 16, wherein the air inlet mechanism includes means for charging air of high pressure for conveying the fuel toward the outlet end of the chamber, and wherein the chamber is of such length that the fuel and air mixture reaches the place of ignition only after the fuel inlet member has closed.

21. In a constant volume explosion plant, the combination of an elongated constant volume explosion chamber having air and fuel inlet members arranged at one end thereof and an outlet member at the opposite end thereof, said inlet mechanism adapted to introduce periodically a charge of air which displaces the residual gases remaining in the chamber from the previous explosion, timing mechanism for said inlet and outlet members constructed to close the outlet member before the advance portion of incoming air

reaches the same, thereby to trap a body of gas at the outlet end section of the chamber, a jacket about the outlet end section of the chamber, a separate jacket about the main body of the explosion chamber, and means for circulating separate bodies of cooling agent through said jackets, the temperature of the cooling agent traversing the first jacket being higher than that of the cooling agent traversing the second jacket, whereby the chamber wall at the outlet end section is maintained at a higher temperature than the main body of the chamber and the temperature of the trapped body of gas is effectively increased by radiation of heat from said end section to the ignition temperature of the combustible mixture formed in the chamber.

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