THERMAL POWER GENERATION

Filed Oct. 25, 1949 3 Sheets-Sheet 1

Fig. 1

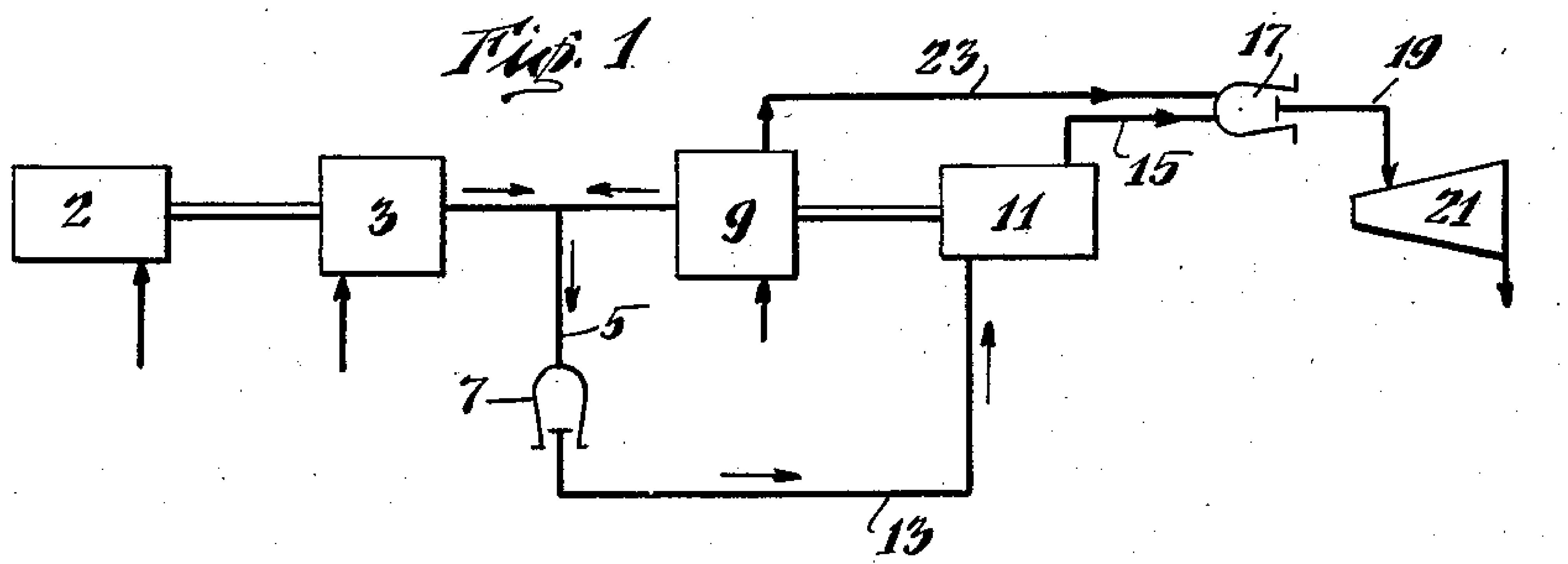

Fig. 2

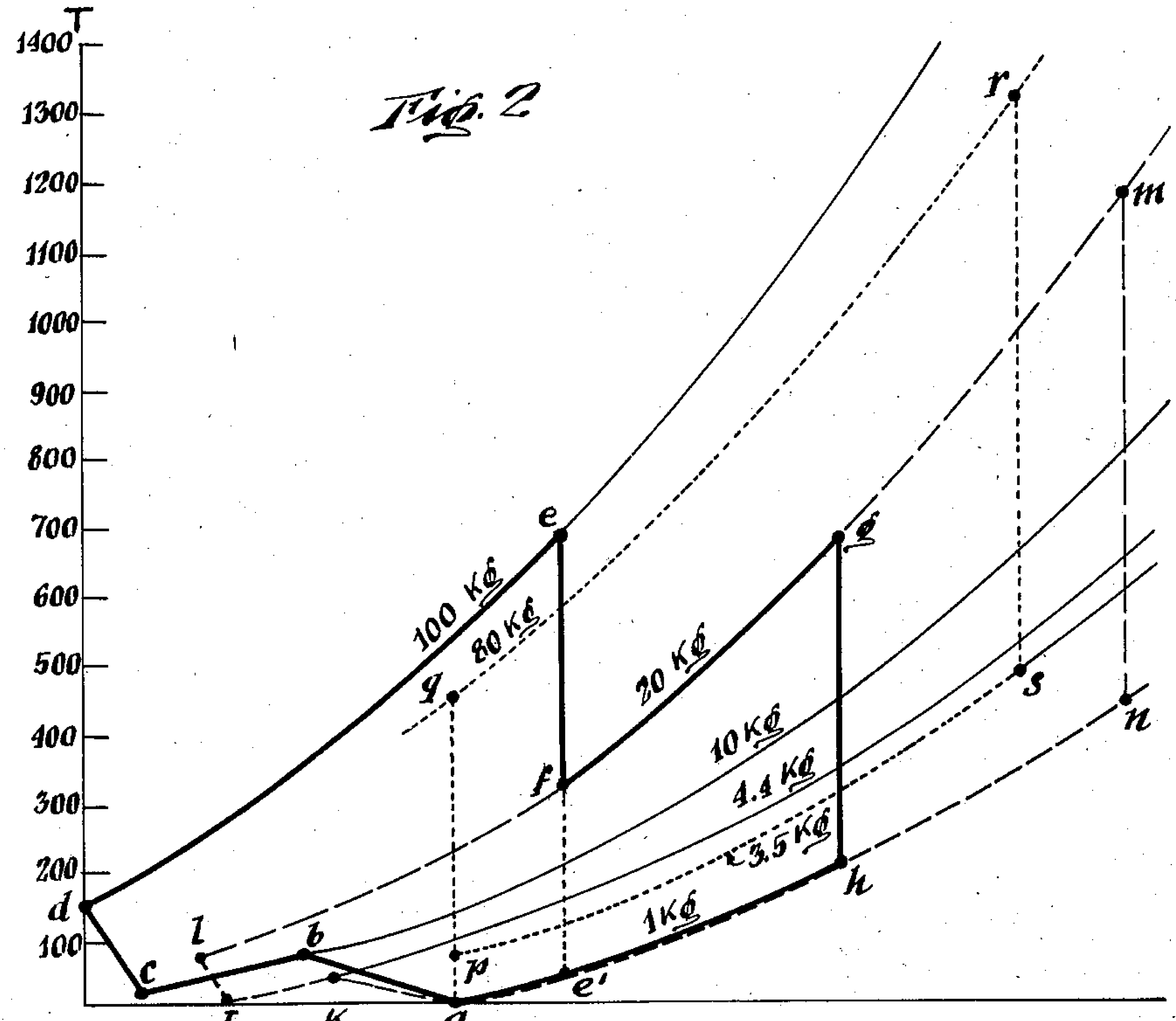

Fig. 4

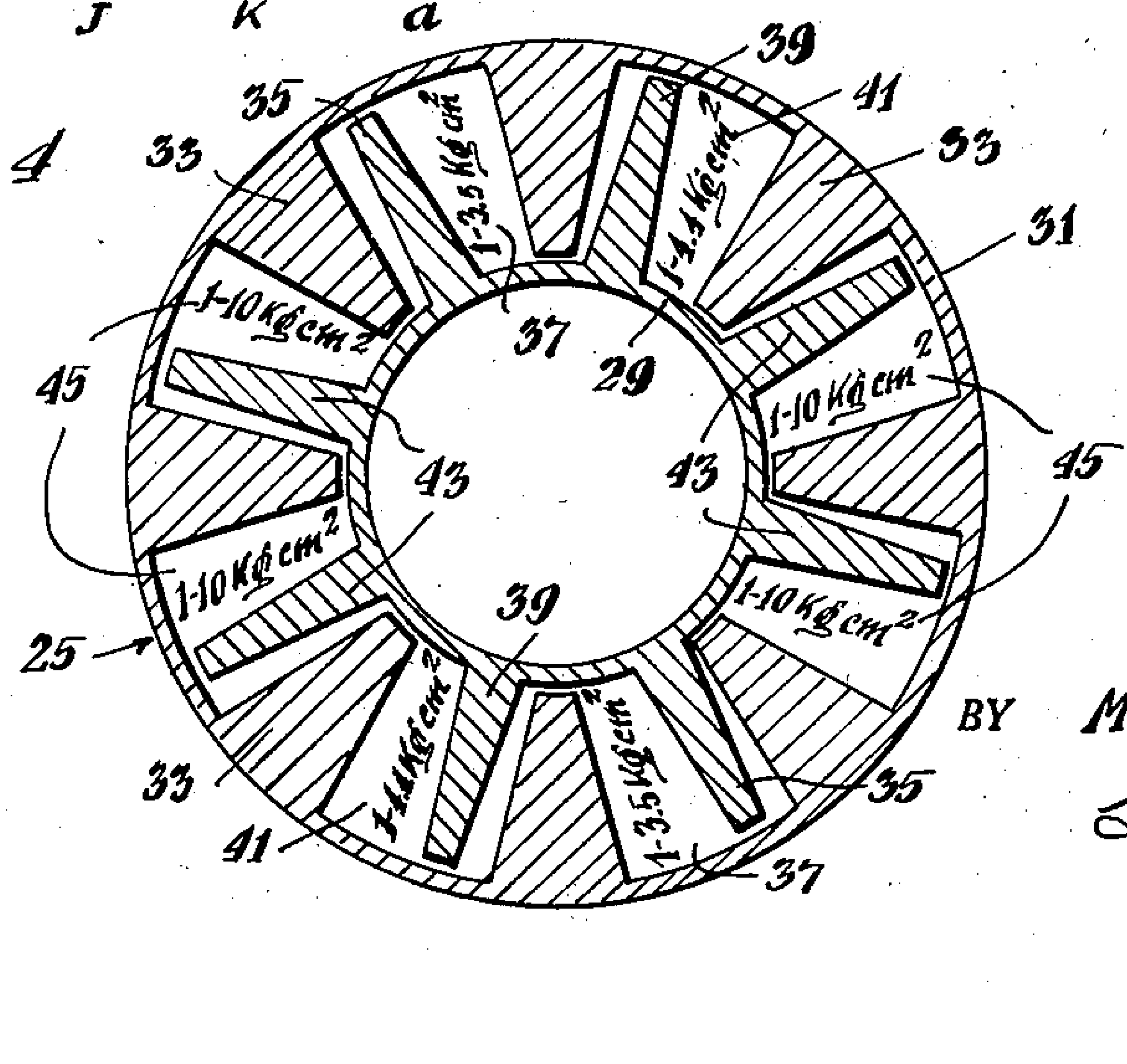

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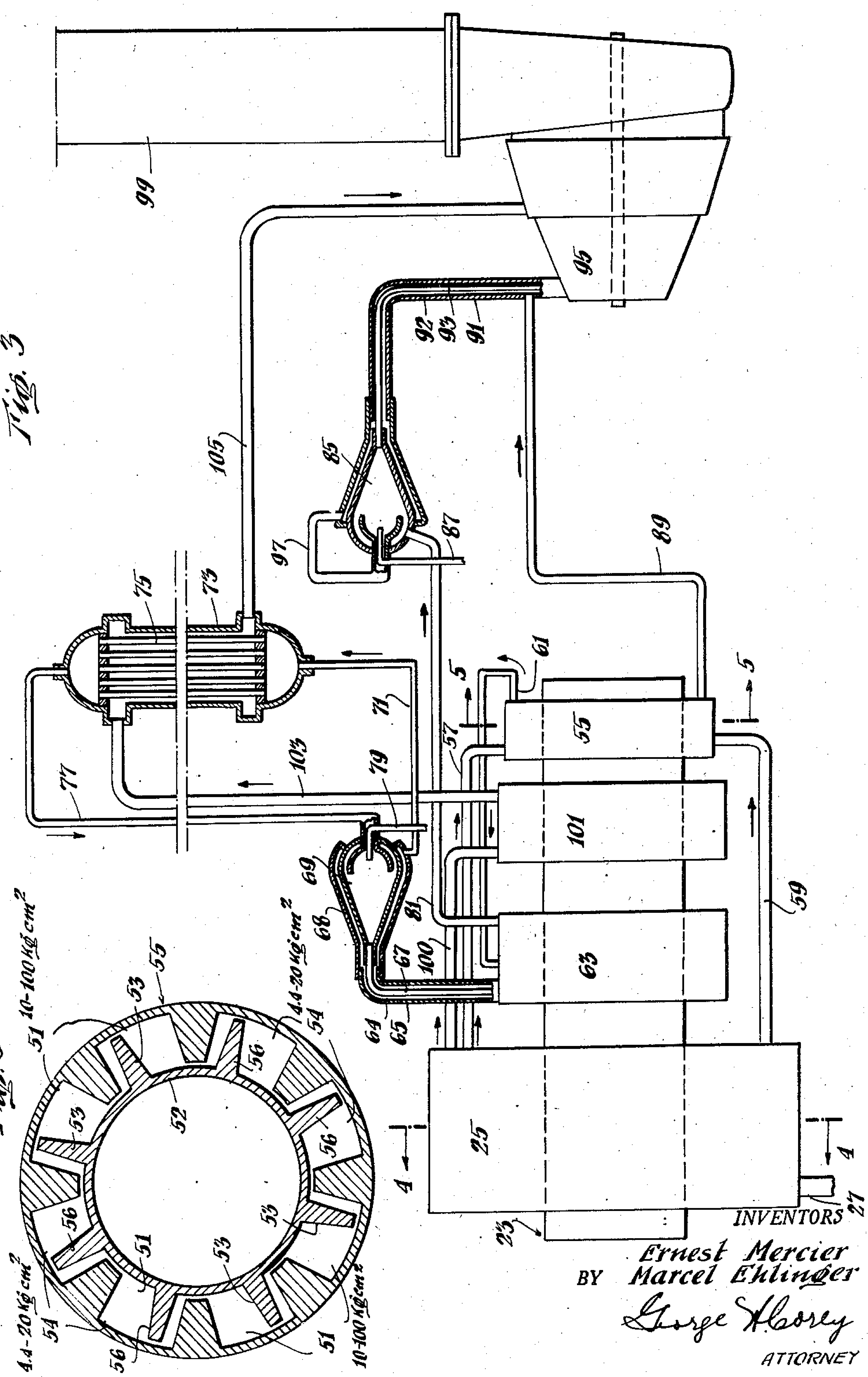
Fig. 3

Fig. 5



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THERMAL POWER GENERATION

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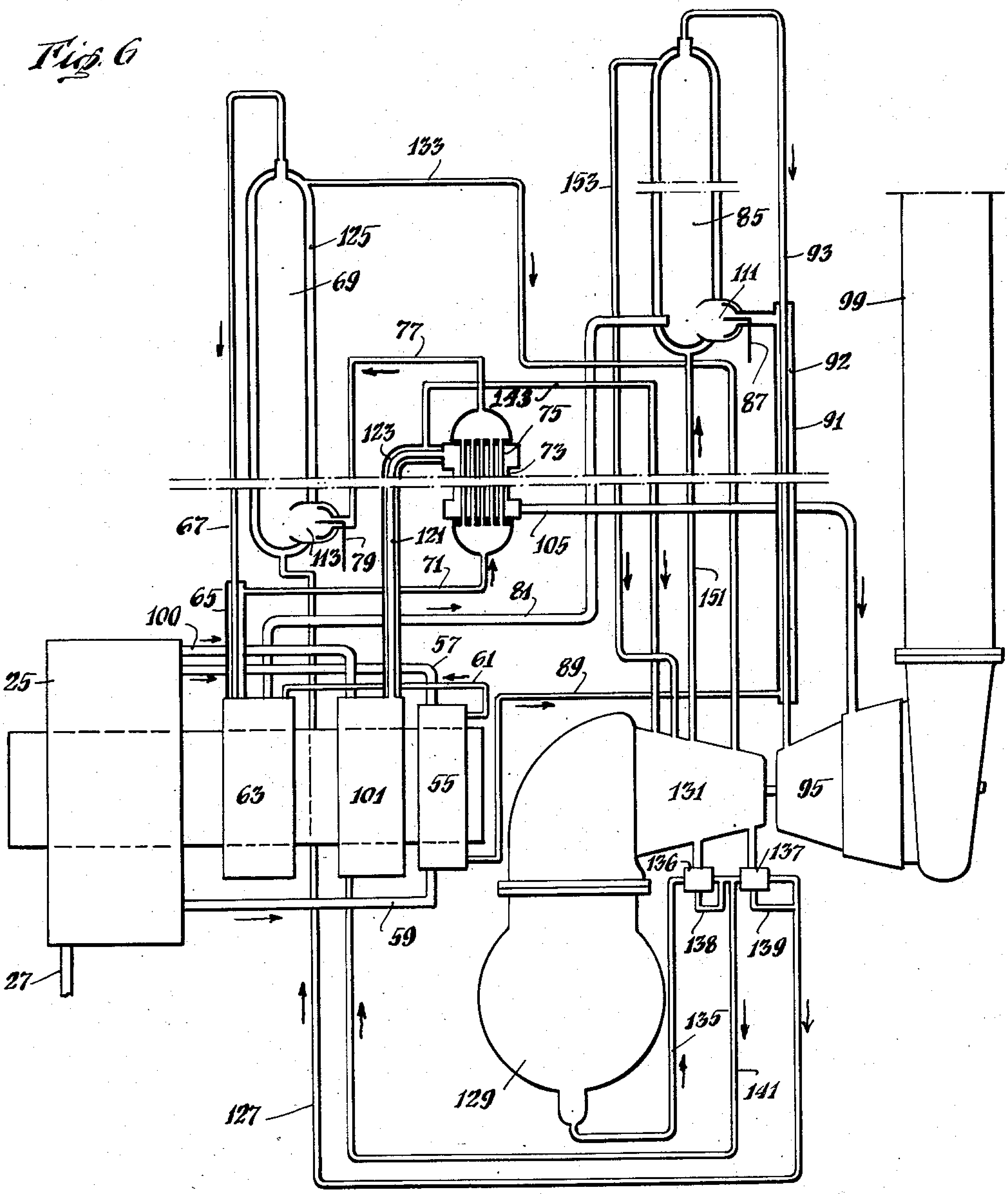
Fig. 6



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THERMAL POWER GENERATION

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22 Claims. (Cl. 60—13)

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This invention relates to a power generating plant and method of operating the same. The invention more especially relates to the production of power in heat utilizing prime movers or engines. The invention in its basic concept particularly relates to the production of power in gas utilizing prime movers and to improvement in a gas thermal cycle. In its more specific embodiment the invention also utilizes vapor generating and heating means and a vapor utilizing prime mover for improvement of the overall thermal cycle.

It is a feature of the invention that the main or power producing gas utilizing prime mover is supplied with hot gases at a suitable pressure which may be a medium pressure of the degree of 20 kg./cm.^{2}. In the cycle in which this prime mover is utilized the medium pressure gases which are supplied to this prime mover are provided at least in part by producing high pressure gases, for example, at 100 kg./cm.^{2}, and expanding these gases in an auxiliary gas utilizing prime mover to the medium pressure. Another part of the gases at medium pressure may be supplied directly to the main gas utilizing prime mover from a suitable combustion chamber and may be produced by the combustion of fuel in such combustion chamber. The auxiliary gas utilizing prime mover provides at least a part of the power required to compress the combustion supporting gas, ordinarily atmospheric air, to the high pressure required for the combustion gases to be supplied to the auxiliary gas utilizing prime mover. This auxiliary gas utilizing prime mover also may supply at least a part of the power to compress the combustion supporting gas or air to the medium pressure for supporting the combustion of fuel at this medium pressure to produce the hot gases which are supplied directly to the main gas utilizing prime mover. Supplementary power which may be necessary for driving the compressors for compressing the combustion supporting gas or air may be provided by internal combustion engines. Preferably the gas compressors, the auxiliary gas utilizing prime movers and the internal combustion engines are free piston engines and in the preferred embodiment of these engines they are of the oscillator type in which at least one oscillatable element oscillates upon an axis and is provided with members acting as pistons within fluid pressure chambers. For simplicity in the following description the main gas utilizing prime mover will be referred to as a gas turbine and the compressors as air compressors.

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It is a further feature of the invention in carrying out the improved operating cycle that the high pressure combustion supporting air before being admitted into the auxiliary gas utilizing prime mover is heated by means of a combustion chamber supplied with fuel to increase the temperature of this air to a reasonably high temperature, say 700° C. The combustion of fuel in this chamber may be supported by supplying at least a part of the high pressure air to the combustion chamber. The hot gases thus produced in the combustion chamber at high pressure which are then supplied to the auxiliary prime mover are expanded therein and the expanded or exhaust gases from this gas utilizing prime mover are carried to the turbine for developing power therein. Before being admitted into this turbine, however, preferably these gases are heated to a reasonably high temperature, say 700° C., by the heat of the combustion which produces the combustion gases at the medium pressure which are supplied directly to the gas turbine. This combustion chamber may be supplied with compressed air produced in a section of the compressor at the medium pressure, e. g. 20 kg./cm.^{2}, the same as the exhaust gases from the auxiliary prime mover.

Since the high pressure gases are supplied to the auxiliary prime mover at a temperature of 700° C. it is necessary to cool the casing of this prime mover. To this end the high pressure air, for example, 100 kg./cm.^{2}, may be circulated without noticeable heat loss through a jacket provided for the casing of the auxiliary gas utilizing prime mover. The very high density of the air at this high pressure insures a high heat transfer coefficient so that such circulation of air through the jacket is quite efficient for effecting the cooling of the auxiliary prime mover and for heating the high pressure air.

This high pressure air may be further heated in a separate heat exchanger through which the air is passed as it flows to the combustion chamber in which the gases which are supplied to the auxiliary prime mover are produced. This heat exchanger may be heated by the exhaust gases from an internal combustion engine which cooperates with the auxiliary gas utilizing prime mover in driving the air compressors. These gases at this exhaust pressure when leaving the heat exchanger are delivered to a corresponding pressure stage of the gas turbine in order to develop power from their remaining thermal and dynamic energy.

As will be more clearly understood in connection with the description to follow taken in connection with the drawings the air compressor may be constructed in sections which will produce compressed air at the different pressures which have been referred to above as well as at other pressures. The air thus may be compressed in stages in which the pressure is raised substantially to the different pressures at which it is utilized in the system. The internal combustion engine thus also may be supplied with compressed air for supercharging.

Supplementing the gas utilizing power generating plant above described, in accordance with the invention vapor or steam generating means may be provided for generation of vapor by the heat of the combustion which produces the high pressure high temperature gases which are supplied to the auxiliary gas utilizing prime mover. This vapor or steam also may be superheated by the heat of this combustion. The vapor or steam thus generated and heated may be supplied to a vapor or steam utilizing prime mover for developing power therefrom. For simplicity this prime mover will be referred to as a steam turbine. Such a steam turbine may be mounted on the same shaft or may be otherwise mechanically connected to the gas turbine to cooperate therewith for developing the useful power.

In another aspect of the invention steam may be extracted or withdrawn from the steam turbine and reheated by the heat of the combustion chamber in which are produced the gases at medium pressure which are supplied to the main gas turbine. This reheated steam may be returned to the steam turbine for further expansion thereof before discharge to the usual condenser.

The condensate from this condenser may be delivered to steam generating means associated with the combustion chamber which produces the high pressure gases supplied to the auxiliary gas utilizing prime mover for generating steam therefrom. Preferably this condensate is first reheated in the conventional manner by steam bled from the steam turbine. In order to provide the requisite cooling medium for the jacket conventionally provided in the internal combustion engine which supplies part of the power for the air compressors, a part of this condensate or of the condensed bled steam may be delivered to this jacket for flow therethrough. In this jacket steam may be generated from this cooling medium and may be superheated in a heat exchanger through which the exhaust gases from the internal combustion engine flow as they are delivered toward the reduced pressure stage of the main gas utilizing prime mover or turbine. The steam thus generated and superheated may be delivered to a reduced pressure stage of the steam turbine for developing power therefrom before discharge to the condenser.

The invention will be further understood from the description to follow taken in connection with the drawings in which

Fig. 1 is a simplified diagram of the power generating plant of the invention;

Fig. 2 is an entropy diagram showing different aspects of the thermal cycle of the invention;

Fig. 3 shows diagrammatically the novel gas utilizing power generating plant of the invention;

Fig. 4 is a section on line **4—4** of Fig. 3;

Fig. 5 is a section on line **5—5** of Fig. 3;

Fig. 6 shows a modification of the power generating plant of the invention which includes steam generating and steam heating apparatus and a steam utilizing prime mover.

In Fig. 1 an internal combustion engine **2** drives an air compressor **3** which discharges high pressure compressed air, for example, at a pressure of 100 kg./cm.^{2}, to the conduit **5** leading to a combustion chamber **7**. An air compressor **9** driven by a gas utilizing prime mover **11** also supplies compressed air to the conduit **5** for delivery to the combustion chamber **7**. The combustion chamber **7** may be supplied with fuel to produce combustion gases at high pressure, for example, 100 kg./cm.^{2}, which are delivered through the conduit **13** to the auxiliary gas utilizing prime mover **11** for expansion therein to develop the power for driving the compressor **9**.

The gases exhausted from the auxiliary gas utilizing prime mover **11** are carried through the conduit **15** to a combustion chamber **17** which may be supplied with fuel to produce therein combustion gases at medium pressure corresponding to the pressure of the exhaust gases from the prime mover **11**, for example, 20 kg./cm.^{2}. The gases produced in the combustion chamber **17** at this pressure are carried through the conduit **19** to a gas turbine **21** for expansion therein and discharge therefrom, for example, at atmospheric pressure. The combustion chamber **17** also is supplied through the conduit **23** with compressed air from the compressor **9** at the requisite medium pressure to support combustion therein for producing the gases in the combustion chamber **17**. It will be understood that the exhaust gases from the auxiliary prime mover **11** thus may be reheated in the combustion chamber **17** before being admitted into the gas turbine **21**. The temperature to which the combined gases, namely those produced by combustion of fuel in the combustion chamber **17** and the exhaust gases from prime mover **11** may be raised may be of the degree of 700° C. when the pressure of the gases produced in the combustion chamber **17** is, for example, 20 kg./cm.^{2}.

In the entropy diagram of Fig. 2 are shown several aspects of the thermal cycle which may be carried out in the power generating plant diagrammatically shown in Fig. 1 and further described hereafter.

The cycle shown in full lines *abcdefghe'a* relates to the air and gases which are produced at high pressure and temperature and are expanded from such high pressure, for example, 100 kg./cm.^{2}, to the medium pressure, 20 kg./cm.^{2}, then are reheated and further expanded to atmospheric pressure.

The cycle represented in dash lines *akjlmna* represents the cycle for gases produced at a medium pressure, for example 20 kg./cm.^{2}, if these gases were not cooled by admixture therewith, as above mentioned, of the exhaust gases from the auxiliary prime mover **11**.

The cycle in dotted line *aarsva* represents the cycle of the internal combustion engine supplied with air at supercharging pressure.

In Fig. 2, by way of example, the lines of constant pressure are shown representing 1 kg./cm.^{2} or atmospheric pressure and the pressures of the several pressure stages developed in the compressor. In the full line diagram the air at atmospheric pressure is compressed first to 10 kg./cm.^{2} along the line *ab* corresponding to polytropic compression not greatly different from isothermal compression. This may be accomplished by the atomization of water within the compression chambers of the compressors in a manner and by means not shown which in themselves are not part of this invention. The air thus compressed at 10 kg./cm.² is cooled along the line *bc* which may be accomplished by a conventional intercooler. This air then is compressed in a second stage from 10 kg./cm.² to 100 kg./cm.² along the line *cd* representing a polytropic compression which departs substantially from the isothermal in order to obtain a final temperature of about 150° C. in the example illustrated in Fig. 2 which substantially corresponds to maximum efficiency. The air at this high pressure then may be circulated, as described generally above, through the jacket of the auxiliary gas utilizing prime mover 11 and thereafter may be further heated by flow through a heat exchanger as will be described in connection with Fig. 2 which may receive heat from the exhaust gases from the internal combustion engine. This heated air may be further heated by mixture with the gases produced within the high pressure combustion chamber 7 and then supplied to the auxiliary prime mover 11 for development of power therefrom. Heating of the air at 100 kg./cm.² is indicated by the isobar *de* in Fig. 2. Adiabatic expansion of these high pressure gases from a temperature of approximately 700° C. in the example of Fig. 2 in the auxiliary gas utilizing prime mover 11 is indicated along the line *ef* to the medium pressure, 20 kg./cm.². The gases exhausted from the auxiliary prime mover at this medium pressure again are heated, as above indicated, in the combustion chamber 17 along the isobar *fg* to a temperature of approximately 700° C. The second adiabatic expansion which is accomplished in the gas turbine 21 is indicated by the line *gh* to atmospheric pressure, 1 kg./cm.², at which pressure the gases are exhausted along the isobar *ha* to close the full line diagram.

In the diagram shown in dash lines a two-stage compression is represented first from the atmospheric pressure to 4.4 kg./cm.² along the line *ak*. Intercooling is represented by the line *kj* and the second stage compression from 4.4 kg./cm.² to 20 kg./cm.² is represented by the line *jl*. The air thus compressed is heated along the isobar *lm* at 20 kg./cm.². In this diagram this heating is not stopped at the final temperature of 700° C., which, for example, may be determined by heating resisting materials available for the purpose, but at the temperature which would be reached if the mixture of the exhaust gases from the auxiliary gas utilizing prime mover 11 with the combustion gases produced in the combustion chamber 17 had not been effected. This temperature then would have risen to a temperature of the degree of 1200° C.

In the diagram in dotted lines the compression of the air for the internal combustion engine 2 from atmosphere to 3.5 kg./cm.² assumed as the supercharging pressure is represented by the adiabatic *ap*, the compression within the internal combustion engine to 80 kg./cm.² being continued along the diabatic *pq*. Heating of the compressed combustion gases within internal combustion engine by the combustion of the fuel supplied thereto is represented along the isobar *qr* and expansion of the gases in the power stroke of the internal combustion engine is represented along the adiabatic *rs* again to the supercharging pressure 3.5 kg./cm.². The cooling of the gases exhausted from the internal combustion engine by heating the air supplied to the high pressure combustion chamber or, in the modified power generating plant, by superheating the steam generated in the jacket of the internal combustion engine is represented by the isobar *sp*. Expansion of these exhaust gases in the gas turbine 19 is effected along the adiabatic *pa*.

From the entropy diagram with the aid of conventional tables the different amounts of energy utilized and the final efficiency of the cycle may be determined without difficulty. In such determinations it is necessary to bear in mind that the air quantities which are involved in the three different cycles hereinabove described are not the same but depend upon the selected final temperature and the selected power of the gas and internal combustion engines. The mass of air at 20 kg./cm.² will depend on the final temperature of this air after heating. It will be smaller according as this temperature is increased. At the same time the mass of air at 3.5 kg./cm.² will depend directly on the power which is chosen for the internal combustion engine. By judicious choice of the various elements it will not be difficult to arrive at a condition where the quantities of air at 20 kg./cm.² and of the supercharging air at 3.5 kg./cm.² both have, for example, a value equal to half the value of the air mass compressed to 100 kg./cm.².

From the point of view of final efficiency as well as from that of simplicity of the equipment, compressors of the free piston type are preferred more particularly those of the free oscillator type. For improvement of efficiency also part of the heat otherwise lost by cooling of the internal combustion engines may be recovered by circulating water under sufficient pressure, for example, 5 kg./cm.², and evaporating a part of this water in the jacket of these engines in accordance with a prior proposal of the applicants. It may be advisable in certain cases from the standpoint of final efficiency to effect cooling of the internal combustion engines by means of air compressed by the apparatus to 100 kg./cm.² or to 20 kg./cm.²

In Fig. 3 the essential elements of the basic gas utilizing power generating plant are shown for carrying out the cycle of Fig. 2. In Fig. 3 the prime mover compressor unit 23 comprises a low pressure compressor section and a high pressure compressor section driven by an auxiliary prime mover utilizing gases at high pressure and temperature and also driven by an internal combustion engine, all of these elements in the embodiment of Fig. 3 being oscillating free piston fluid pressure machines with the oscillating members thereof supported for oscillation on a common axis and mechanically connected together for effecting compression of the air upon oscillating movement of the compressor members produced by the oscillating movement of the prime mover members of this unit. All of these elements, as will be understood more clearly from the more detailed description to follow of the compressor sections, may be constructed, for example, with eight chambers in which respectively vanes carried by the respective oscillating members reciprocate, the compression of the air to the several pressures required for the cycle described in connection with Fig. 2 being accomplished in the different chambers of the low pressure and of the high pressure sections of the compressor. The expansion of the high temperature high pressure gases and of the gases produced in the internal combustion engine is effected in similar chambers respectively of the auxiliary prime mover and of the internal combustion engine concomitantly with reciprocation in these chambers of the vanes of these prime movers.

In Fig. 3 a low pressure section 25 of the air compressor receives atmospheric air through the intake 27. This air compressor, being of the oscillating type comprises, as shown more or less diagrammatically in Fig. 4, an oscillating member 29 supported for oscillation upon its axis and provided with vanes outwardly extending therefrom respectively reciprocating within compression chambers formed within a casing 31 between inwardly extending sectors 33. The two oppositely disposed vanes 35 reciprocate within the respective chambers 37 for compression of the air from 1 kg./cm.^{2} to 3.5 kg./cm.^{2}. The two oppositely disposed vanes 39 reciprocating within the respective chambers 41 compress the air from 1 kg./cm.^{2} to 4.4 kg./cm.^{2} in the first stage of the two-stage compression to 20 kg./cm.^{2}. The four vanes 43 reciprocating in the four chambers 45 compress air from 1 kg./cm.^{2} to 10 kg./cm.^{2} in the first stage of the two-stage compression for producing air at 100 kg./cm^2. For simplicity the requisite connections between the chambers and the valve gear for controlling the air as it is being compressed and for controlling delivery thereof from the low pressure section 25 of the compressor are not shown in Fig. 4. It will be apparent, nevertheless, that the compressed air may be discharged from the respective chambers at the pressures requisite for supercharging the internal combustion engine as well as for further compression in the high pressure section 55 of the compressor. It will be noted consistent with the above description of the particular cycle represented in Fig. 2 that in the low pressure section 25 two chambers are provided for compression of the air from 1 kg./cm.^{2} to 3.5 kg./cm.^{2}, two chambers are provided for compression from 1 kg./cm.^{2} to 4.4 kg./cm.^{2} and four chambers are provided for compression from 1 kg./cm.^{2} to 10 kg./cm.^{2}

Through the pipe 57 air compressed in the low pressure section 25 of the compressor to 10 kg./cm.^{2} is delivered to the high pressure section 55 of the compressor for compression therein to 100 kg./cm.^{2}. As shown in Fig. 5 which is a section on line 5—5 of Fig. 3, the high pressure section 55 is constructed similarly to the low pressure section as an oscillating free piston compressor and is similarly provided with four chambers 51 in which vanes 53 carried by the oscillating member 52 reciprocate, these four chambers providing for compression to 100 kg./cm.^{2} of the air first compressed in the low pressure section to 10 kg./cm.^{2} . Through another pipe 59 air compressed in the low pressure section to 4.4 kg./cm.^{2} is delivered to the other four chambers 54 of the high pressure section 55 to be compressed therein to 20 kg./cm.^{2} by vanes 56.

It will be understood that in some cases the air quantities required may not be exactly in the ratio of 2 to 1 assumed in the above discussion. Variation, however, may be made to meet different conditions by varying the amount of clearance between the vanes on the oscillatable members and the sectors which provide the end walls of the chambers in which these vanes reciprocate. Moreover, it is possible to construct the oscillating free piston machines which chambers of different radial extent and with correspondingly different radial dimensions of the vanes reciprocating therein.

The compressed air at high pressure, 100 kg./cm.^{2}, is delivered from the high pressure section 55 through pipe 61 to the jacket of the auxiliary gas utilizing prime mover 63 which supplies part of the power for driving the air compressors 25, 55 to effect cooling of this auxiliary gas utilizing prime mover and heating of this high pressure air. This air is then delivered to the annular space 64 between the jacket 65 and the gas supply pipe 67 carrying high pressure high temperature gases to the auxiliary gas utilizing prime mover 63 and is further heated in this jacket. As shown in Fig. 3 the annular space 64 is connected to the annular space 68 formed between the double walls extending about a combustion chamber 69 so that the compressed air after passing through the jacket of the auxiliary prime mover 63 and through the jacket 65 passes through the annular space 68 and is heated therein while preventing undue loss of heat from the combustion chamber walls. This high pressure air thus heated continues through the pipe 71 to a space at one end of a tubular heat exchanger 73 supplied with heating gases as hereinafter described for flow through the tubes 75 of this heat exchanger to the space at the opposite end thereof from which the pipe 77 leads to carry the high pressure air thus further heated in the heat exchanger 73 to the combustion chamber 69 for support of combustion therein of fuel supplied to the combustion chamber through the pipe 79. The heat thus added to the air at high pressure, e. g. 100 kg./cm.^{2}, may be such as to bring its temperature to say 700° C. as explained in connection with Fig. 2. These high pressure high temperature combustion gases are expanded in the auxiliary gas utilizing prime mover driving the compressor sections and are exhausted therefrom at 20 kg./cm.^{2} through the pipe 81 which conducts these gases to the combustion chamber 85.

This combustion chamber is supplied with fuel through pipe 87 for producing combustion gases therein at the medium pressure, namely, 20 kg./cm.^{2} in the example under discussion. From the chambers of the high pressure section 55 of the compressor in which air is compressed from 4.4 kg./cm.^{2} to 20 kg./cm.^{2} the compressed air at 20 kg./cm.^{2} is delivered through the pipe 89 to a jacket 91 forming an annular space 92 about a pipe 93. From the combustion chamber 85 combustion gases at the medium pressure are delivered through pipe 93 to the main gas utilizing prime mover 95 which in the embodiment illustrated in Fig. 3 is a gas turbine. The compressed air at the medium pressure flows through space 92 of the jacket 91 and through annular space 86 provided by the spaced walls of the combustion chamber 85 and through the pipe 97 into the combustion chamber 85 adjacent the burner for supporting combustion of the fuel supplied by the fuel pipe 87 to produce gases at the medium pressure. It thus will be apparent that the gases supplied to the turbine 95 through pipe 93 comprise the gases produced directly by combustion of the fuel at the medium pressure as well as the gases exhausted from the auxiliary gas utilizing prime mover 63 at the medium pressure, 20 kg./cm.^{2}. In the embodiment of Fig. 3 the gases from the turbine 95, after expansion thereof, are exhausted to atmosphere through the pipe 99.

From the chambers of the low pressure section 25 of the compressor in which the air is compressed to 3.5 kg./cm.^{2} air is delivered through the pipe 100 to the internal combustion engine 101 for supercharging the internal combustion engine. The exhaust gases leaving this internal combustion engine substantially at the pressure of 3.5 kg./cm.^{2} flow through the pipe 103 to the space about the tubes 75 of the heat exchanger 73 to heat the high pressure compressed air flowing through these tubes as above described. The exhaust gases then are discharged from the heat exchanger 73 through the pipe 105 and are delivered to a reduced pressure stage of the gas turbine 95 for expansion therein to atmospheric pressure as referred to above in the description in connection with the entropy diagram in dotted lines in Fig. 2.

It will be understood in accordance with conventional practice that intercoolers may be provided between the stages of compression effected by the low pressure and high pressure sections of the compressor for effecting cooling, as indicated above in connection with Fig. 2, of the air compressed in a lower stage before further compression thereof in a higher stage. Such intercoolers if required may be connected, for example, in the pipes 57 and 59 of Fig. 3.

In Fig. 6 is shown a modification of the power generating plant of Fig. 3 in which the combustion chambers 69 and 85 respectively also serve for generating and superheating vapor, such as steam from water, and for reheating such vapor or steam for expansion thereof in a steam turbine, the reheated steam being delivered again to the turbine for further expansion in the reduced pressure stage thereof. In Fig. 6 for the most part the corresponding elements and members of the apparatus are identified by the same reference numerals as in Fig. 3. Thus in Fig. 6 the air compressed in the low pressure section of the compressor 25 is delivered through the pipe 59 at 4.4 kg./cm.^{2} to the high pressure section 55 to be compressed therein to 20 kg./cm.^{2} and then is delivered through the pipe 89 to the jacket 91 surrounding the gas supply pipe 93 leading to the gas turbine 95. The compressed air at 20 kg./cm.^{2} is heated in passing along the annular space 92 of the jacket 91 by the gases flowing from the combustion chamber 85 through the pipe 93 to the turbine 95. The air at this pressure thus heated is delivered to the burner 111 for support of the combustion of the fuel supplied to this burner by the pipe 87. Similarly to the embodiment of Fig. 3 through the pipe 81 the exhaust gases from the auxiliary gas utilizing prime mover 63 driving the air compressors also is delivered to the combustion chamber 85 at the medium pressure of 20 kg./cm.^{2} in the example under discussion. Thus, it will be apparent that the combustion chamber 85 in the embodiment of Fig. 6 operates at this medium pressure and that the gases supplied to the gas turbine are derived in part from the exhaust of the auxiliary prime mover and in part from the combustion of fuel at the burner 111, as in Fig. 3.

In the embodiment of Fig. 6 as in that of Fig. 3 air compressed in the low pressure section 25 to 10 kg./cm.^{2} is delivered through the pipe 57 to the high pressure section 55 to be compressed to 100 kg./cm.^{2}. Air at this high pressure is delivered through the pipe 61 to the jacket of the auxiliary prime mover 63 and discharged from this jacket to the jacket 65 surrounding the pipe 67 which carries the hot high pressure gases from the combustion chamber 69 to the auxiliary prime mover 63.

The air at high pressure from the jacket 65, as in the embodiment of Fig. 3, is delivered through pipe 71 and through the tubes 75 of the heat exchanger 73 and through the pipe 77 to the burner 113 to which through the pipe 79 fuel is supplied for combustion thereof in the combustion chamber 69. The combustion gases thus produced at high pressure of the degree of 100 kg./cm.^{2} in this example are expanded in the auxiliary prime mover through pipe 67. As above stated the exhaust gases at 20 kg./cm.^{2} from the auxiliary prime mover 63 are delivered through pipe 81 to the combustion chamber 85.

As in Fig. 3 supercharging air is supplied at 3.5 kg./cm.^{2} to the internal combustion engine 101 through the pipe 100 from the low pressure section 25 of the compressor. The exhaust gases from the internal combustion engine 101 in this embodiment are delivered at 3.5 kg./cm.^{2} through the pipe 121 to the heat exchanger 73 for heating the air at high pressure flowing through tubes 75 of this heat exchanger. The gases upon discharge from the heat exchanger 73 are carried through pipe 105 to a reduced pressure stage of the turbine 95 for further expansion therein.

In the embodiment of Fig. 6 the high pressure combustion chamber 69 is provided with a water wall 125 enveloping this chamber to which through pipe 127 the condensate from a condenser 129 receiving the steam from the steam turbine 131 is delivered. Although not shown in Fig. 6 the conventional banks of tubes or other means for absorbing heat from the gases also may be provided within the combustion chamber 69 for generating steam from the water received through pipe 127 and for superheating this steam. This superheated steam may be carried through pipe 133 to a high pressure stage of the turbine 131 for expansion therein to the condensing pressure and discharge of the steam at this pressure to the condenser 129 to produce the condensate. This condensate is carried through the pipe 135 to conventional water heaters 136, 137 which are heated by steam bled from the turbine 131, the steam condensed in the heaters 135, 137 being returned through pipes 138, 139 to the water flow pipes to be mixed with the condensate from the condenser 129.

Steam may be bled from the turbine, for example at 5 kg./cm.^{2}, for heating the condensate in the heater 136 to 150° C. this heated water being delivered through the pipe 141 to the jacket of the internal combustion engine 101 for effecting cooling of this internal combustion engine. Steam is generated from this water in this jacket and is carried through the jacket 123 surrounding the exhaust pipe 121 in which jacket it is superheated for extracting heat from the exhaust gases from the internal combustion engine. This superheated steam then is carried through the pipe 143 to a reduced pressure stage of the steam turbine 131 for expansion therein to the condensing pressure.

Enveloping the combustion chamber 85 operating at the medium pressure of 20 kg./cm.^{2}, or in conventional arrangements to receive the heat of the combustion chamber, steam carrying passages are provided. Steam extracted from a reduced pressure stage of the steam turbine 131 is carried through the pipe 151 to these passages of the combustion chamber 85 for reheating therein and return through the pipe 153 to an adjacent stage of the steam turbine 131 for further expansion therein to the condensing pressure.

In the power generating plant shown in Fig. 6 the burner 113 instead of merely developing the heat for raising the temperature of the gases to that requisite for delivery to the auxiliary prime mover, which requires only a part of the oxygen in the high pressure air delivered to the combustion chamber, may develop heat to heat the water for generating steam and for superheating this team. This steam may be and preferably is generated at a pressure of the same degree, e. g. 100 kg./cm.^{2}, as that of the combustion gases produced in the combustion chamber 69. Power generating plants utilizing combustion chambers thus operated at "equipressure" are disclosed in our Patent No. 2,466,723, April 12, 1949, and in a copending application of Ernest Mercier Serial No. 472,217 filed January 13, 1943, now abandoned, and in a copending application of Ernest Mercier Serial No. 103,893, filed July 9, 1949, now Patent No. 2,547,135, which latter is a continuation in part of the said application Serial No. 472,217.

It will be understood, although the jacket 65 surrounding the pipes 67 and the jacket 91 surrounding the pipe 93 are not shown in Fig. 6 extending the full length respectively of the pipes 67 and 93, that these jackets may be of any desired length and if desired may cover the full length of the pipes from the outlet connection from the combustion chambers 69 and 85 respectively to the auxiliary prime mover 63 and the gas turbine 95 in order to prevent loss of heat from these pipes and to recover therefrom heat for heating the high pressure air and for heating the medium pressure air for the combustion of the fuel in the respective combustion chambers.

It will be understood further that within the scope of the invention to suit different conditions various combinations of the steam generating and steam reheating apparatus with the gas generating and gas utilizing apparatus may be used. For example, in Fig. 6 the reheating of steam extracted from the steam turbine may be omitted, the gases at the medium pressure being produced in a combustion chamber in the manner shown and described in connection with Fig. 3 for supply of these gases to the gas turbine. The cooling of the internal combustion engine also may be accomplished without the generation of steam or without the superheating thereof in the heat exchanger represented by the pipe 121 and the jacket 123. The air compressed at medium pressure may be heated by the exhaust gases from the internal combustion engines.

Other variations may be made without departing from the main inventive concept according to which a gas utilizing prime mover, such as a gas turbine, is supplied with hot gases at medium pressure, a part of which gases may be and preferably are supplied by the exhaust from an auxiliary gas utilizing prime mover supplying at least a part of the power for driving the air compressor, this air compressor supplying air for support of combustion directly to produce gases at the medium pressure for expansion in the gas turbine and also supplying air for support of combustion at high pressure to produce high pressure high temperature gases for supplying the auxiliary prime mover to develop power therefrom.

It will be understood that liquid or colloidal fuels or solid fuel (powdered coal) may be burned in the respective combustion chambers 7, 17, 69, 85 for developing heat in these combustion chambers.

In a further modification within the scope of the invention instead of using water in the jacket of the internal combustion engine for cooling this engine, compressed air, for example at 100 kg./cm.^{2}, may be circulated in this jacket before being delivered to the combustion chamber. Moreover, the heat remaining in the exhaust gases from the gas turbine may be partially recuperated by heating the air or the water at suitable points in the cycle. For example, these gases may be used in some cases in a suitable heat exchanger to heat or to aid in heating the air for combustion of fuel to produce the high pressure gases.

In the claims reference is made to "main" and "auxiliary" combustion chambers and prime movers for conveniently distinguishing between the combustion champer supplying the gases to the gas utilizing prime mover, the gas turbine in the embodiment described, which delivers the useful power and the combustion chamber which supplies the high pressure gases to the prime mover supplying power to the air compressors.

We claim:

1. Power generating plant comprising means providing a combustion chamber for combustion of fuel therein, means for effecting combustion of fuel in said combustion chamber to produce gases at a predetermined pressure substantially above atmospheric pressure, a main gas utilizing prime mover connected to said combustion chamber for utilizing the gases therefrom under said predetermined pressure to develop power in said prime mover by expansion of said combustion gases, means for compressing a combustion supporting gas to a pressure effective for delivering said gas to said combustion chamber against the pressure of the combustion gases therein, said combustion chamber being connected to said compressing means to receive said compressed combustion supporting gas therefrom without substantial expansion thereof, an auxiliary prime mover utilizing gases at high temperature and at a pressure initially in excess of said predetermined pressure to develop power therefrom by expansion thereof to an exhaust pressure substantially corresponding to said predetermined pressure of said gases in said combustion chamber, said auxiliary prime mover being operatively connected to said compressing means for driving said compressing means independently of said main prime mover to effect said compression of said combustion supporting gas, and means for delivering the exhaust gases from said auxiliary prime mover driving said gas compressing means to said combustion chamber to be delivered therefrom with and to cooperate with said gases produced in said combustion chamber for developing power therefrom in said main prime mover upon further expansion thereof from said exhaust pressure.

2. Power generating plant comprising means providing a combustion chamber for combustion of fuel therein, means for effecting combustion of fuel in said combustion chamber to produce gases at a predetermined pressure substantially above atmospheric pressure, a main gas utilizing prime mover connected to said combustion chamber for utilizing the gases therefrom under said predetermined pressure to develop power in said prime mover by expansion of said combustion gases, means for compressing a combustion supporting gas to a pressure effective for delivering said gas to said combustion chamber against the pressure of the combustion gases therein, said combustion chamber being connected to said compressing means to receive said compressed combustion supporting gas therefrom substantially at said pressure to which it is compressed,

an auxiliary prime mover, means cooperating with said auxiliary prime mover to effect utilization of gases at high temperature and at a pressure initially substantially in excess of said predetermined pressure to develop power therefrom by expansion thereof to an exhaust pressure substantially corresponding to said predetermined pressure of said gases in said combustion chamber, said auxiliary prime mover being operatively connected to said compressing means for driving said compressing means independently of said main prime mover to effect said compression of said combustion supporting gas, and means for delivering the exhaust gases from said auxiliary prime mover driving said gas compressing means to said combustion chamber to be heated by the heat of the combustion therein and to be delivered therefrom with and to cooperate with said gases produced in said combustion chamber for developing power therefrom in said main price mover upon further expansion thereof from said exhaust pressure.

3. Power generating plant as defined in claim 1 which comprises an internal combustion engine operatively connected to said compressing means to provide part of the power required for operating said compressing means.

4. Power generating plant as defined in claim 1 in which said compressing means and the prime mover driving said compressing means are free piston fluid pressure machines.

5. Power generating plant as defined in claim 3 in which said compressing means and said auxiliary gas utilizing prime mover and said internal combustion engine are free piston fluid pressure machines of the oscillator type.

6. Power generating plant as defined in claim 3 which comprises compressing means connected to said internal combustion engine for supplying supercharged combustion supporting gas thereto.

7. Power generating plant as defined in claim 1 which comprises a cooling jacket for said auxiliary prime mover, and means for delivering compressed combustion supporting gas from said compressing means through said jacket for cooling said auxiliary prime mover and heating said compressed combustion supporting gas.

8. Power generating plant as defined in claim 1 which comprises an auxiliary combustion chamber, means for effecting combustion of fuel in said auxiliary combustion chamber to produce said gases at said high temperature and at said pressure initially in excess of said predetermined pressure, said auxiliary combustion chamber being connected to said auxiliary prime mover to deliver said combustion gases thereto to said exhaust pressure to develop power therefrom by expansion thereof in said auxiliary prime mover.

9. Power generating plant as defined in claim 8 which comprises means for delivering compressed combustion supporting gas at a pressure of the degree of the pressure of the gases produced in said auxiliary combustion chamber to said auxiliary combustion chamber for support of the combustion therein.

10. Power generating plant as defined in claim 8 which comprises a jacket enveloping said auxiliary combustion chamber, means for delivering compressed combustion supporting gas at a pressure of the degree of the pressure of the gases produced in said auxiliary combustion chamber to said jacket for flow therethrough for intercepting heat otherwise lost from the walls of said combustion chamber and heating said combustion supporting gas, and means for delivering said compressed combustion supporting gas heated in said jacket to said auxiliary combustion chamber for support of the combustion therein.

11. Power generating plant as defined in claim 1 which comprises a heat exchanger, means for delivering compressed gas at a pressure of the degree of the pressure of said gases at high temperature and pressure utilized in said auxiliary prime mover to said heat exchanger to be heated therein, means for delivering said heated compressed gas to said auxiliary prime mover for said power developing expansion therein an internal combustion engine cooperating with said auxiliary prime mover for developing power for driving said compressing means, means connecting said internal combustion engine to said heat exchanger for delivering exhaust gases from said internal combustion engine to said heat exchanger for heating said compressed gas therein, and means for delivering said exhaust gases from said heat exchanger to a reduced pressure stage of said main prime mover for developing therein power from said exhaust gases.

12. Power generating plant as defined in claim 1 which comprises a heat exchanger, means for delivering compressed combustion supporting gas at a pressure of the degree of the pressure of said gases at high temperature and pressure utilized in said auxiliary prime mover to said heat exchanger to be heated therein, an auxiliary combustion chamber, means for delivering said heated compressed combustion supporting gas from said heat exchanger to said auxiliary combustion chamber for support of combustion therein, means for effecting combustion of fuel in said auxiliary combustion chamber to produce said gases at high temperature and at said pressure initially in excess of said predetermined pressure, said auxiliary combustion chamber being connected to said auxiliary prime mover to deliver said combustion gases thereto for said power developing expansion therein, an internal combustion engine cooperating with said auxiliary prime mover for developing power for driving said compressing means, means connecting said internal combustion engine to said heat exchanger for delivering exhaust gases from said internal combustion engine to said heat exchanger for heating said compressed combustion supporting gas therein, and means for delivering said exhaust gases from said heat exchanger to a reduced pressure stage of said main prime mover for developing therein power from said exhaust gases.

13. Power generating plant as defined in claim 12 in which said internal combustion engine is provided with a cooling jacket, a steam utilizing prime mover, means for supplying steam to said steam utilizing prime mover to develop power therefrom by expansion of said steam in said steam utilizing prime mover, means for condensing steam withdrawn from said steam utilizing prime mover after expansion thereof, means for delivering the condensate through said jacket of said internal combustion engine for effecting cooling of said internal combustion engine and for generating steam from said condensate in said jacket, heat exchange means connected between said internal combustion engine and said heat exchanger for flow of the exhaust gases from said internal combustion engine through said heat exchange means to said heat exchanger, said heat exchange means being connected to said jacket of said internal combustion engine to receive the generated steam therefrom for super-

heating said steam by the heat of said exhaust gases.

14. Power generating plant comprising means providing a main combustion chamber for combustion of fuel therein, means for effecting combustion of fuel in said combustion chamber to produce gases at a predetermined pressure substantially above atmospheric pressure, a main gas utilizing prime mover connected to said main combustion chamber for utilizing the gases therefrom under said predetermined pressure to develop power in said main prime mover by expansion of said combustion gases, means for compressing a combustion supporting gas to a pressure effective for delivering said gas to said combustion chamber against the pressure of the combustion gases therein, said combustion chamber being connected to said compressing means to receive said compressed combustion supporting gas therefrom without substantial reduction of the pressure thereof, an auxiliary combustion chamber for combustion of fuel therein, means for effecting combustion of fuel in said auxiliary combustion chamber to produce gases at high temperature and at a pressure initially substantially in excess of said predetermined pressure, an auxiliary prime mover connected to said auxiliary combustion chamber and utilizing therefrom said gases at high temperature and at said pressure in excess of said predetermined pressure to develop power by expansion thereof to an exhaust pressure substantially corresponding to said predetermined pressure of said gases in said main combustion chamber, said auxiliary prime mover being operatively connected to said compressing means for driving said compressing means independently of said main prime mover to effect said compression of said combustion supporting gas, means for delivering the exhaust gases from said auxiliary prime mover driving said compressing means to said main combustion chamber to be heated therein and to be delivered therefrom with and to cooperate with said gases produced in said main combustion chamber for developing power therefrom in said main prime mover upon further expansion thereof from said exhaust pressure, steam generating means cooperating with said auxiliary combustion chamber for generating steam by the heat of said combustion therein, and a steam utilizing prime mover connected to said steam generating means to receive therefrom said steam generated therein for expansion of said steam in said steam utilizing prime mover.

15. Power generating plant comprising means providing a main combustion chamber for combustion of fuel therein, means for effecting combustion of fuel in said combustion chamber to produce gases at a predetermined pressure substantially above atmospheric pressure, a main gas utilizing prime mover connected to said main combustion chamber for utilizing the gases therefrom under said predetermined pressure to develop power in said main prime mover by expansion of said combustion gases, means for compressing a combustion supporting gas to a pressure effective for delivering said gas to said combustion chamber against the pressure of the combustion gases therein, said combustion chamber being connected to said compressing means to receive said compressed combustion supporting gas therefrom without substantial reduction of the pressure thereof, an auxiliary prime mover utilizing gases at high temperature and at a pressure initially substantially in excess of said predetermined pressure to develop power therefrom by expansion thereof to an exhaust pressure substantially corresponding to said predetermined pressure of said gases in said combustion chamber, said auxiliary prime mover being operatively connected to said compressing means for driving said compressing means independently of said main prime mover to effect said compression of said combustion supporting gas, means for delivering the exhaust gases from said auxiliary prime mover driving said compressing means to said main combustion chamber to be heated therein and to be delivered therefrom with and to cooperate with said gases produced in said combustion chamber for developing power therefrom in said main prime mover upon further expansion thereof from said exhaust pressure, a steam utilizing prime mover, means for supplying steam to said steam utilizing prime mover to develop power therefrom by expansion of said steam in said steam utilizing prime mover, steam reheating means heated by the heat of said main combustion chamber, means connecting a reduced pressure stage of said steam utilizing prime mover to said steam reheating means for reheating steam withdrawn at said reduced pressure from said steam utilizing prime mover, and means for returning said reheated steam of said reduced pressure from said reheating means to a reduced pressure stage of said steam utilizing prime mover for further expansion thereof in said steam utilizing prime mover.

16. Power generating plant as defined in claim 15 in which said reduced pressure of said steam withdrawn from said steam utilizing prime mover is of the degree of the pressure of the combustion gases within said main combustion chamber.

17. Power generating plant as defined in claim 1 which comprises an internal combustion engine cooperating with said auxiliary prime mover for generating power for driving said compressing means, said internal combustion engine being provided with a cooling jacket, a steam utilizing prime mover, means for supplying steam to said steam utilizing prime mover to develop power therefrom by expansion of said steam in said steam utilizing prime mover, means for condensing steam withdrawn from said steam utilizing prime mover after expansion thereof, means for delivering the condensate through said jacket of said internal combustion engine for effecting cooling of said internal combustion engine and for generating steam from said condensate in said jacket, heat exchange means connected to said internal combustion engine to receive the exhaust gases therefrom, said heat exchange means being connected to said jacket of said internal combustion engine to receive therefrom the steam generated therein for superheating said steam by the heat of said exhaust gases, means for delivering said exhaust gases from said heat exchange means to a reduced pressure stage of said main gas utilizing prime mover for developing therein power from said exhaust gases, and means for delivering said superheated steam from said heat exchange means to a reduced pressure stage of said steam utilizing prime mover for developing therein power from said superheated steam.

18. Power generating plant comprising means providing a main combustion chamber for combustion of fuel therein, means for effecting combustion of fuel in said combustion chamber to produce gases at a predetermined pressure substantially above atmospheric pressure, a main gas

utilizing prime mover connected to said combustion chamber for utilizing the gases therefrom under said predetermined pressure to develop power in said prime mover by expansion of said combustion gases, means for compressing a combustion supporting gas to a plurality of pressures, at least a given one of said pressures being effective for delivering at least a portion of said combustion supporting gas to said main combustion chamber against the pressure of the combustion gases therein, said main combustion chamber being connected to said compressing means to receive said compressed combustion supporting gas therefrom substantially at said given pressure, an auxiliary prime mover utilizing gases at high temperature and at a pressure initially substantially in excess of said predetermined pressure to develop power therefrom by expansion thereof to an exhaust pressure substantially corresponding to said predetermined pressure of said gases in said main combustion chamber, an internal combustion engine, said auxiliary prime mover and said internal combustion engine being operatively connected to said compressing means and cooperating to drive said compressing means as a unit independently of said main gas utilizing prime mover for effecting compression of said combustion supporting gas, said internal combustion engine being connected to said compressing means to receive therefrom combustion supporting gas at a pressure for supercharging said internal combustion engine, an auxiliary combustion chamber, means for effecting combustion of fuel in said auxiliary combustion chamber to produce said gases at high temperature and at said pressure in excess of said predetermined pressure, said auxiliary combustion chamber being connected to said compressing means to receive therefrom combustion supporting gas at a high pressure for combustion of fuel in said auxiliary combustion chamber at said pressure in excess of said predetermined pressure, said auxiliary combustion chamber being connected to said auxiliary prime mover to deliver thereto said combustion gases at said high temperature and substantially at said pressure in excess of said predetermined pressure to develop power therefrom, and means for delivering the exhaust gases from said auxiliary prime mover to said main combustion chamber to be heated therein and to be delivered therefrom with and to cooperate with said gases in said main combustion chamber for developing power therefrom in said main prime mover upon further expansion thereof from said exhaust pressure.

19. Power generating plant as defined in claim 13 in which said steam generating means is adapted for generating said steam at a pressure of the degree of the pressure of the combustion gases within said auxiliary combustion chamber.

20. Power generating plant comprising an internal combustion engine, a supercharger air compressor driven by said engine and connected to said engine to deliver thereto supercharging air at a pressure providing for exhausting the gases from said internal combustion engine at a pressure substantially above atmosphere pressure, a high pressure air compressor driven by said internal combustion engine, a high pressure combustion chamber connected to said high pressure compressor to receive high pressure air therefrom for effecting combustion of fuel to produce combustion gases substantially at said high pressure, an auxiliary gas utilizing prime mover cooperating with said internal combustion engine to drive said compressors and connected to said combustion chamber to receive therefrom said high pressure combustion gases for expansion in said auxiliary prime mover to a predetermined pressure substantially higher than said exhaust pressure of said internal combustion engine, a second combustion chamber, means for supplying fuel and air to said second combustion chamber for producing therein combustion gases substantially at said predetermined pressure, said auxiliary gas utilizing prime mover being connected to said second combustion chamber to deliver thereto the exhaust gases from said auxiliary prime mover at said predetermined pressure, a gas turbine connected to said second combustion chamber to receive therefrom said combustion gases produced therein and said exhaust gases heated therein by the heat of combustion for expansion of said exhaust and combustion gases in said turbine, said internal combustion engine being connected to a reduced pressure stage of said gas turbine to deliver thereto the exhaust gases from said internal combustion engine for further expansion in said gas turbine, said internal combustion engine and the auxiliary prime mover being connected to said compressors to drive said compressors independently of said gas turbine.

21. Power generating plant as defined in claim 20 in which said internal combustion engine and said auxiliary prime mover are free piston prime movers and said compressors are free piston compressors, said free piston engine and said auxiliary prime mover and said free piston compressors respectively being constructed with two elements oscillatable with respect to each other, given oscillatable elements of said engine and said auxiliary prime mover and said compressors being operatively connected together and the other elements of said engine and said auxiliary prime mover and said compressors also being operatively connected together to provide for oscillation of the connected given elements and the connected other elements with respect to each other.

22. Power generating plant comprising means providing a combustion chamber for combustion of fuel therein, means for effecting combustion of fuel in said combustion chamber to produce gases at a predetermined pressure substantially above atmospheric pressure, a main gas utilizing primer move connected to said combustion chamber for utilizing the gases delivered therefrom to said prime mover substantially at said predetermined pressure to develop power in said prime mover by expansion of said combustion gases, means for compressing a combustion supporting gas to a pressure effective for delivering said gas to said combustion chamber against the pressure of the combustion gases therein, said combustion chamber being connected to said compressing means to receive said compressed combustion supporting gas therefrom without substantial expansion thereof, means for developing from the combustion of fuel auxiliary gases at high temperature and at a pressure initially in excess of said predetermined pressure, an auxiliary prime mover connected to said auxiliary gas developing means for utilizing said gases at high temperature and at said pressure in excess of said predetermined pressure to develop power therefrom by expansion thereof in said auxiliary prime mover to an exhaust pressure substantially corresponding to said predetermined pressure of said

gases in said combustion chamber, said auxiliary prime mover being operatively connected to said compressing means for driving said compressing means independently of said main prime mover to effect said compression of said combustion supporting gas, and means for delivering the exhaust gases from said auxiliary prime mover driving said compressing means to said combustion chamber to be delivered therefrom with and to cooperate with said gases produced in said combustion chamber for developing power therefrom in said main prime mover upon further expansion thereof from said exhaust pressure.

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