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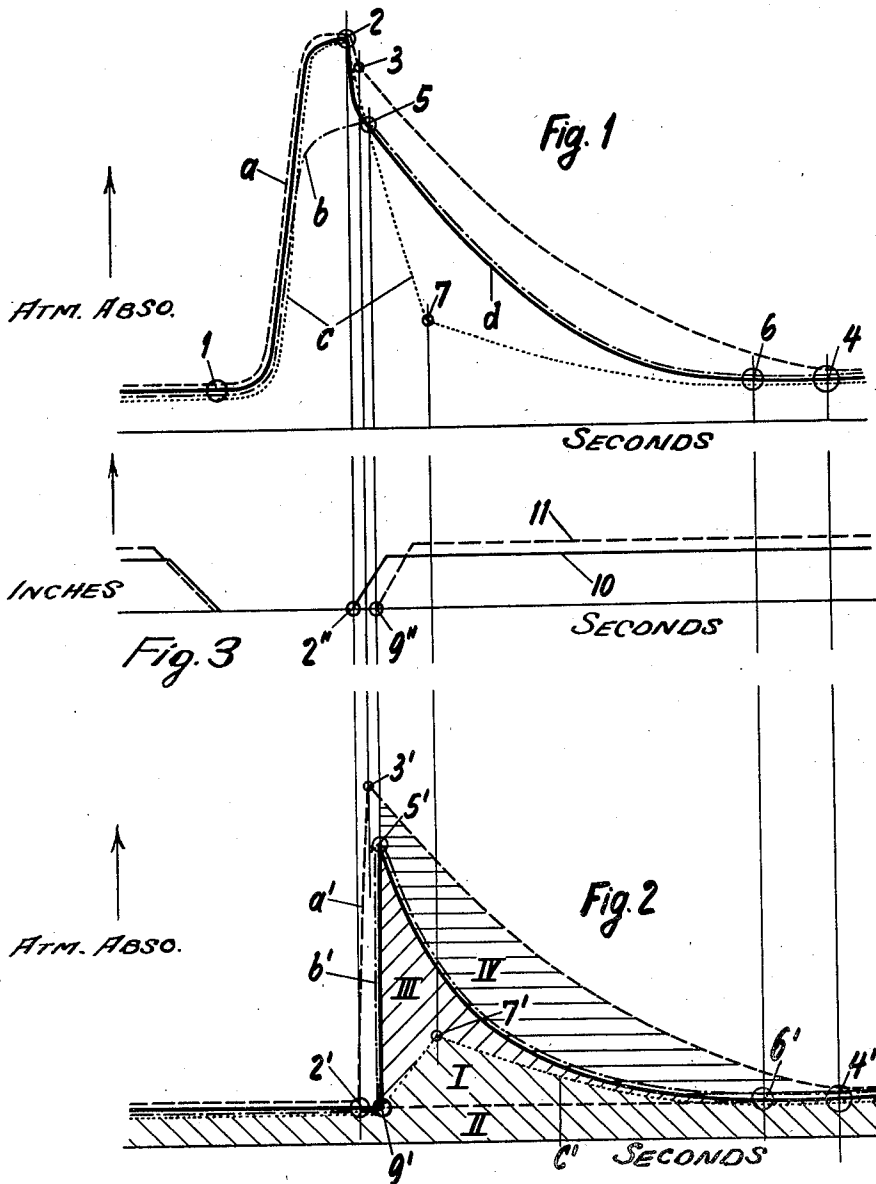
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2,063,928

HEAT EXCHANGE WITH EXPLOSION GASES

Filed Dec. 21, 1933

4 Sheets-Sheet 1



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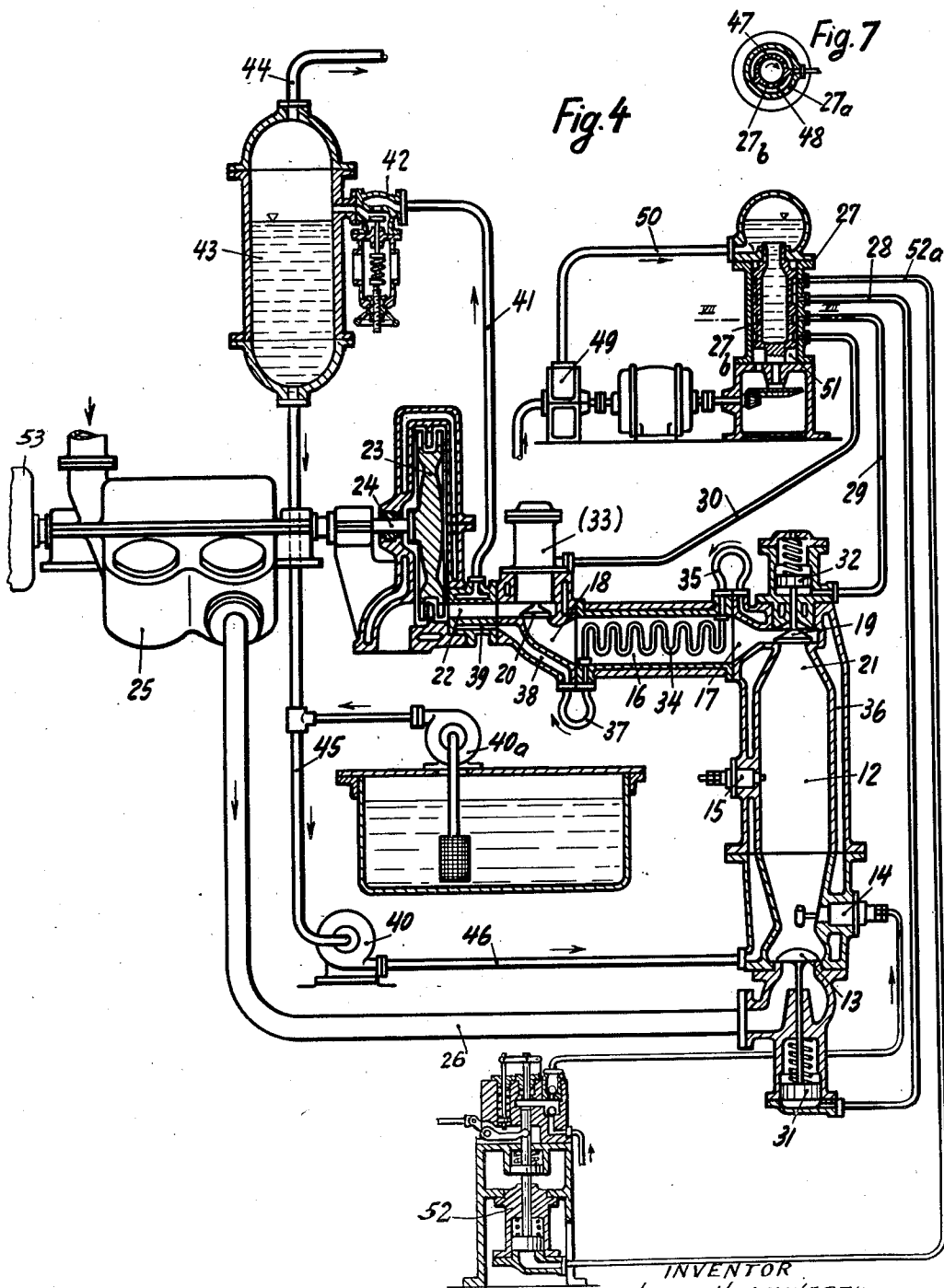
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HEAT EXCHANGE WITH EXPLOSION GASES

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4 Sheets-Sheet 2



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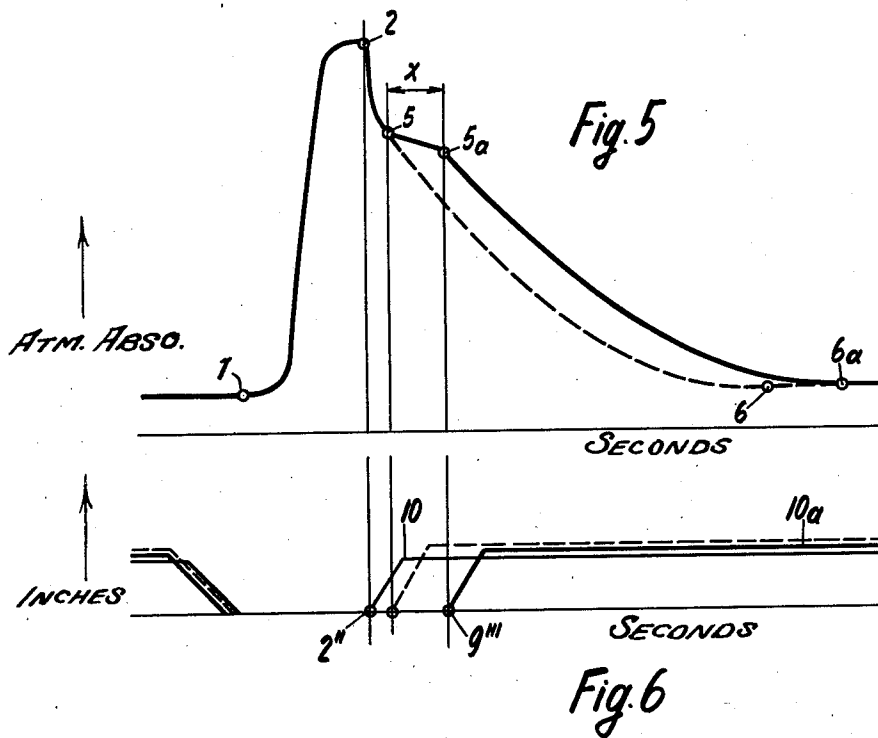
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HEAT EXCHANGE WITH EXPLOSION GASES

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4 Sheets-Sheet 3



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HEAT EXCHANGE WITH EXPLOSION GASES

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4 Sheets-Sheet 4

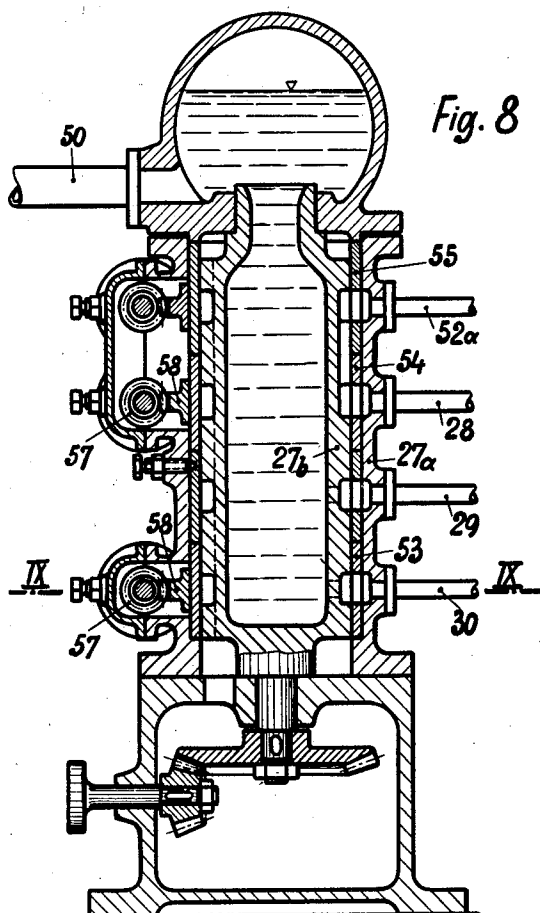


Fig. 8

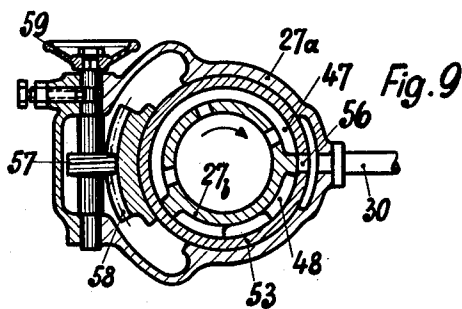


Fig. 9

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HEAT EXCHANGE WITH EXPLOSION
GASESHans Holzwarth, Dusseldorf, Germany, assignor
to Holzwarth Gas Turbine Co., a corporation
of DelawareApplication December 21, 1933, Serial No. 703,465
In Germany December 21, 1932

5 Claims. (Cl. 60—49)

The present invention relates to a process for operating combined constant volume explosion chamber and heat exchanger arrangements, especially those including steam generators wherein the heat exchanger is struck by high pressure combustion gases generated in the explosion chambers, after which the gases are used for the production of mechanical energy, a part of the sensible heat contained in the gases being withdrawn therefrom in the heat exchanger prior to the actual utilization of the gases for mechanical purposes.

It is the object of the invention to provide an improved process and apparatus for abstracting heat, for steam generating and superheating and other purposes, from the live, high temperature, high pressure gases generated by explosion under constant volume wherein the disadvantageous effects of the presence of the heat exchanger in the path of the gases flowing, for example, to a turbine, and resulting primarily from the enlarged gas space presented by the heat exchanger are reduced to a minimum. The present invention thus provides an arrangement of the type indicated wherein the heat exchanger is advantageously placed to be swept by gases at practically maximum explosion temperature and at high velocity, the rate of heat interchange being thus high, while a too severe drop in pressure and other difficulties of prior arrangements are avoided.

It has already been proposed to operate heat exchangers, such as boilers, with the high pressure gases discharging from constant volume explosion chambers, and even to arrange the heat exchanger within the explosion chamber itself. Both of these methods for utilizing the high temperatures of the explosion gases had however, serious disadvantages. In the first method, wherein the gases were discharged into the heat exchanger and then passed immediately into a turbine, there was a serious fall in pressure which prevented the turbine from utilizing efficiently the residual energy of the gases; and in the second, disturbances in the course of the combustion resulted, while at the same time the resistance to the flow of the gases was increased, and the exchanger was exposed to the destructive influences of the explosions and the high thermal stresses.

The present invention provides a solution of the problem of utilizing the high heat transmitting character of the explosion gases while eliminating the disadvantages of the prior proposals above described. The process according to the invention is characterized essentially by the fact that the combustible mixture formed in the explosion chamber is exploded while the latter is closed with

respect to the heat exchanger, whereupon the explosion chamber and the heat exchanger arranged after the same are connected with each other while the gas-filled spaces are otherwise closed on all sides. After the lapse of a definite interval, during which sensible heat is withdrawn from the gases, the latter are discharged, preferably into a gas turbine arranged after the heat exchanger. In a further development of the invention, my improved mode of operation can be so modified that the combustion gases are discharged from the heat exchanger after any desired controllable period of action upon the heat transferring surfaces of the heat exchanger.

The apparatus for carrying out my improved process is characterized by the feature that both at the explosion gas inlet as well as at the explosion gas outlet of the heat exchanger arranged after the explosion chamber periodically operated control members or valves are arranged. The control for the member located at the gas inlet of the heat exchanger is so determined that it is opened only after the explosion of the mixture confined within the explosion chamber has been substantially completed. The control of the member arranged at the gas outlet of the heat exchanger, on the other hand, is so regulated that it remains closed for a certain period of time after the opening of the member at the explosion gas inlet.

The advantages of this new mode of operation are readily apparent. In the first place, the explosion chamber remains closed up to the end of the explosion process, and does not have to be altered in any way from the form determined exclusively by thermodynamic and thermo-technical considerations. The course of the explosion cycle is accordingly undisturbed while a complete combustion or explosion is obtained. On the other hand, there are avoided the undesirably large drops in pressure caused by the escape of gases out of the heat exchanger during the filling of the exchanger with the high pressure gases flowing out of the explosion chamber after the explosion. The fall in pressure accompanying the filling of the heat exchanger with gases is kept within comparatively small limits, so that the pressure energy which remains is still sufficiently large to supply the whole compression work required for keeping the plant in operation.

The invention will be further explained with the aid of the diagrams on the accompanying drawings which illustrate also a practical embodiment of the invention. In said drawings,

Fig. 1 shows a pressure-time diagram of the

above-described known processes compared with the diagram obtained according to the invention;

Fig. 2 shows a pressure-time diagram according to the process of Fig. 1 behind the heat exchanger, that is, directly in advance of the nozzle of the turbine wheel arranged after the heat exchanger;

Fig. 3 illustrates the valve-lift diagrams of the control members or valves;

Fig. 4 shows diagrammatically a structural arrangement embodying the invention;

Fig. 5 illustrates a pressure-time diagram representing a further development of the inventive idea; while

Fig. 6 shows the corresponding valve lift diagrams;

Fig. 7 is a horizontal section through the distributor along the line VII—VII of Fig. 4;

Fig. 8 is a vertical section through the distributor on an enlarged scale; and

Fig. 9 represents a horizontal section along the line IX—IX of Fig. 8.

In the diagram shown in Fig. 1, the abscissae indicate time while the ordinates represent pressures. The dash line *a* represents the typical pressure-time diagram of the known constant volume explosion chamber, such as is employed for operating explosion turbines. The ignition of the combustible mixture in the explosion chambers occurs at the point 1, at which instant the charging pressure prevails in the explosion chamber. By the resulting explosion, the pressure in the explosion chamber rises to the point 2, at which instant the outlet member, usually termed the "nozzle valve", is opened, whereupon the high pressure combustion gases discharge from the explosion chamber. The discharging gases first fill the nozzle channel between the nozzle valve and the subsequent nozzle. Although this nozzle channel is made comparatively small, in view of known thermo-dynamic principles, in the usual explosion turbines which are now under consideration, yet, because the gases continue during this filling period to escape through the nozzle, there occurs a drop in pressure to the point 3 before equalization of the pressures in the explosion chamber and the nozzle channel occurs. From this point 3 on, the regular expansion of the combustion gases through the nozzle begins, the gases being directed by the nozzle into the turbine, until at the point 4, the charging or scavenging pressure is reached in the explosion chamber. At the instant 4 the next working cycle begins with the scavenging or charging of the explosion chamber. The curve 1—2—3—4 thus indicates the individual process phases of the explosion cycle between the instant of ignition and the instant of initiation of the charging or scavenging.

The dot-dash curve *b* shows the pressure course in an arrangement in which the heat exchanger is connected permanently to the explosion chamber, only the latter, however, receiving fuel to avoid injury to the exchanger by explosion therein. As an increase in pressure occurs in the so limited combustible mixture-filled space, then even during the explosion, combustion gases flow into the residual gas-filled space of the heat exchanger where they compress such residual gases. As a result, only a comparatively low maximum combustion pressure can develop.

This is shown in the pressure line *b* in which the point 5 indicates the maximum explosion pressure. At the instant 5 the periodically operated nozzle valve, which is arranged in the path

of the gases beyond the heat exchanger, is opened and the expansion begins, which at the point 6 reaches the charging or scavenging pressure, whereupon a new scavenging and charging of the explosion chamber is begun. The point 1 indicates the moment of ignition also for the curve *b*.

By comparing the two diagrams *a* and *b*, it will clearly be seen that the maximum pressure of the curve *b*, represented by the point 5, is considerably lower than the maximum pressure, represented by the point 2, of the typical pressure-time diagram of the ordinary constant volume explosion chamber.

The first known mode of operation above discussed, in which the heat exchanger is arranged in the path of the gases beyond the controlled outlet valve of the explosion chamber, is represented in Fig. 1 by the dotted line *c*. Here again the normal pressure course occurs up to the point 2, and up to such point the pressure line 20 beginning at the ignition instant 1 agrees exactly with the corresponding pressure curve of the diagram *a*. To show these two curves more clearly upon the drawings they have been shown as slightly separated between the points 1 and 2. The nozzle valve opens at the point 2. However, as the heat exchanger increases enormously the space between the nozzle valve and the subsequent nozzle which directs the gases to the turbine rotor, and as the gases continue to escape from such channel during the filling of this enlarged space, the explosion pressure in the explosion chamber falls very suddenly and very considerably during this filling process, in fact down to the point 7 on the dotted curve *c*, before equalization of pressure occurs. From the point 7 on the regular expansion out of the nozzle channel proceeds.

The course of the pressure as indicated by the diagram *c* shows that by the sudden and considerable fall in the explosion pressure from the point 2 to the point 7, as contrasted with the other diagrams *a* and *b*, a considerable reduction in the working area occurs. Such a reduction in the working area, however, resulting in reduction of the turbine output below the compressor intake, can in no case be permitted if a commercial apparatus is to be obtained.

The continuous line *d* in Fig. 1 represents the pressure conditions in the process according to the invention, in which the combustible mixture is exploded in the explosion chamber while the latter is closed with respect to the heat exchanger arranged in the discharge path of the gases. After the explosion, the explosion chamber is connected with the heat exchanger, such structures remaining, however, otherwise completely closed on all sides. Diagram *d* representing such process shows first of all the normal pressure course of the explosion line between the points 1 and 2. At the point 2 the outlet member of the explosion chamber is opened. As now, according to the invention, the explosion chamber and heat exchanger are placed in communication with each other while the gas filled spaces therein are otherwise completely closed, the pressure drop upon the filling of the heat exchanger, which is closed with respect to the nozzle, is comparatively small in contrast with the process according to the line *c*. Pressure equalization between the chamber and the heat exchanger is reached approximately at the instant 5, which corresponds to the maximum explosion pressure of the diagram *b*. At the instant 5, the discharge member in the path of the

gases behind the heat exchanger is opened; the expansion line is represented by the course of the line 5—6, which corresponds to the expansion line of the diagram b of Fig. 1.

5 The pressure diagrams of the different processes shown in Fig. 1 indicate, of course, only the pressure conditions inside of the gas filled spaces (explosion chamber and heat exchanger). The diagrams show, however, in spite of the
10 fact that they are not real output diagrams, that is, they are not p_v diagrams, a fairly clear picture of the available outputs in the explosion chamber. However, diagrams do not give a clear picture of the outputs which are available in
15 the turbine arranged in the path of the gases beyond the heat exchanger, that is, immediately in advance of the nozzle. These outputs are illustrated in Fig. 2 in which the pressures prevailing in the above-described process immediately in front of the nozzle of the turbine have
20 been plotted as ordinates.

The dash line a' shown in Fig. 2 represents the pressure course 2'—3'—4' immediately in advance of the turbine nozzle in a normal, pure
25 explosion turbine plant corresponding to the diagram 1—2—3—4 of Fig. 1. At the point 3' the nozzle channel is completely filled with gases at the pressure prevailing in the explosion chamber and from this point the expansion of the
30 combustion gases proceed to the point 4' exactly as shown between the points 3—4 of Fig. 1.

If that known process, according to Fig. 1, is used in which the heat exchanger is arranged in the path of the gases in advance of the nozzle
35 or outlet valve of the explosion chamber, then there are obtained pressures in advance of the nozzle as indicated by the dot and dash line b' in Fig. 2. As according to the mode of representation selected in Fig. 1 the outlet member
40 lying in the gas path beyond the heat exchanger opens at the instant 5 which is later than the instant 2 of the normal diagram a , the filling line in Fig. 2 in the diagram b' also begins later by the same time interval and in fact at the instant
45 9'. In view of the strong cooling of the combustion gases in the heat exchanger, which is accompanied by a corresponding reduction in the gas volume and a considerable loss in pressure, the result is obtained that the filling line rising
50 at the point 9' does not reach the point 3' of the diagram a' but ends below the point 3', still, however, above the point 5'. This filling line would end at the instant 5' itself if the same arrangement here under consideration was used
55 but operated with the formation of a dividing zone between the incoming air and the discharging gases, wherein an ignitable mixture formed only in the actual explosion spaces itself, while the combustion gas residue of the preceding explosion remained in the heat exchanger. In
60 such a mode of operation the expansion line will be represented by the line 5'—6', while by the use also of the gas conducting heat exchanger space as additional explosion space, the expansion line runs somewhat above line 5'—6' but below the line 3'—4'. From this consideration it
65 will be evident that the expansion lines obtainable in the known process involving a heat exchanger arranged in the gas path in advance of the outlet member lie between the expansion
70 lines 5'—6' and 3'—4'. The lines approach the line 5'—6' to the degree in which the heat exchanger remains filled to a greater and greater extent with the residual gases of the previous explosion; on the other hand, they approach

more toward the line 3'—4' the less the amount of heat absorbed by the heat exchanger.

The pressure conditions in advance of the nozzle, according to the known process represented by the diagram c , in which the heat exchanger is arranged in the gas path beyond the
5 controlled outlet member of the explosion chamber in the direction of the nozzle, are represented in Fig. 2 by the dotted curve c' . In this case the filling process, in consequence of the
10 greatly increased nozzle channel volume, runs from 2' to 7'; at the latter instant the expansion begins.

From the above described diagram a' , b' and c' there results, as can clearly be seen in Fig. 15 2, three working areas of different sizes. Upon closer observation of these working or output surfaces it will be recognized that the output available at the nozzle of the turbine in the last-mentioned process is indicated by the sum of the
20 areas I and II, the area II corresponding to the work which a constant pressure turbine would deliver. The wedge-shaped area I accordingly represents a gain in output over the constant pressure turbine output II. This area I, how-
25 ever, does not increase the constant pressure output II to such a degree that the required compressor work could be covered with the last-mentioned process since the combined turbine and compressor efficiency is only about 50%.
30 This compressor work is secured only by the addition of the working area III by which an available output is provided at the turbine nozzle with which the whole compressor intake can be
35 supplied.

The sum of the working areas I, II, III, IV represents the output of the pure gas turbine. This output exceeds by a considerable amount the required compressor work.

The improved process according to the invention, which on the one hand avoids difficulties
40 resulting from the arrangement of the heat exchanger in the gas path in advance of the control member or nozzle valve of the explosion chamber, while on the other hand the gas turbine
45 output in such process is high enough to cover at least the necessary compressor work, and which is represented in Fig. 1 by the full-line diagram 1—2—3—5—6, is illustrated in Fig. 2 as follows: The outlet member of the explosion chamber in
50 applicant's arrangement, which at the same time represents the inlet member of the heat exchanger, opens at the point 2', while the gas filled spaces remain otherwise closed, that is, while the outlet member (the true nozzle valve) arranged beyond
55 the heat exchanger in the path of the gases is closed. Corresponding to the increase in volume by the gas space of the heat exchanger, the gas pressure in the explosion chamber falls (see curve 2—5 in Fig. 1). At the point 9' of Fig. 2 the outlet
60 member (nozzle valve) arranged between the heat interchanger and the turbine assembly is opened, and there now occurs, corresponding to the line 9'—5', a pressure equalization between the explosion chamber and heat exchanger on
65 the one hand and nozzle channel on the other. At the point 5' the expansion line begins, and at the point 6' it reaches the line of the scavenging or charging pressure. It will thus be seen that the turbine output according to the invention is
70 represented by the sum of the areas I, II and III. This turbine output is sufficiently large to take care of the whole compressor intake.

As the true explosion chamber in the process according to the invention is not subjected to any
75

complications of structure and to the disturbances associated therewith, the efficiency of the combustion can be raised to the highest attainable value. In this way it has become possible, by virtue of the present invention, to obtain a good overall efficiency with an entirely satisfactory arrangement of heat exchanger from the combustion-technical standpoint. In connection therewith the advantage can be realized that the prior normal capacity of the heat exchanger, in view of the unusually high gas velocities and of the resulting high rate of heat interchange, is secured with an extremely small heat exchange surface or, conversely, with the usual size of heat exchanger the output can be considerably increased.

It is desired to point out further that the working areas I, II, III and IV of Fig. 2 are not identical with the absolute values of the available outputs, but are to be regarded only schematically as output areas. An exact representation of the proper values of the working and heat areas would require the aid of entropy diagrams. The latter, however, would not as clearly explain and illustrate either the inventive idea or the state of the art, as do the pressure-time diagrams shown on the drawings.

In Fig. 3 are shown the valve lift diagrams of the outlet members which are controlled one after the other in accordance with the invention. The curve 10 shows the diagram for the outlet member between the explosion chamber and the heat exchanger, while curve 11 shows the corresponding diagram of the later opening nozzle valve which is arranged between the heat exchanger and the subsequent turbine assembly. The first outlet member opens at the point 2" and the second at the instant 9".

Fig. 4 shows by way of example a satisfactory arrangement according to the invention. The numeral 12 indicates the explosion chamber which is provided in the usual manner with an inlet member 13 for scavenging and charging air, with a fuel inlet member 14 and an igniting device 15. The heat exchanger 16 comprises a separate compartment arranged in the path of the gases behind the explosion chamber 12. In accordance with the invention, there are arranged periodically controlled valves 19 and 20 at the gas inlet 17 of the heat exchanger 16 and at the gas outlet 18 thereof, respectively. The valve member 19 simultaneously controls the outlet 21 of the explosion chamber, while the control member 20 is arranged immediately in front of the nozzle 22 of the turbine 23. The control member 20 is thus to be designated as the true nozzle valve.

To the turbine shaft 24 is coupled the compressor 25 which feeds the required scavenging and charging air under pressure through the conduit 26. Both the charging air valve 13 as well as the outlet members 19 and 20 may advantageously be controlled hydraulically by means of oil under pressure which is brought into action periodically at predetermined instants by a rotary distributor 27 of known construction, the oil being charged through conduits 28, 29 and 30 and acting upon control pistons 31, 32 and 33 (the last of which is not illustrated) connected with the respective control or valve members. The heat exchanger 16 consists of a tubular coil 34 connected on the one hand with the cooling space 36 of the explosion chamber through the curved goose-neck connection 35, and with the cooling spaces 38 and 39 through the similar connection 37. The cooling agent is conducted to the cooling space 36 of the explosion chamber under high pressure by the

pump 40 and is withdrawn in highly heated condition from the cooling space 39 by the conduit 41. After being partially decompressed in the reducing valve 42 the heated cooling agent flows to a steam separator 43 in which the generated steam under pressure is withdrawn at 44, while the unvaporized cooling agent is returned by conduit 45 to the pump 40 and by the conduit 46 to the cooling space 36 of the explosion chamber. The cooling water withdrawn from the cooling water circuit in the form of steam is replaced with fresh feed water by the pump 40a.

According to the invention, the valves 19 and 20 are so controlled, as indicated in Fig. 3, that the mode of operation represented by the solid lines in Figs. 1 and 2 takes place. There are obtained in this way the novel effects which have been described above with the aid of these figures.

In a further development of the invention, the improved mode of operation can be so carried out that the duration of the action of the combustion gases on the heat transferring surfaces of the heat exchanger is regulated in a definite manner. In this way it is possible, upon change of the load conditions on the gas turbine and on the heat exchanger located in the path of the gases, always to adjust the output of the exchanger in proper degree to the amount of heat receiving medium, (for example, steam) required at any time. This development is based upon the recognition that certain cases exist in which the output of the heat exchanger and that of the gas turbine vary with respect to each other, as when the need for steam from the heat exchanger or the load on the gas turbine is subject to rather large fluctuations. Conversely, there are cases in which the steam requirement remains practically unchanged while the load on the gas turbine, or on any other energy consuming machine, varies greatly at certain times. This will be the case, for example, when the machine driven by the combustion gases operates a current generator, as indicated at 53 in Fig. 4, whose network is subjected to varying loads due to the irregular demand for power, particularly by the cutting in or cutting out of certain electrically driven machines and devices.

It is advantageous to combine the load changes of the above mentioned aggregates with a suitable regulation of the output of the explosion chamber or chambers by changing the load conditions in such manner that the output of the explosion chamber is always fitted in correct degree to the load condition of the said aggregates at any moment. However, the heat content of the generated gases changes with a change in the output of the explosion chambers. As is known, the heat content of the high pressure combustion gases, together with other factors, is controlling for the heat transfer to the heat transmitting surfaces of the heat exchanger, and it will also be clear that with every change in the output of the explosion chambers there will occur also a change in the amount of heat transmitted in the heat exchanger. If, corresponding to the known mode of operation, the duration of the action or contact of the explosion gases upon the heat transferring surfaces of the heat exchanger remains practically uninfluenced by the change in output of the explosion chambers themselves, that is, such duration is maintained at an initially adjusted value, the output of the heat exchanger does not correspond to the actual requirements. In order to fit the output of the heat exchanger correctly to the steam requirement at any time, the duration of action of the combustion gases upon the

heat transmitting surfaces of the heat exchanger is suitably altered, according to the invention, upon change in the relative magnitudes of the loads on the heat exchanger and on the gas-operated machine (e. g. turbine). In consequence there is effected an increase in the time of action of the gases upon increase in the load on the heat exchanger, and in the reverse case this time is reduced. If, on the other hand, only the gas-driven mechanism, such as a gas turbine arranged in the gas path following the heat exchanger, is subjected to changes in the load, while the output of the heat exchanger is to be maintained constant, then also in this case the duration of the action of the gases must be regulated since, as already mentioned, a change in the amount of heat generated by the explosion accompanies a change in the output of the explosion chambers effected by regulation of the feed supply in known manner. In order to maintain constant the quantity of heat to be transferred in the heat exchanger in such case, it is necessary either to reduce the time of action of the gases upon the heat exchanger upon increase in their heat content, or to increase such time of action upon reduction of the heat content.

For carrying out the above described process, there is employed a control for the closure member located in the gas path beyond the heat exchanger (i. e., the outlet member 20 in Fig. 4) which opens this member in dependence upon the moment defining the termination of the period of action of the gases upon the heat transferring surfaces of the heat exchanger. The conditions involved in such control are diagrammatically presented in Figs. 5 and 6. The diagram shown in Fig. 5 repeats in the curve 1—2—5—6 the full line diagram *d* of Fig. 1 representing the basic process of the invention, according to which the ignition of the combustible charge in the explosion chamber occurs at the instant 1. At the instant 2, in which the maximum pressure is obtained in the explosion chamber 12, the outlet member 19 is opened. In the valve lift diagram of Fig. 6, this instant corresponds to the point 2''. It indicates the initial point for the lift diagram of the outlet member 19 represented by the light line 10. The explosion gases escaping from the explosion chamber then fill the heat exchanger 16, whose outlet is closed, until at approximately the instant 5 the pressures in the gas filled spaces of both the heat exchanger and the explosion chamber is equalized. In accordance with the further development of the invention, the expansion line does not, as in Fig. 1, begin at the instant 5, such expansion line of Fig. 1 being indicated in Fig. 5 by the dotted line running to point 6, but such expansion begins later by the variable time interval x . The expansion xx thus begins at the point 5a. In the valve diagram of Fig. 6, this point corresponds to the point 9''' at which the lift diagram 10a of the outlet member 20 of the heat exchanger begins. The expansion continues from the point 5a to the point 6a, approximately when the scavenging or charging pressure is reached in the explosion chamber. Because of the fact that when the opening of the outlet 20 of the heat exchanger is delayed by the variable time interval x after pressure equalization has been reached in the gas filled spaces of the heat exchanger and explosion chamber, the combustion gases act for a correspondingly longer time upon the heat transferring surfaces. To a degree depending upon the length of the interval x , a greater amount of heat will be withdrawn from

the gases than is the case when the expansion line begins at the instant 5 or at the instant 2. As the quantity of heat generated in the heat exchanger, other factors, particularly the co-efficient of heat transfer, remaining the same, is dependent upon the duration of the action of the gases, the present invention makes it possible, by proper measurement of the arbitrarily variable time of action of the gases upon the heat exchanger surfaces, accomplished by the shifting of the instant 5a and of the valve opening instant 9''', to regulate exactly the amount of heat absorbed in the heat exchanger. In this way the amount of heat transmitted to the heat exchanger can be fitted in an economical way to the amount of heated medium (steam or hot water) required at the place of use.

If in the explosion turbine plant shown in Fig. 4 the process is one in which the load on the explosion turbine 23 operated by the gases discharged by the outlet member 20 of the heat exchanger 16, is substantially constant, while the consumption of steam (or hot water) produced in the heat exchanger 16 varies, for example falls, then the stay or the period of action of the combustion gases in the heat exchanger, that is, the interval x , is correspondingly reduced, and the charging conditions of the explosion chamber 12 are likewise changed, in so far as the latter measure is necessary to keep the output of the gas turbine 23 constant. In the reverse case, that is, upon increase in the steam requirement, the interval x , and thus the period of heating by the combustion gases, is increased. The heating period of the combustion gases required at any time is adjusted by advancing or retarding the moment of opening of the outlet member 20 of the heat exchanger 16.

The explosion plant of Fig. 4 can also be operated in such manner that the load on gas turbine 23 falls while the consumption of steam generated in the heat exchanger remains substantially constant. If the load on the gas turbine changes, the output of the explosion chamber is adjusted to the load conditions at any time. This results necessarily in a simultaneous change in the charging conditions of the explosion chamber. The change in the charging conditions, as already explained, is accompanied by a change in the heat content of the combustion gases. In order to avoid irregularities in the output of the heat exchanger, the period of action of the combustion gases is reduced or increased to produce a constant generation of steam.

In order to avoid harmful reactions, particularly pre-ignitions when the wall temperatures of the explosion space become very hot, upon the mixture which is to be ignited at a predetermined instant or upon the components of the mixture, it is necessary to regulate the quantities of heat acting upon such mixture. Ordinarily there is retained in the explosion chamber a certain amount of residual gases from the preceding explosion by premature closing of the outlet member. The sensible heat contained in such gases acts upon the components of the mixture to prepare or prime the same. As the wall temperatures of the explosion chamber assist in priming the mixture by radiation of heat thereto, provision must be made in the case of very high wall temperatures to prevent the required priming condition of the mixture being exceeded by excessive heating. In a further development of the invention this result can be obtained, 75

for example, by varying the displacement or scavenging process of the residual gases remaining from the preceding explosion. The change in the scavenging process can occur in a variety of ways, as has already been proposed in a known method of operation. The regulation of the quantity of heat acting upon the mixture has proved to be particularly advantageous when the narrowest discharge cross section, which is controlling for the displacement of the residual gases, is varied during the process. However, simultaneously with such change, or separately, the duration of the residual gas displacement can be regulated. The regulation of both of these factors is associated with a change in the quantity of residual gases trapped in the explosion chamber, and thus with the scavenging of the chamber. If now the wall temperature of the explosion space is very high, then in accordance with these proposals the undesired excessive influence of the heat upon the mixture can be prevented by a more vigorous scavenging, the amount of residual gases left in the explosion chamber being reduced either by exposing larger outlet cross sections or by increasing the scavenging period or by adopting both measures. The outlet cross-sections may be regulated as disclosed in my Patent No. 1,756,139; while the duration and hence the degree of scavenging can be controlled in the manner described in my Patent No. 2,003,292.

It will be noted that the heat exchanger compartment is small as compared with the explosion chamber; in fact, the free space in the heat exchanger should be made as small as possible consistent with efficient heat transfer in order to reduce the pressure drop attending the equalization of the pressures in the explosion chamber and heat exchanger.

Fig. 7 represents that part of the distributor which controls the piston 32 of the nozzle valve 19 through pipe line 29. The stationary housing is designated by the number 27a, the rotary part by 27b. The space 47 is connected with the interior of the rotary part 27b and thus with the oil pump 49 through the pipe 50 (of Fig. 4), the space 48 with a drain leading to the space 51 (of Fig. 4) of the distributor. During rotation of the rotary part 27b, therefore, pressure oil is alternately admitted or released from the piston 32 (of Fig. 4) opening and closing the nozzle valve 19 accordingly.

Figures 8 and 9 show constructions which allow for varying the moment of action for the control members 13, 20 or the hydraulically operated fuel pump 52 (of Fig. 4). Around the rotary part 27b are arranged movable sleeves 53, 54, and 55. By turning said sleeves the moment of actuating the corresponding mechanical devices is changed as shown for the sleeve 53 in

Fig. 9. The sleeve 53 is provided with a slot 56 which furnishes the controlling edges for admitting or releasing the pressure medium to or from the pipe 30. As soon as the sleeve 53 and therewith the slot 56 is moved by means of the spiral gears 57 and 58 and the hand wheel 59 in a direction against the direction of rotation of the rotary part 27b the piston 33 of the valve 20 is actuated earlier, and as soon as the sleeve 53 is moved in the opposite direction the valve 20 is actuated later. In this way the opening of the valve 20 may be varied as compared to the opening of the valve 19. In the same way the scavenging period may be influenced by turning the sleeve 54, thus changing the moment of opening 15 or closing the valve 13, while the admission of the fuel may be varied accordingly by shifting the sleeve 55.

I claim:

1. The combination of a constant volume explosion chamber, a heat exchanger connected with said chamber and arranged in the path of the gases discharging from such chamber, a control member at the inlet of the heat exchanger, a second control member at the outlet of the heat exchanger, and means for timing the opening and closing of said control members in sequence to regulate the time interval during which the explosion gases remain under high pressure in the heat exchanger before they are discharged by the second control member.

2. The combination as set forth in claim 1, wherein said timing means is constructed to open the first control member only after the combustion of the explosive mixture in the explosion chamber has been substantially completed.

3. The combination as set forth in claim 1, wherein said timing means is constructed to open first the control member at the inlet of the heat exchanger, the control member at the outlet remaining closed, and then to open the second control member after a selected time interval during which the pressure in the explosion chamber and heat exchanger has become substantially uniform.

4. The combination as set forth in claim 1, wherein the timing means is constructed to open the control member at the outlet of the heat exchanger at the end of a predetermined interval after the opening of the control member at the inlet of the heat exchanger to enable the gases to exert a predetermined heating effect in the heat exchanger.

5. Apparatus according to claim 1, including a combustion gas turbine arranged to receive and be driven by the gases discharged under pressure by the control member at the outlet of the heat exchanger.

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