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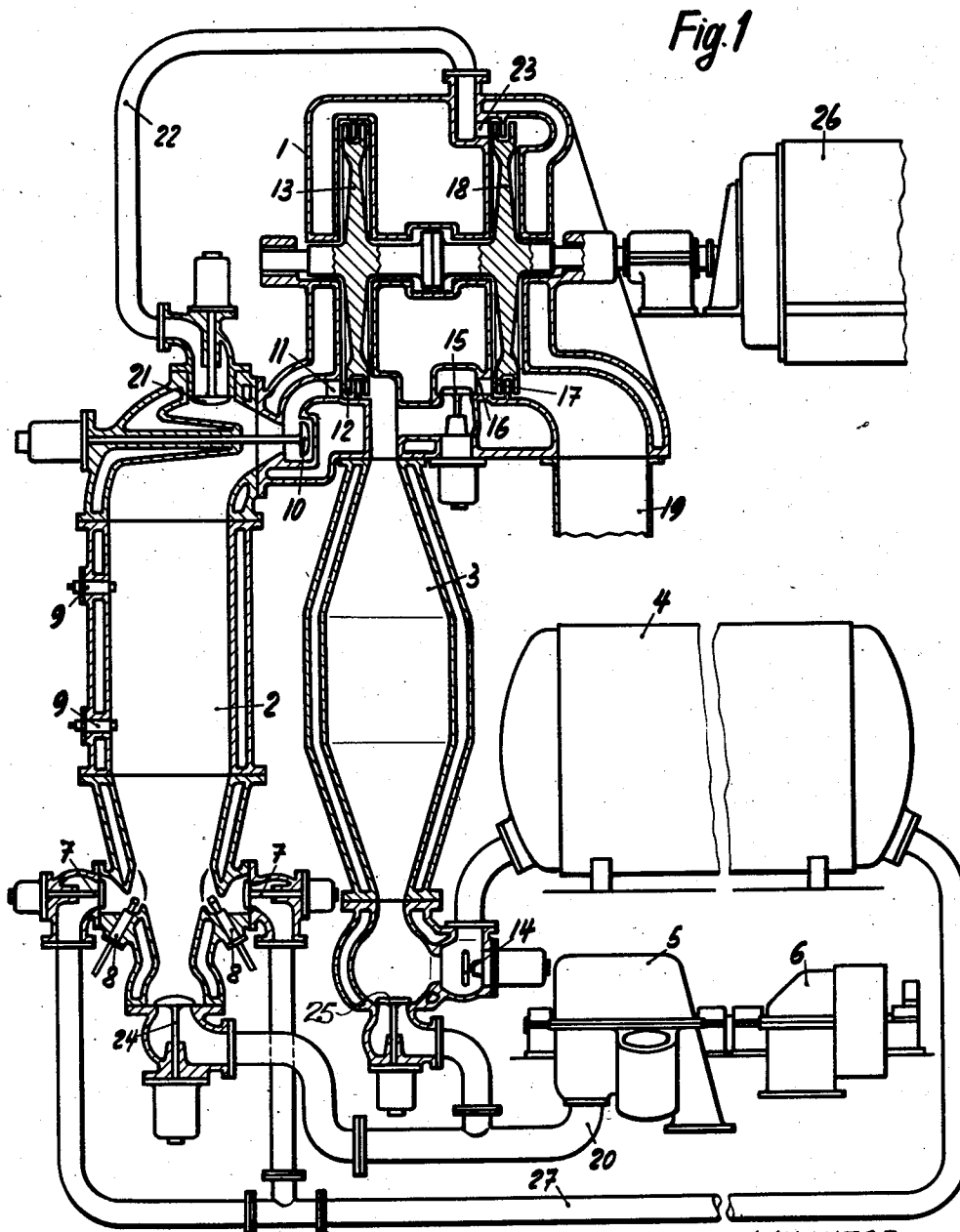
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2,081,149

METHOD AND APPARATUS FOR DIRECT COMPRESSION OF GASEOUS OR VAPOROUS MEDIUM

Filed Feb. 25, 1933

6 Sheets-Sheet 1



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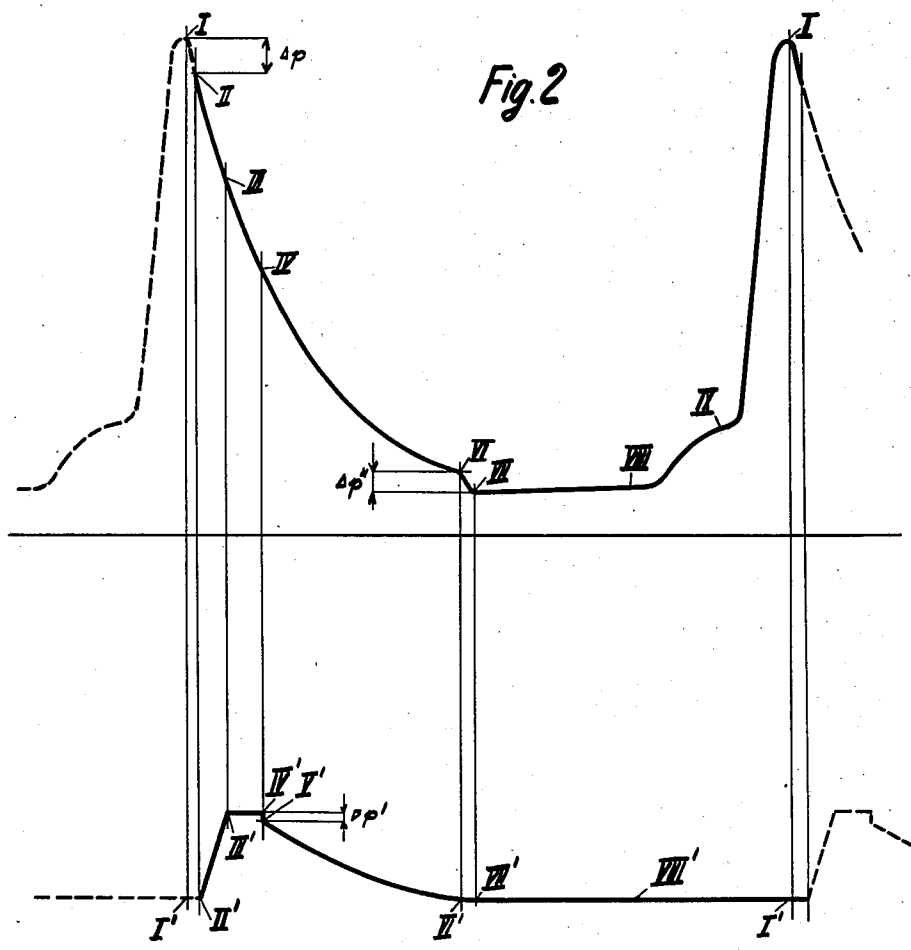
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6 Sheets-Sheet 2



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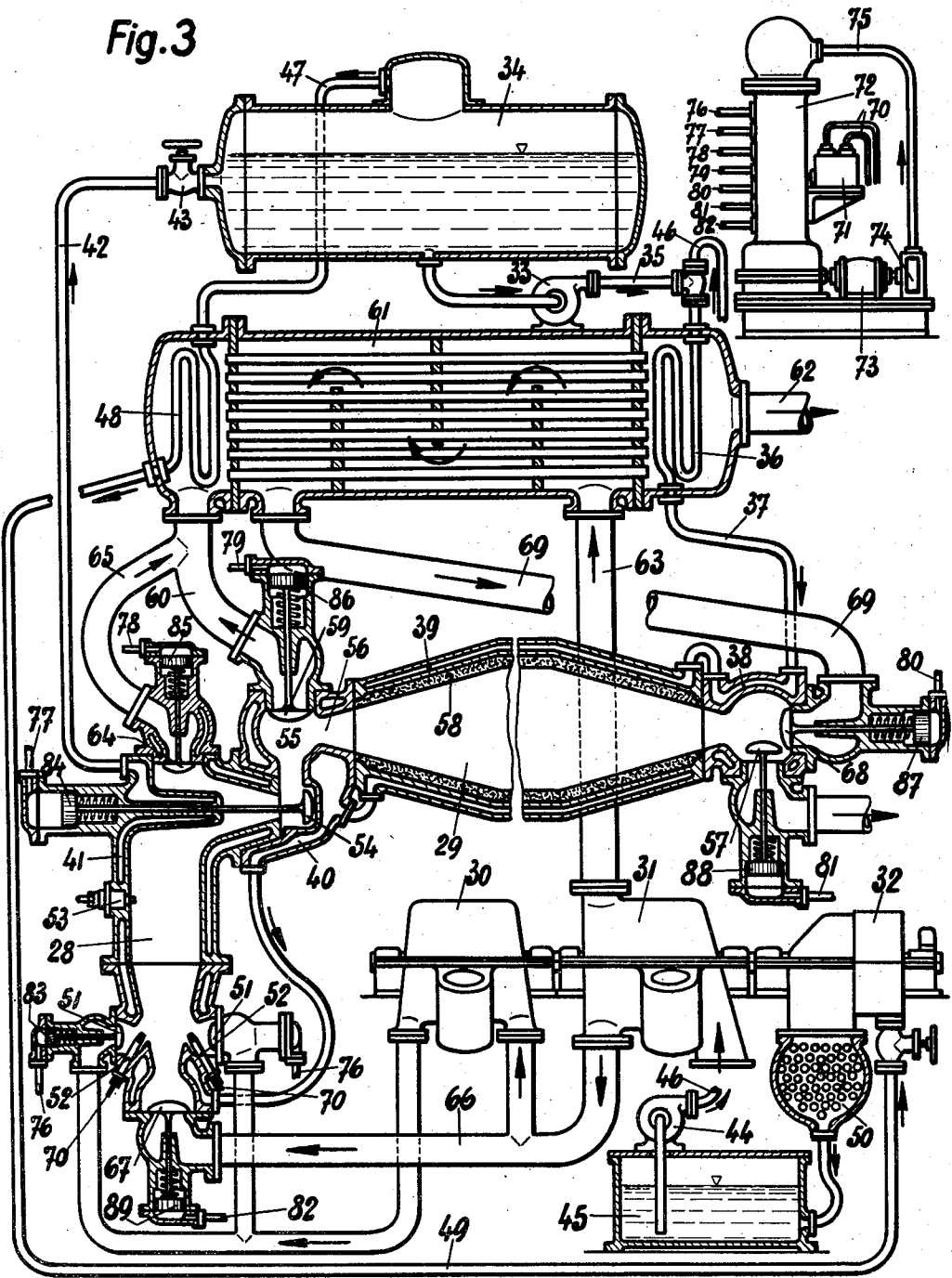
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6 Sheets-Sheet 3



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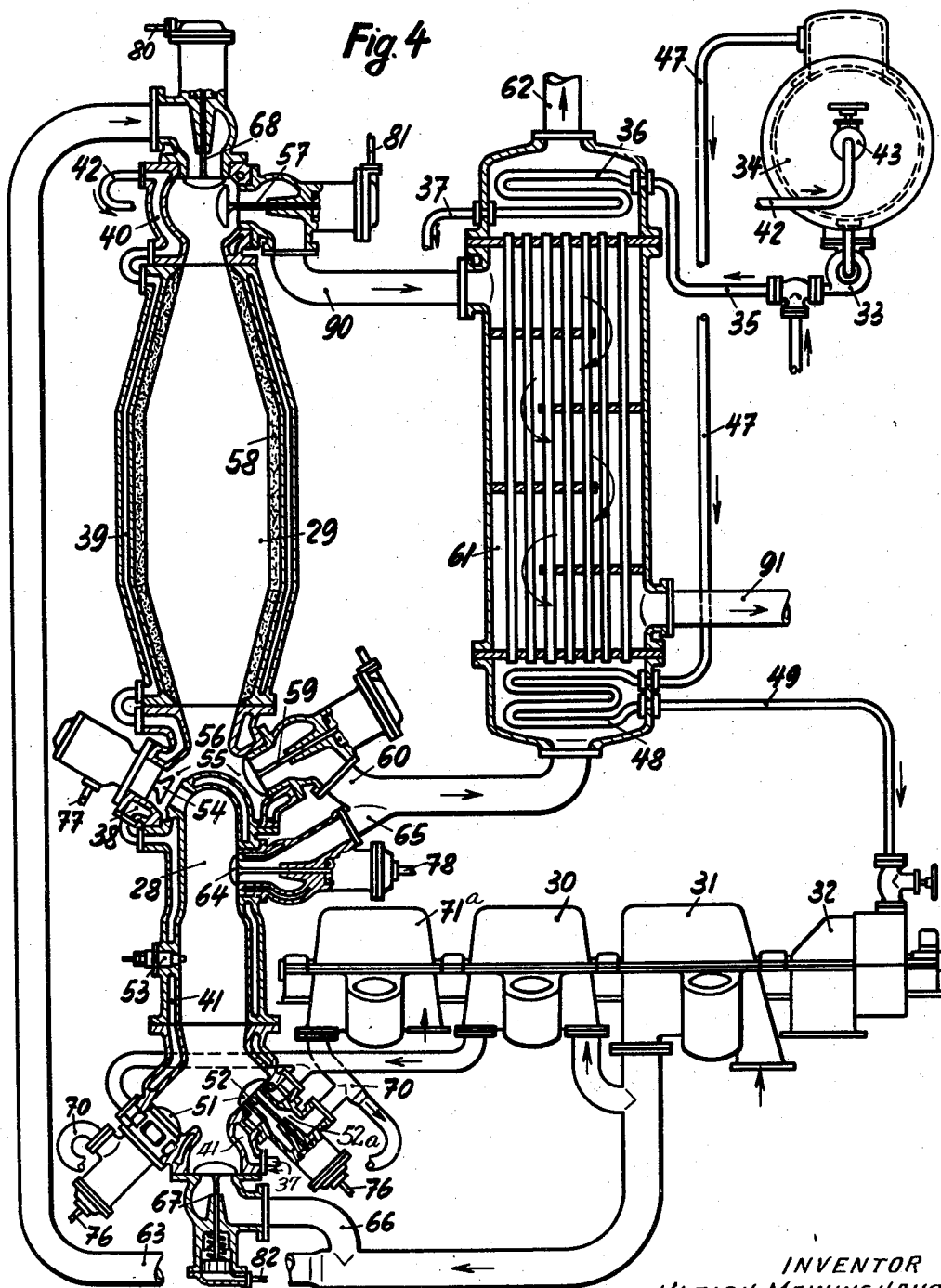
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6 Sheets-Sheet 4



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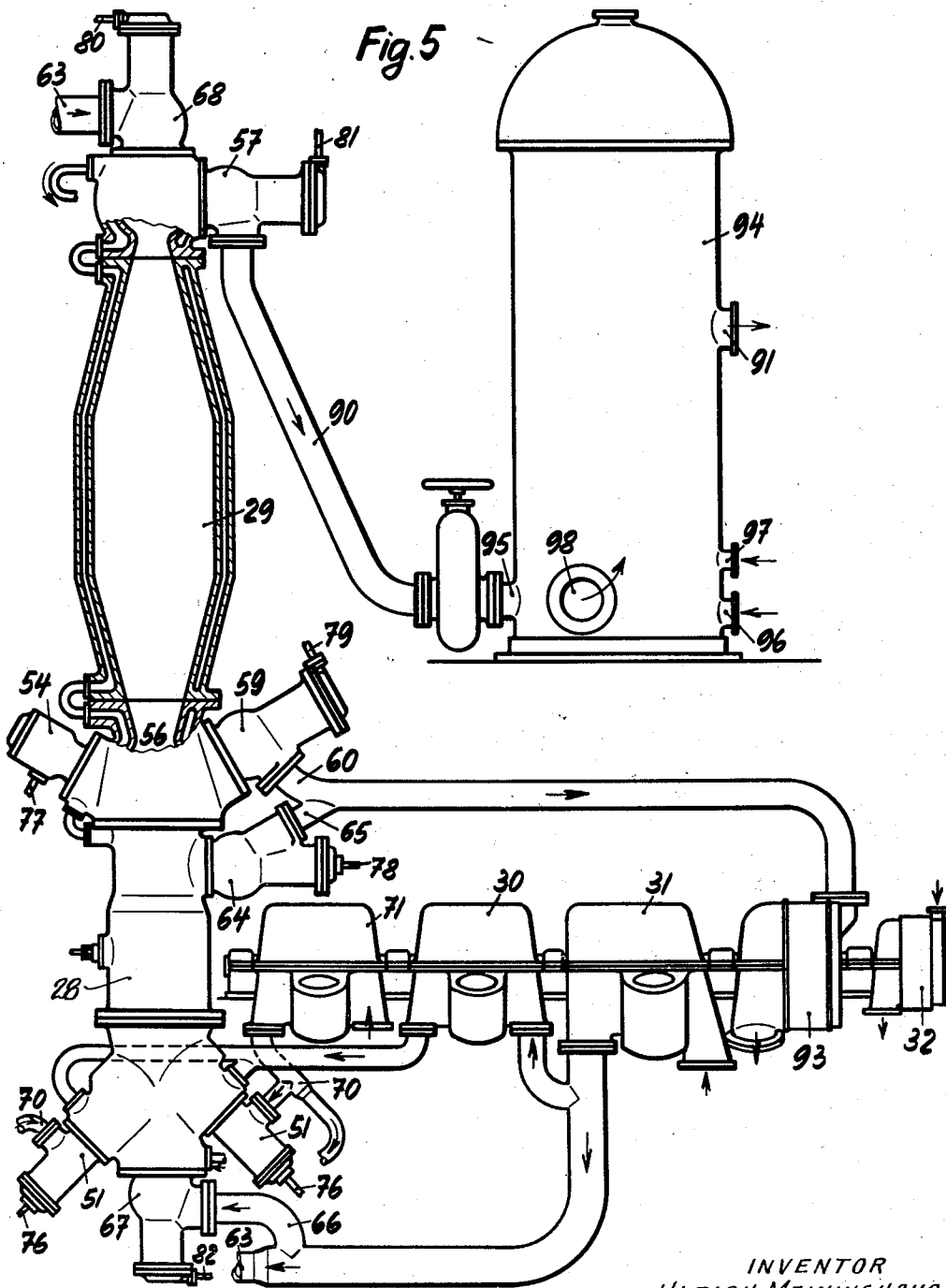
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6 Sheets-Sheet 5



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METHOD AND APPARATUS FOR DIRECT COMPRESSION OF GASEOUS OR VAPOROUS MEDIUM

Filed Feb. 25, 1933

6 Sheets-Sheet 6

Fig. 6

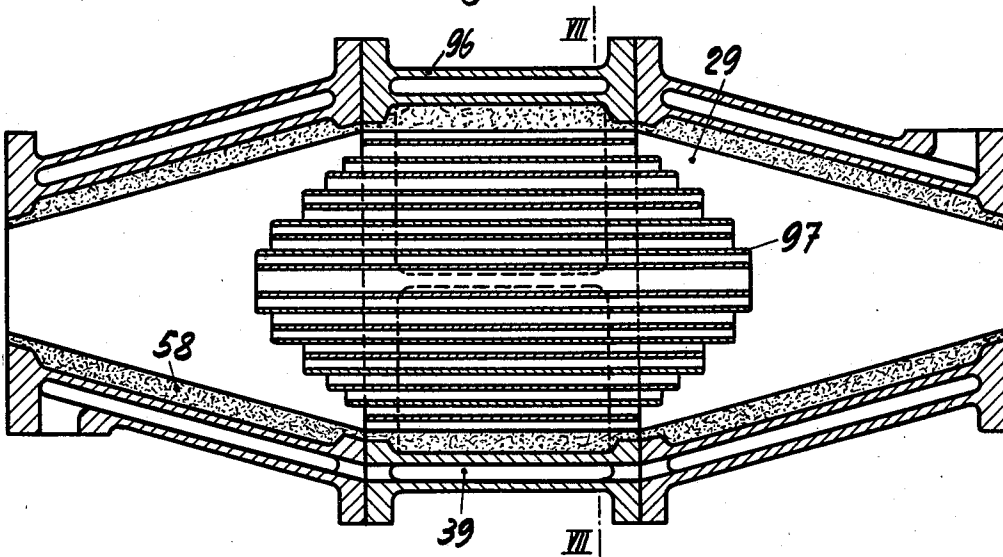
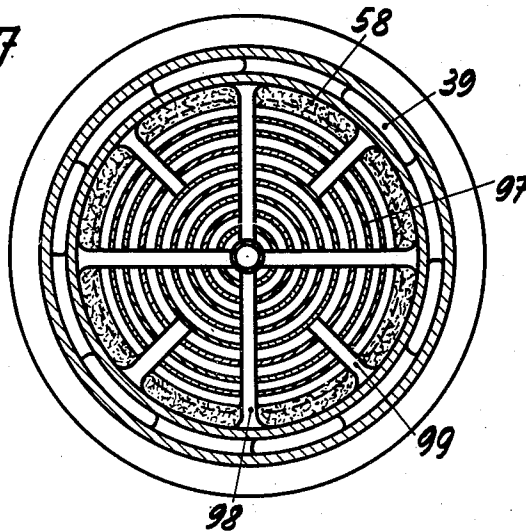


Fig. 7



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UNITED STATES PATENT OFFICE

2,081,149

METHOD AND APPARATUS FOR DIRECT
COMPRESSION OF GASEOUS OR VA-
POROUS MEDIUM

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Application February 25, 1933, Serial No. 658,609
In Germany March 1, 1932

29 Claims. (Cl. 60—41)

My invention relates to the compression of one gaseous or vaporous medium by means of another gaseous or vaporous medium of higher pressure, or of higher pressure and temperature, and has for its general object the provision of an improved process and apparatus for the compression, and if desired also the heating of one medium by another medium in a simple and efficient manner.

Described briefly, my invention involves the compression of one gaseous or vaporous medium by another gaseous or vaporous medium by the direct action of the later medium upon the first medium without the intermediary of mechanical energy transmitting means or energy converting devices, whereby the losses incident to the operation of mechanical and electrical mechanisms are at least in large part eliminated.

It is one of the novel and surprising features of my improved process and apparatus for the direct compression of one gaseous or vaporous medium by another such medium that although the masses of two such media are in direct contact, there is practically no mixing therebetween, or at most to a negligible degree. The present invention utilizes to this end a discovery which was made in the field of the explosion gas turbine, to the effect that it is possible to expel the residual gases of a constant volume explosion turbine by means of an expanding body of air of slightly higher pressure without causing mixing and heat exchange between the two gaseous media to an unpermissible degree. The measures for accomplishing such results include the proper shaping of the explosion chamber and of the passageway between the conduit which introduces the compressed medium and the main body of the chamber, and also the selection of a favorable relationship between the pressure of the compressing medium and the medium to be compressed. Thus, for example, by constructing the explosion chamber in the form of an elongated cylinder, and making the inlet end of the chamber which provides the passageway between the cylindrical walls of the chamber and the inlet conduit for the compressing medium, in the form of a conical member, it has proved possible to obtain a uniform distribution of the higher pressure medium throughout the whole cross-section of the chamber, so that such medium advances in the manner of a piston and shows no tendency to whirl and mix with the medium which was originally in the chamber and is compressed and then expelled from the chamber by such pressure medium. In order that the movement of the

necessary valves may produce no disturbances in the results so obtained, the passageways between such valves and the conical connections are made in the form of Venturi nozzles. There is thus created immediately behind the inlet valve of each explosion chamber a reduced inlet cross section defined by solid, immovable walls from which a constant widening of the conical passageway begins, which insures the uniform distribution of the high pressure medium through the chamber cross section and the formation of a planar dividing layer or zone between the two media, and hence the uniform advance and orderly compression and subsequent discharge of the medium originally in the chamber.

According to the present invention, therefore, a gaseous or vaporous medium is compressed by a second such medium of higher pressure in a compression chamber built along the lines of the explosion chamber just described. In addition to the discovery of this first condition for the solution of the problem, the invention involves the recognition that this fundamental condition is alone not sufficient to provide an economical direct compression process. If the events leading to the direct compression of a gaseous or vaporous medium by a higher pressure medium are considered, two sources of loss will be recognized which are of prime importance from the standpoint of the economy of the process. If a high pressure compressing medium flows into a chamber which is closed on all sides and is filled with a gaseous or vaporous medium of lower pressure which to be compressed, so that by its entry and advance such compressing medium compresses the medium in the chamber to a greater and greater degree and finally expels it through an opened outlet member when the end point of the compression is reached, it is unavoidable that the high pressure medium will expand upon entry into the chamber from its high pressure to a lower pressure; for its entry pressure must in every case be higher than the final pressure of the medium to be compressed, while the latter, on the other hand, still possesses the initial pressure upon entry of the compressing medium into the compression space. Consequently, upon entry of the compressing medium into the compression space, the energy corresponding to this difference in pressure is converted into high velocity. This velocity cannot, however, be reconverted into useful pressure energy since the pressure is given in the compression space.

A second source of loss occurs when the compression space, after the compression is com-

plete and the medium to be compressed is expelled, must be scavenged of the mass of the first medium remaining in the compression space. The residue of the compressing medium remains in the compression space at least under a pressure corresponding to the end pressure of the medium which has been compressed. This residue therefore still contains a considerable content of available energy. This energy becomes free when the residue of the compressing medium is expanded to the pressure at which it is displaced by a newly entering charge of medium to be compressed. As such pressure may be, and preferably is above atmospheric, a further loss occurs when the residue of compressing medium, after the compression is finished, is caused to expand to atmospheric pressure from such displacing or expulsion pressure.

The process proposed by the present invention for the direct compression of a gaseous or vaporous medium by means of an already compressed gaseous or vaporous medium, is accordingly further characterized by the feature that the energy of the high pressure compressing medium liberated during the compression of the medium to be compressed is effectively utilized; furthermore, there is utilized also the energy of the residual mass of compressing medium which is liberated during the discharge of such medium from the compression space, as during the displacement of such compressing medium from such space by the incoming new charge of medium to be compressed, it being understood that the compression chamber is alternately charged with medium to be compressed and with high pressure compressing medium. As will be described more in detail below, the quantity of energy in excess of that necessary for the production of a definite inflow velocity into the compression space is converted into mechanical energy in at least one turbine stage in advance of the compression space. The same occurs with the energy which the residue of the compressing medium contains when it leaves the compression space after the compression; this energy also may be utilized in at least one turbine stage. It is, of course, within the scope of the invention to utilize the same turbine stage for converting the energy of the compressing medium both before and after the compression by connecting such turbine by suitable switch devices first with the path of the compressing medium of high pressure flowing to the compression space, and then with the path of such medium after the compression. The compression of a gaseous or vaporous medium according to my improved process thus takes place without mechanical losses; there occur only flow and heat interchange losses but to so small a degree that their influence upon the economy of the compression process can be neglected. The process has particular significance in connection with the compression of comparatively small quantities of fluid to a high pressure, as in such cases the losses in compressors driven by power machines become extraordinarily high. My improved process makes possible, further, in particular in combination with already existing turbine stages, a very light construction for the devices for carrying out the compression, as containers or chambers of constant volume and of cylindrical form, in which the compression space is located, can be kept low in weight, in which connection it should be borne in mind that the whole driving apparatus is dispensed with.

A highly suitable apparatus for carrying out the present invention is presented by explosion gas turbine plants, as compressed gases are generated in such plants by periodic explosion of combustible mixtures and are thus available for the compression of another gaseous or vaporous medium. In a further development of the present invention it is therefore proposed to generate the compressed medium, which is to act as the compressing agent, by periodic explosion of a combustible mixture. An especially advantageous mode of carrying out the process results when the combustion gases produced by explosion compress and expel a medium to be compressed, preferably air, introduced into a compression space, while simultaneously filling such space; the liberated combustion gas energy corresponding to the pressure drop from the explosion pressure to the pressure of admission into the compression chamber being converted into mechanical output in one or more turbine stages arranged between the explosion chamber and the compression chamber, whereupon the combustion gases are discharged from the compression chamber, if desired with simultaneous filling of the compression space with a new charge of medium to be compressed, the gases being expelled by such medium, the residual available combustion gas energy being then converted into mechanical energy in one or more turbine stages arranged in the path of the gases beyond the compression chamber. The explosion chamber may with advantage remain shut off from the compression space during the expulsion of the combustion gases from the compression space by the medium to be compressed, so that the possibility is afforded of expelling the combustion gas residue from the explosion chamber, preferably through a turbine stage, simultaneously with the expulsion of the combustion gases from the compression space.

A particularly suitable application of the present invention is in multi-stage explosion gas turbines in which pressure equalizers are arranged between the individual turbine stages, and especially between the first or explosion turbine and the subsequent turbine, for equalizing the pressure of the explosion gases. This pressure equalizer or equalizers can be built in the form of compression spaces, so that in a further development of the invention it is proposed to effect the compression of a gaseous or vaporous medium in pressure equalizing chambers arranged between explosion gas turbine stages with the aid of the explosion gases whose pressure is to be equalized.

The invention will now be described with the aid of the accompanying drawings which show by way of example an arrangement for carrying out the invention. In said drawings,

Fig. 1 shows schematically the complete arrangement of apparatus for carrying out the process in accordance with the invention with production of mechanical energy, the explosion and compression chambers and the turbine stages being shown in vertical longitudinal section;

Fig. 2 shows diagrams illustrating the course of the pressure variations in the explosion and compression chambers;

Fig. 3 represents schematically an apparatus for carrying out my improved process with increased heat transfer, the explosion and compression chambers as well as the heat exchangers being shown in vertical longitudinal section;

Fig. 4 shows a construction similar to that of

Fig. 3 where the additional heat exchanger is arranged behind the compression chamber;

Fig. 5 represents a modification of Fig. 4, showing a continuous current gas turbine behind the compression chamber; and

Figs. 6 and 7 illustrate by way of example how the exchange of heat in the compression chamber may be increased by mechanical means, Fig. 6 giving a longitudinal section through the compression chamber on an enlarged scale, and Fig. 7 a section along the line VII—VII of Fig. 6.

In Fig. 1 the numeral 1 indicates the housing of the rotor of an explosion gas turbine plant which includes a constant volume explosion chamber 2 and the turbine wheels 13 and 18. The compression chamber is shown at 3, a supply tank for compressed air at 4, an air compressor at 5, and a steam turbine for driving the air compressor at 6. The two turbine rotors 13 and 18 are coupled to an electric generator 26 which receives the mechanical output of the plant. The operation of the important elements of the plant so far described is as follows:

The explosion chamber 2 is first charged by the air charging valves 7 with compressed air from the tank 4 through conduit 27, while fuel is introduced through the injection valves 8. There is thus formed in the chamber at the termination of the charging period a combustible mixture which is ignited by the spark plugs 9, the nozzle or exhaust valve 10 being closed. After the explosion the nozzle valve 10 is opened and discharges the high pressure, high temperature combustion gases into the expansion nozzle 11; the gases are directed by the latter against the blades 12 of the rotor 13 of the first turbine stage. The combustion gases which have been only partially expanded in the nozzle 11 and bladings 12 of the turbine rotor then flow into the elongated compression chamber 3, and because of the conically formed inlet portion of such chamber, which leads to the cylindrical main body portion thereof, the gases are subjected to a continual diffusion over the whole chamber cross-section so that they compress, in the manner of a piston, the already pre-compressed air existing in such chamber. At the instant in which this further compression of the air in the chamber 3 has reached a predetermined end pressure, the valve 14 is opened, so that the compressed air is forced into the supply tank 4 under the action of the advancing combustion gases. During this process the valve 15 is closed. As soon as the air has been substantially completely displaced from the chamber 3 by the combustion gases and forced into the tank 4, the valve 14 closes and the valve 15 is opened. The combustion gases now filling the chamber 3, which are at least at the pressure of the air in the supply tank 4, now flow through the nozzle 16 and impinge the blades 17 of the rotor 18. At the same time the combustion gases expand out of the explosion chamber 2 through the open nozzle valve 10, nozzle 11 and blading 12; they mix with the combustion gases expanding in the compression chamber 3 and flow together with such gases through nozzle 16 to the blading 17 and then leave the turbine through the exhaust pipe 19. As soon as the pressure of the combustion gases still contained in the compression chamber 3 has fallen to the pressure of the scavenging air delivered by the compressor 5 and the conduit 20, the nozzle valve 10 of the explosion chamber 2 is closed while the auxiliary discharge valve 21 is simultaneously

opened. The residual combustion gases now flow from the explosion chamber through the conduit 22 to the nozzle 23 by which they are directed against the blading 17 of the lower stage rotor 18. As a result the pressure of the residual combustion gases in the explosion chamber 2 falls to the scavenging air pressure of the compressor 5 and the conduit 20. The valves 24 and 25 are now opened. The scavenging air entering the explosion chamber 2 and compression chamber 3 at the scavenging air pressure existing in the conduit 20 now drives the residual combustion gases of these chambers before it and pushes them through the associated nozzles 23 and 16, respectively, to the blading 17 of the rotor 18. After the scavenging is complete, that is, after substantially all of the combustion gases have been driven out of the chambers, the valves 21 and 15 are closed and likewise the scavenging air valves 24 and 25. Both the explosion chamber 2 and the compression chamber 3 are filled with pure, pre-compressed air so that upon the introduction of charging air from conduit 27 and valves 7 (i. e. air of a higher pressure for supporting the combustion) and of the fuel the combustible mixture for the next explosion is formed in the explosion chamber. The above-described cycle of events is then repeated.

Fig. 2 shows diagrammatically the course of the pressure variations with respect to time in the explosion and compression chambers. The ordinates of both diagrams indicate the pressures, while the abscissae indicate time. At the point I in the upper diagram the explosion in the explosion chamber is completed and the highest pressure is attained. At this instant the nozzle valve 10 is opened. There occurs at first a definite fall in pressure Δp , caused by the filling of the space between the valve 10 and nozzle 11 with gas. At the point II the flow of gas into the compression chamber 3 begins, so that in such chamber the pressure rises from the point II' on the lower diagram, while at the same time the pressure in the explosion chamber 2 falls in accordance with the upper diagram. At the point III' of the lower diagram the required end compression is attained in the compression chamber, whereupon the valve 14 is opened to permit the compressed air to discharge into the storage tank 4. The section III'—IV' of the lower curve corresponds to the transfer of the compressed air into the tank 4. At the point IV' the air valve 14 closes and the nozzle valve 15 opens. Upon opening of the valve 15 there occurs a sudden pressure drop $\Delta p'$ from the point IV' to the point V' as the space between the nozzle valve 15 and nozzle 16 must first be filled with gas. At the point V' the expansion from the compression chamber 3 begins, such expansion occurring simultaneously with the continuing expansion from the explosion chamber 2 through nozzle 16 in accordance with the upper diagram. At the instant VI', the pressure in the compression chamber 3 has fallen to the scavenging air pressure of the rotary compressor 5. The scavenging air valve 25 is now opened and likewise the exhaust valve 21 of the explosion chamber 2, while at the same time the nozzle valve 10 of the latter closes. Upon the opening of the valve 21 there again occurs a fall in pressure in the explosion chamber 2 which is represented by $\Delta p''$, because the space between the valve 21 and nozzle 23 must first be filled with gas. After the fall in pressure is completed, the scavenging air valve 24 opens at the instant

VII. The scavenging of the compression chamber 3 now takes place with the aid of the air admitted by the scavenging air valve 25, the residual gases in such chamber being expelled through valve 15 and nozzle 16; at the same time there occurs the scavenging of the explosion chamber 2 by means of the scavenging air introduced through valve 24, the displaced gases being discharged through valve 21 and nozzle 23. The scavenging of the explosion chamber is terminated at approximately the instant VIII, while the scavenging of the compression chamber ends at approximately the instant VIII'. At the instant VIII or VIII' the valves 21, 24 or 15, 25 close. At the same time the valves 7 of the explosion chamber are opened, such valves charging air into the chamber as fuel is simultaneously injected by the injection valves 8. At the instant IX a combustible mixture is present in the explosion chamber 2, so that ignition can now take place with the aid of the spark plugs 9. The explosion now takes place and at the instant I the highest combustion gas pressure is reached. The cycle just described is now repeated.

It is within the scope of the invention to utilize in other ways the energy of the compressing medium which becomes liberated during the compression of the medium to be compressed than for the production of mechanical energy. For example, there are cases in which the medium to be compressed is to be utilized at high temperature. The present invention accordingly contemplates also the conversion of that quantity of energy which is in excess of the amount required for the production of a definite inflow velocity into the compression space, into sensible heat by whirling and to transfer a large part of such heat by radiation and conduction to the medium to be compressed. This transfer may occur very advantageously by radiation and conduction by alternating impingement of the heat transfer surfaces which may, for example, be the walls of the compression chamber itself.

Arrangements of the type above described are shown in Figs. 3 to 7. In Fig. 3 the explosion chamber is indicated at 28, the compression chamber at 29, the compressor for the supercharging air at 30, the compressor for scavenging air at 31, and the steam turbine for driving the compressors at 32. The cooling of the parts heated by the combustion gases is accomplished by a circulating body of water which is circulated under pressure by the pump 33. The pump sucks the water from the steam boiler 34 and forces it through the conduit 35, the pre-heating coil 36, conduit 37, valve housing jacket 38, cooling jacket 39 of the compression chamber 29, valve space 40 between the explosion chamber 28 and the compression chamber 29, cooling jacket 41 of the explosion chamber 28, and finally through the conduit 42 and a throttling member 43 back to the boiler 34. In this circuit the water is gradually heated far above its normal boiling point and upon partial decompression in the throttling member 43 of the boiler 34 a part of it is converted into steam. The steam formed in the boiler 34, after doing work and being re-condensed, is added again to the conduit 35 through conduit 46 by means of the pump 44 which feeds it from the storage tank 45. The steam separated in the boiler 34 passes through the conduit 47 to the superheating coils 48 and into the conduit 49 and operates the steam turbine 32 which drives the compressors 30 and 31. The exhaust

steam is precipitated in the condenser 50 and flows to the condensate tank 45. The method of operation of the parts just described is as follows:

The explosion chamber 28 is first charged with air from the compressor 30 through the air valves 51, while fuel is introduced through the valves 52. The explosive mixture in the chamber is then ignited by the spark plug 53. After the combustion is complete, the valve 54 is opened and the high pressure, high temperature combustion gases then discharge into the whirling space 55; the gases partially expanded in such space 55, which gases, because of the destruction of the inherent flow energy thereof, have greatly increased in temperature, then flow through the inlet end 56 which is built in the form of a Venturi nozzle, into the elongated compression chamber 29. Due to the conical passageway leading to the main cylindrical portion of the chamber, the gases undergo a constant diffusion throughout the whole chamber cross section so that they compress, in the manner of a piston, the pre-compressed and pre-heated air contained in such chamber. At the instant at which this further compression of air in the compression chamber 29 has reached a predetermined end pressure, the valve 57 opens, so that the compressed air is discharged to a place of storage or use (not shown) under the action of the advancing combustion gases. In this compression and displacement process the walls of the compression chamber 29, which are lined with a heat-resisting lining 58, are swept and heated by the hot combustion gases, so that in the first portion of the next working cycle the introduced air which is to be compressed is effectively heated by radiation and conduction. At the same time, as a result of the increase in temperature of the combustion gases through the whirling, an effective heat transfer from the combustion gases to the air takes place by radiation and conduction at the piston-like dividing layer or zone between the two media. In this way the air can be heated to a temperature as high as that which is attained, for example, in the known "Cowpers" or regenerative air preheaters for blast furnaces (see "Huettenkunde", "Taschenbuch fuer Eisenhuettenleute" Berlin, 1910, Wilhelm Ernst & Sohn, page 505).

During the above-described events the valve 59 is kept closed. As soon as the air has been displaced from the chamber 29 by the combustion gases and has been driven out toward the place of use through the open valve 57, the latter is closed and the valve 59 opened. The combustion gases filling the compression chamber at a pressure at least equal to the compression end pressure of the expelled air, now flow through the conduit 60 to the heat exchanger 61 which they leave by the exhaust pipe 62. As soon as the pressure of the gases remaining in the compression chamber 29 has fallen to approximately the pressure of the scavenging air delivered by the compressor 31 into the conduit 63, the valve 54 of the explosion chamber 28 closes while the valve 64 is simultaneously opened. The residual combustion gases from the explosion chamber now flow through the connecting conduit 65 to the heat exchanger 61 which they likewise leave through the pipe 62. The pressure of the residual gases in the chamber 28 thus falls to the pressure of the scavenging air delivered by the rotary compressor 31 into the conduit 66. The valves 67 and 68 are

now opened. The scavenging air at the scavenging air pressure of the conduit 66 entering the explosion chamber 28, and the scavenging air entering the compression chamber 29 through the conduit 63, the heat exchanger 61 and the conduit 69 now drives the residual combustion gases from these chambers before it and pushes them out toward the heat exchanger 61 through the associated valves 64 and 59 and conduits 65 and 60, respectively. After the scavenging is complete, that is, after substantially all of the residual combustion gases have been expelled from the chambers, the valves 64 and 59 close, as do likewise the scavenging air valves 67 and 68. Both the explosion chamber 28 and the compression chamber 29 are now filled with pure pre-compressed air at scavenging air pressure, and upon introduction into the explosion chamber of the higher pressure air fed by the compressor 30, and the admission of fuel, the explosive mixture for the next explosion is formed in such chamber. The periodic fuel admission to the fuel injection valves 52 is effected through the conduits 70 by the fuel pump 71, such pump being driven by the motor 73 simultaneously with the oil-distributor 72 which operates the valves in the proper sequences. The control of the valves is effected through such distributor by means of oil under pressure in known manner, the oil being fed by a pump 74 and conduit 75 to the distributor by which it is distributed to the various pressure oil conduits 76 to 82 leading to the corresponding actuating pistons 83 to 89 of the valves 51, 54, 64, 59, 68, 57 and 67. The oil pressure acts upon the pistons in known manner against the opposing influence of a spring (not shown) in each case.

In Fig. 4 the same numerals designate the same parts as in Fig. 3. There is a small variation in the flow of the cooling medium over that shown in Fig. 3, the cooling medium passing from the pipe 37 first through the cooling chamber 41 of the explosion chamber 28 and then through the cooling chambers 38, 39 and 40 of the compression chamber 29, leaving the chamber 40 through pipe 42. Furthermore a gaseous fuel for charging the explosion chamber is used which is compressed in the centrifugal compressor 71a (replacing the oil pump 71 of Fig. 3) and is charged through pipes 70 and special channels 52a of the air valves 51 (replacing the injection apparatus 52 of Fig. 3). But the main change in comparison with Fig. 3 is represented by the different arrangement of the heat exchanger 61. In Fig. 4 the finally compressed air leaving the compression chamber 29 through the valve 57 flows through pipe 90 into the heat exchanger 61 where it is subjected to a further heating and is then conducted to the point of use through pipe 91. In Fig. 3 the air flows through the heat exchanger before entering the compression chamber 29 which arrangement is preferred in cases where such a high temperature of the compressed air is desired that the heat exchanger 61 could not endure it if built with ordinary materials. The arrangement of Fig. 4 requires less work to be expended for the compression as air of low temperature and accordingly small specific volume is compressed in the compression chamber 29 but the final air temperature will be not as high as in the arrangement of Fig. 3.

Fig. 5 shows a modified arrangement which is

particularly suitable where low work of compression and high final air temperatures are desired. The numerals refer to the corresponding parts of Figs. 3 and 4, but the heat exchanger 61 is dispensed with and the exhaust gases of the explosion chamber 28 and the compression chamber 29 flow through pipes 65 and 60 into pipe 92 and to the gas turbine 93. Thus the energy contained in the exhaust gases is used for driving the compressors 30, 31 and 71a, preferably together with the steam turbine 32. The finally compressed air leaving the compression chamber through valve 57 and pipe 90 is conducted to a heat exchanger 94. This heat exchanger may be of the "Cowper" type above referred to through which air to be heated and entering through connection 95 leaving at 91 flows for a certain period of time while alternately a fuel as blast furnace gas is burnt inside of the heat exchanger heating up the material of high heat resistance and capacity, the fuel and combustion air entering at 96 and 97, the combustion gases being discharged at 98 in well known manner.

In all arrangements shown it may be necessary to increase the heat transfer between the air to be compressed and the explosion gases inside of the compression chamber. Figs. 6 and 7 show such an arrangement which provides an increased surface and increased mass for exchanging and storing the heat. The compression chamber 29 is shown with a somewhat shortened cylindrical part 96 to permit illustration on an enlarged scale. The compression chamber may be again lined with heat resisting or insulating material 98 and provided with cooling jackets 99. Preferably in the cylindrical part 96 sheets 97 of a heat resisting material as special steel or other alloy are arranged in a way that does not disturb the flow of the gases, especially does not impair the piston effect during compression and scavenging. The sheets 97 may be arranged in circular shape as shown and supported by means of radially disposed ribs 98 and 99. The form shown gives a very effective shape to the spaces between the sheets for obtaining a good rate of heat transfer by a large surface exposed to the different media and a great mass for storage of exchanged heat between the cycles of the process and sustains the piston effect as described above.

It will be understood that suitable valve-timing devices, such as hydraulic distributors, will be used with the apparatus shown in Figs. 1, 4 and 5, for example, the distributor 72 shown in Fig. 3. It will be noted that the valve controlling fluid conduits in Figs. 4 and 5 are numbered corresponding to the conduits leading from the distributor 72 in Fig. 3. These distributors are well known, being shown in United States Patents Nos. 877,194, 1,763,154, and 1,969,753, and no invention is claimed therein.

The present invention is not limited to the use of simple gases or vapors for the compressed medium and the medium to be compressed. It is obvious that gas mixtures, vapor mixtures, and gas-vapor mixtures can be utilized as the high pressure (compressing) medium and also as the medium to be compressed.

I claim:

1. The method of compressing a gaseous or vaporous medium by means of a gaseous or vaporous medium of higher pressure, which comprises developing the medium of higher pressure within one space, introducing such medium into a separate space containing the medium of lower pressure, and intermediately reducing the velocity

of the high pressure medium so as to insure the formation of a substantially planar fluid dividing zone between the two media and thereby effect direct compression of the lower pressure medium by expansion of the other medium while preventing mingling of the two media to any considerable degree.

2. The method of compressing a gaseous or vaporous medium by means of a gaseous or vaporous medium of higher pressure, which comprises developing the medium of higher pressure within one space, abstracting excess energy from such medium, introducing the latter into a separate space containing the medium of lower pressure and forming a substantially planar fluid dividing zone between the two media and thereby effecting direct compression of the lower pressure medium by expansion of the other medium.

3. The method according to claim 2, wherein the abstracted energy is converted into sensible heat and is transferred at least in part to the medium to be compressed.

4. The method according to claim 1, including the step of conducting the two media alternately along heat exchange surfaces, whereby sensible heat of the expanded medium is transferred to the medium to be compressed.

5. The method according to claim 1, wherein the medium of higher pressure is also of higher temperature, and wherein the medium to be compressed is preheated by the compressing medium prior to the compression.

6. The method according to claim 1, including the step of discharging the expanded compressing medium separately of the medium to be compressed and utilizing the energy liberated during the discharge of the expanded medium from the compression space for generating power.

7. The method according to claim 2, wherein the abstracted energy is converted into mechanical energy.

8. The method according to claim 2, wherein the compressed medium is also of a higher temperature than the medium to be compressed, said method including the step of utilizing the abstracted energy to increase the heat transfer to the medium to be compressed by partially expanding the compressed medium before the compression and thereby increasing the velocity thereof, and then converting such velocity into whirls with resultant increase in the temperature of such compressed medium prior to the compression step.

9. The method according to claim 1, wherein the compressed medium is generated by periodic explosion of combustible mixtures under constant volume.

10. The method of compressing a gaseous or vaporous medium by means of a gaseous or vaporous medium of higher pressure, which comprises exploding a combustible mixture in an explosion chamber under constant volume, discharging the explosion gases from the chamber and utilizing part of the pressure energy of the explosion gases for generating power, then introducing the still highly compressed gases into a compression chamber filled with the medium to be compressed, and forming a planar fluid dividing zone between the two media and thereby effecting compression and discharge of the medium to be compressed by the explosion gases, then introducing a charge of medium to be compressed into the compression chamber and simultaneously discharging the expanded explosion

gases, and utilizing the energy of the gases discharged from the compression chamber.

11. The method as set forth in claim 10, wherein part of the energy of the explosion gases is converted into mechanical energy before the gases enter the compression chamber, and wherein the residual energy of the expanded explosion gases discharged from the compression chamber is likewise converted into mechanical energy.

12. The method of compressing a gaseous or vaporous medium by means of a gaseous or vaporous medium of higher pressure, which comprises exploding a combustible mixture in an explosion chamber under constant volume, discharging the explosion gases from the chamber into a whirling space wherein part of the pressure of such gases is converted into sensible heat, introducing the still highly compressed gases into a compression chamber filled with the medium to be compressed and forming a planar fluid dividing zone between the two media and thereby effecting compression and discharge of the medium to be compressed by the explosion gases, introducing a charge of medium to be compressed into the compression chamber and simultaneously discharging the expanded explosion gases, and conducting the expanded explosion gases leaving the compression chamber in heat exchange relation with the medium to be compressed.

13. The method according to claim 10, wherein the explosion chamber is kept closed from the compression chamber during the expulsion of the expanded explosion gases from the compression chamber by the new charge of medium to be compressed.

14. The method according to claim 10, wherein, during the expulsion of the expanded explosion gases from the compression chamber, the residual explosion gases are driven out of the explosion chamber.

15. The method according to claim 1, wherein the medium to be compressed is pre-compressed before it is acted upon by the medium of still higher pressure.

16. The method according to claim 10, wherein pre-compressed air is charged into the explosion and compression chambers to scavenge the same.

17. The method according to claim 10, wherein air is compressed by the explosion gases and is introduced into the explosion chamber as charging air.

18. The method of compressing a gaseous or vaporous medium by means of a gaseous or vaporous medium of higher pressure, which comprises exploding a combustion mixture in an explosion chamber under constant volume, discharging the explosion gases from the chamber and introducing them under high pressure into a compression chamber filled with the medium to be compressed and forming a planar fluid dividing zone between the two media and thereby effecting compression and discharge of the medium to be compressed by the explosion gases, then introducing a charge of medium to be compressed into the compression chamber and simultaneously discharging the expanded explosion gases, utilizing the energy of the gases discharged from the compression chamber, and abstracting heat from the walls of the explosion and compression chambers for generating mechanical energy and pre-compressing the medium to be compressed with such energy.

19. The method of compressing a gaseous or vaporous medium by means of a gaseous or va-

porous medium of higher pressure, which comprises exploding a combustible mixture in an explosion chamber under constant volume, expanding the explosion gases in a plurality of turbine stages, charging the gases exhausting from a turbine stage into a compression chamber connecting such stage with the next stage and serving as a pressure equalizer for such gases and thereby compressing the medium to be compressed in such equalizer by means of said exhausting explosion gases, periodically introducing the medium to be compressed into, and withdrawing the same in compressed condition from the compression chamber, and directing the partially expanded combustion gases expelled from the compression chamber by the incoming charges of medium to be compressed into the next turbine stage.

20. Apparatus for the direct compression of one gaseous or vaporous medium by another, comprising a constant volume explosion chamber equipped with devices for charging air and fuel thereto and for exploding the combustible mixture therein, an elongated compression chamber connected with such explosion chamber, the ends of said compression chamber being of conical form, said conical ends adapted to produce a piston-like fluid dividing zone between the two media, means for charging the medium to be compressed into the compression chamber and means for withdrawing the same therefrom in compressed condition.

21. Apparatus according to claim 20, wherein the ends of the compression chamber are shaped as diffusers of Venturi nozzles.

22. Apparatus for the direct compression of one gaseous or vaporous medium by another, comprising a constant volume explosion chamber equipped with devices for charging air and fuel thereto and for exploding the combustible mixture therein, an elongated compression chamber connected with such explosion chamber, the ends of said compression chamber being of conical form, said conical ends adapted to produce a piston-like fluid dividing zone between the two media, means for charging the medium to be compressed into the compression chamber, a compressor for pre-compressing the medium to be compressed, a conduit for withdrawing such medium in more highly compressed condition from the compression chamber, and a conduit for withdrawing the expanded explosion gases from such chamber.

23. Apparatus for directly compressing a gaseous or vaporous medium by high pressure combustion gases, comprising a multi-stage explosion gas turbine including a constant volume explosion chamber, valve mechanism for discharging explosion gases under pressure from said chamber into the first turbine stage, a compressing chamber arranged between the first and second turbine stage and adapted to receive the explosion gases exhausting from the first turbine stage, means for periodically introducing the medium to be compressed into said compression chamber, means for discharging said medium from said chamber in compressed condition, and a conduit for receiving the expanded combustion gases as they are expelled by the charges of medium to be compressed entering the compression chamber and conducting them to the second turbine stage.

24. Apparatus for the direct compression of one gaseous or vaporous medium by another, comprising a constant volume explosion chamber

equipped with devices for charging air and fuel thereto and for exploding the combustible mixture therein, an elongated compression chamber connected with such explosion chamber, the ends of said compression chamber being of conical form, said conical ends adapted to produce a piston-like fluid dividing zone between the two media, means for charging the medium to be compressed into the compression chamber, a turbine stage arranged in the path of the gases between the explosion and compression chambers, a turbine stage arranged to receive the explosion gases discharging from the compression chamber, a compressor for delivering to said compression chamber the medium to be compressed in a pre-compressed condition, a storage tank connected with the compression chamber to receive the medium to be compressed, hydraulically operated valves controlling the inlets and outlets of said compression chamber, and a distributor for timing the operation of said valves.

25. Apparatus for the direct compression of one gaseous or vaporous medium by another, comprising a constant volume explosion chamber equipped with devices for charging air and fuel thereto and for exploding the combustible mixture therein, an elongated compression chamber connected with such explosion chamber, the ends of said compression chamber being of conical form, said conical ends adapted to produce a piston-like fluid dividing zone between the two media, means for charging the medium to be compressed into the compression chamber, and a whirling chamber arranged between the explosion and compression chambers wherein the flow energy of the compressed explosion gases is converted into sensible heat before their entry into the compression chamber.

26. Apparatus for the direct compression of one gaseous or vaporous medium by another, comprising a constant volume explosion chamber equipped with devices for charging air and fuel thereto and for exploding the combustible mixture therein, an elongated compression chamber connected with such explosion chamber, the ends of said compression chamber being of conical form, said conical ends adapted to produce a piston-like fluid dividing zone between the two media, and means for charging the medium to be compressed into the compression chamber, the walls of the compression chamber being lined with a heat-resisting material.

27. Apparatus for the direct compression of one gaseous or vaporous medium by another, comprising a constant volume explosion chamber equipped with devices for charging air and fuel thereto and for exploding the combustible mixture therein, an elongated compression chamber connected with such explosion chamber, the ends of said compression chamber being of conical form, said conical ends adapted to produce a piston-like fluid dividing zone between the two media, means for charging the medium to be compressed into the compression chamber, a heat exchanger, and conduits for conducting separately to said exchanger the medium to be compressed and the explosion gases discharging from said compression chamber.

28. Apparatus according to claim 20, wherein said explosion chamber forms part of a multi-stage explosion turbine, one of the turbine stages receiving the gases from the explosion chamber before they enter the compression chamber, said compression chamber being arranged between the

first and second turbine stages to receive the gases discharging from the first turbine stage and subsequently discharge them into the next stage.

29. The method of compressing and preheating
5 air which comprises exploding a combustible mixture of air and fuel within one confined space, and charging a mass of air to be compressed into a separate space, discharging the hot, high pressure explosion gases from the first space under
10 throttling to impart a high velocity thereto, bring-

ing the still highly compressed gases into contact with the air at one end of the second space while enabling the gases to expand gradually, whereby the gases flow as an orderly stream without substantial whirling and act in the manner
5 of a fluid piston to compress the body of air without mingling therewith to any considerable degree, and discharging the compressed air to a place of use.

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