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STEAM GENERATOR

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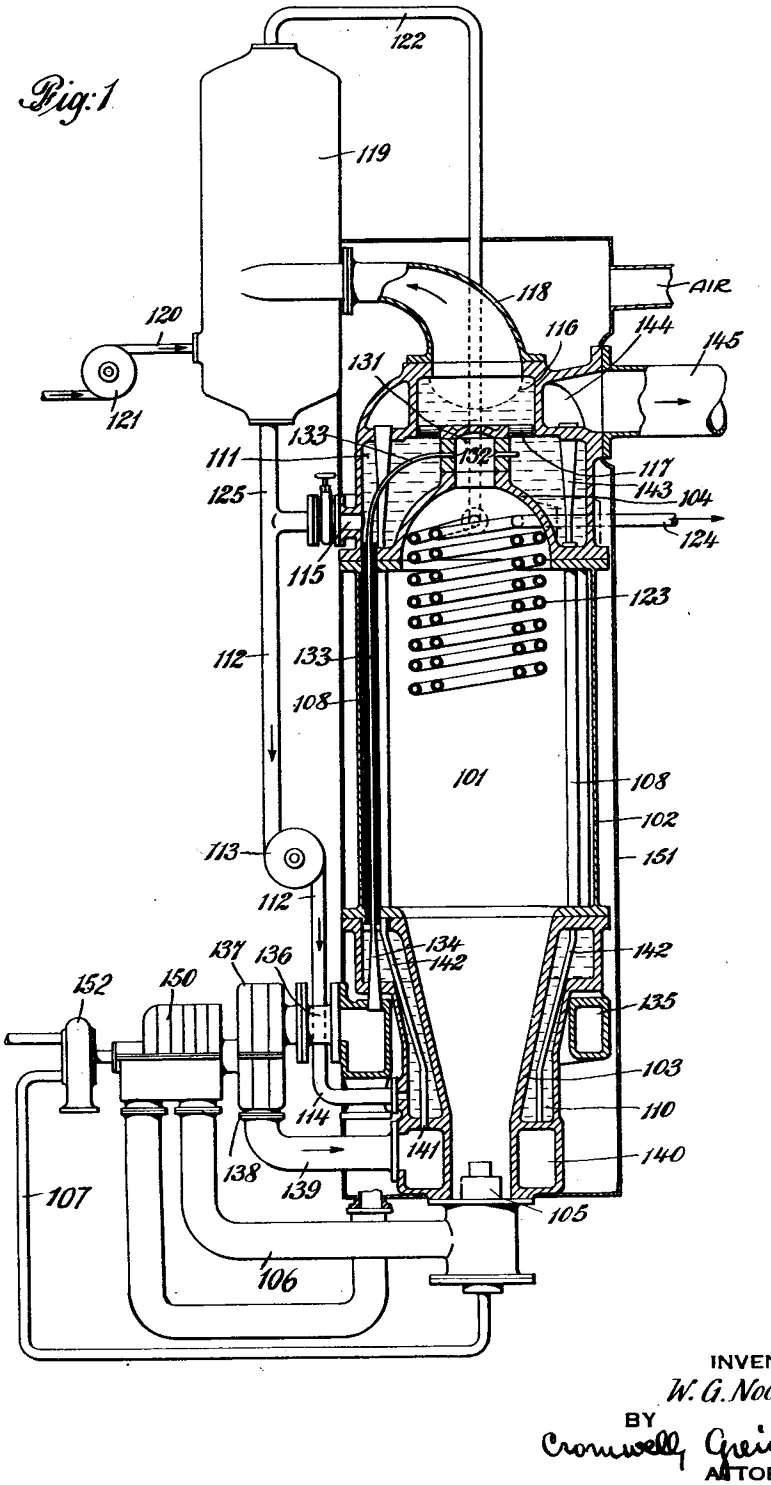
Fig: 1



INVENTOR
W. G. Noack
BY
Cromwell Greist Warden
ATTORNEY

UNITED STATES PATENT OFFICE

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STEAM GENERATOR

Walter Gustav Noack, Baden, Switzerland, assignor to Aktiengesellschaft Brown Boveri & Cie, Baden, Switzerland, a joint-stock company of Switzerland

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6 Claims. (Cl. 122—24)

This invention relates to steam generators and has as its object an improved type of steam generators which, owing to their special working conditions and construction, smallness in size, weight and water capacity, no longer form boilers in the accepted meaning of the word, but rather constitute steam generating machines. The chief features of these mechanized steam generators are the burning of the fuel mixture under high pressure in a pressure resisting combustion chamber, and the exceptionally high velocities at which the combustion gases are passed over the heating surfaces, ensuring small heating surfaces, cross-sectional area of the gas passages, and water spaces. As a matter of fact, it has been known for some time that, by increasing the pressure and the velocity, the transmission of heat from a gas to the water to be heated may be considerably improved. In the application to practice, however, the velocity of the heating gases is always kept relatively low, so that it is hardly likely that steam generators exist in which velocities higher than about 25 m/sec., have found application. This, in spite of the fact that scientific research has already extended its investigation into the transmission of heat at higher velocities, so that, for instance, for elastic fluids (gases), velocities have been experimented with up to 100 m/sec. However, heretofore no practical boilers utilizing these velocities were ever built, because the economical way for obtaining these high velocities was apparent to the art.

I have investigated the behaviour of gases in regard to the transmission of heat and flow resistance at velocities considerably exceeding the hitherto investigated range and found that by utilizing gas velocities of the order of 200 meters per second or more in the neighborhood of the velocity of the sound, it is possible to economically develop the pressure drop necessary for the generation of these high velocities and produce steam generators which occupy only a fraction of the space and have only a fraction of the weight of boilers of the same capacity made heretofore. The known laws of heat transmission and resistance to flow do not apply when a certain velocity is exceeded. If the velocity of the gas amounts to more than one third or one half of the critical speed (velocity of sound at the corresponding pressure and temperature) then the flow of gases is no longer similar to the flow of an inflexible fluid, but properties of the gases become apparent which are caused by the elasticity (compressibility) of the gas. The cooling of the gas during the flow in the tubes has a further influence, in that this cooling effects a reduction in velocity resulting from an increase of the density which causes a recompression of the gas (increase of the potential energy as a result of the decrease of the kinetic energy).

To obtain these high flow velocities pressure drops are necessary which amount to one hundred to a thousand times the usual draught met with in steam generators. These high pressure drops cannot be obtained with the system of forced draught, as used in ordinary boilers, but special measures must be provided for, several of which I have already described in previous applications. In the generator of application Serial No. 333,345, filed January 18th, 1929, the pressure drop was obtained by precompressing the fuel mixture and exploding it. The resulting pressure intermittently drives the exhaust gases through the heating tubes. This pressure drop, however, is only partially converted into high velocity, the remainder of the pressure drop being used to drive a gas turbine, which is coupled to a compressor which delivers the scavenging and charging air for the combustion chamber. The value of the gas velocity varies according to the pressure change in the chamber after the explosion and during the discharge and charging, and alternates between approximately 500 and 200 m/sec.

In the generator of application Serial No. 414,428, filed December 16th, 1929, the combustion takes place at constant pressure. The pressure drop to develop the high gas velocities also remains constant just as the gas velocity, which has a value of between half to full velocity of sound, amounting therefore to at least 200 m/sec. The compressor which maintains the pressure drop is driven by a heat engine the heat cycle of which is so coupled with that of the steam generator that all the heat that is not utilized for the compression is directed to the steam generator for the production of steam.

In the generator of application Serial No. 419,026, filed January 7th, 1930, the combustion takes place in the combustion chamber also with constant pressure, and the heating gases also reach over 200 m/sec. The compressor, which develops the pressure in the burner, is driven by a gas turbine which is connected to the end of the heat-exchanging ducts and driven by the exhaust gases which acquire their full velocity immediately on leaving the combustion chamber and are completely or almost completely cooled before entering the gas-turbine.

The steam generator of the present invention constitutes a further very advantageous modification of the above described mechanized steam generators. Like the generators referred to above, it comprises a pressure resisting combustion chamber, heat-exchange ducts, a gas turbine, and a compressor. The combustion takes place at a constant pressure considerably above atmospheric, which imparts to the gases a high flow velocity along the heating surface of the ducts. The pressure is maintained by means of a compressor which is coupled with a gas turbine that is driven by the combustion gases. It distinguishes over the previous constructions by a different consecutive arrangement of the heating spaces and gas turbine as also by a different method of operation. The gas turbine is not placed at the end of the heat-exchanging bodies, but between them and driven by gases which still possess a large quantity of heat, and are comparatively hot. The output of this gas turbine is then so large that it enables operation of the compressor with a compression ratio which is considerably greater than the expansion ratio of the gas expanding in the turbine. Large pressure differences are thus made available between the delivery end of the compressor and the inlet duct of the turbine, and between the turbine exhaust and the atmosphere, imparting high velocities to the flow of the gases through the heat-exchangers before the turbine, as well as through the heat-exchangers after the turbine. These velocities should be at least $\frac{1}{3}$ of the velocity of sound, i. e. at least 150 m/sec., and higher. The expansion ratio of the gas expanding in the turbine may amount approximately $\frac{8}{10}$ of the compression ratio in the compressor.

The foregoing and other features and objects of the invention will be best understood from the following description, reference being made to the accompanying drawing showing a diagrammatic view of the new steam generating system.

It comprises a combustion chamber 101 formed by a pressure resisting cylinder 102, and is closed at the bottom by the inlet header 103 and at the top by an outlet header 104. The inlet header 103 is shown tapering down towards the bottom, and mounted therein is a burner 105 to which is supplied combustion air and fuel through the air pipe 106 and the fuel pipe 107. The walls of the cylinder 102 may be made of steel or other material capable of withstanding a high pressure, and are protected against overheating by water tubes 108 extending vertically along the chamber walls and lining same. Around the walls of the inlet header 103 there is a water chamber 110, and around the outlet header 104 is a water outlet chamber 111. The water tubes 108 extend between the water inlet chamber 110 and the water chamber 111, and permit a rapid circulation of water from the lower chamber to the upper chamber. Circulation of the water is effected by means of circulating pipes 112 and a pump 113 connected between the pipe 114 of the water inlet chamber 110 and the outlet 115 of the water outlet chamber 111.

The upper portion of the water chamber 111 forms a steam separator compartment 116 which is divided from the lower portion of the chamber by a set of blades 117 tending to impart a rotary motion to water flowing upwards. The water separated from the steam in the portion 116 is led directly by a pipe (not shown in the figure) to the inlet pipe 112. The top of the steam separator compartment is connected by a pipe of large diameter 118 with a relatively small steam collector 119; which acts as a further steam separator, and into the lower portion of this steam separator feed-water is injected by a feed-water pump 121 and supply pipe 120. To the top of the steam collector 119 a steam pipe 122 is connected which leads on into a superheater coil 123 mounted in the upper portion of the chamber; the superheated steam passing through steam delivery pipe 124 to the steam engines or turbines or other consuming apparatus where it is to be used. By a pipe 125 the lower portion of the steam collector 119 is connected to the circuit of the water circulating pipe 112, by means of which the water is circulated through the water tubes 108 arranged around the periphery of the combustion chamber 101.

In the upper end of the inner wall of the outlet header 104, enclosing the top of the combustion chamber, there is a gas outlet chamber 131 having around its periphery a set of nozzles 132. To these nozzles are connected a set of high-pressure gas discharge ducts in the form of tubes 133 extending downwards through one portion of the water tubes 108 disposed around the periphery of the combustion chamber. The bottom ends of these gas discharge tubes 133 open up into diffusors 134 which open into a high-pressure stage gas chamber 135. To the gas chamber 135 there is connected through pipe 136 an inlet to a gas turbine 137 and the outlet end 138 of the gas turbine is connected by a pipe 139 to an annular gas discharge duct 140 at the lower end of the inlet header 103. In the top of the gas discharge duct 140 are fitted outlet nozzles 141 to which are connected a set of low-pressure gas discharge ducts in the form of tubes 142 extending upwards through another portion of the water tubes 108 disposed around the periphery of the combustion chamber. The upper ends of the low-pressure gas discharge tubes 142 also open up into diffusors 143 which lead into a gas outlet duct 144 in the upper end of the outlet header 104, the gas escaping from the outlet duct through the exhaust pipe 145. The gas turbine 137 is coupled to a compressor 150 which takes in air that has first been passed through an enclosure 151 jacketing the combustion chamber, and its attachments. The compressor takes in the preheated air and delivers it at high pressure through pipe 106 to the burner 105. A fuel pump 152, which may likewise be driven by the gas turbine 137, supplies fuel, such as oil, gas or pulverized fuel through pipe 107 to the fuel inlet of the burner 105.

The nozzles and blades of the gas turbine are so designed that a pressure is created before the turbine which is lower than in the combustion chamber 101 to the extent of a few metres water column. This pressure difference is utilized to impart to the gases in the heating tubes 133 a high velocity of flow in order to obtain a high transmission of heat. This high transmission of heat makes it possible to have comparatively short tubes so that, in spite of high velocities of flow, the friction losses due to the tube resistance are relatively small. This resistance is further reduced due to the fact that the cooling of the gases while passing through the tubes 133 and the diffusors 134 causes a compression which counteracts the pressure loss due to friction in the tubes. The temperature of the gases in the first heat exchanger (tubes 133) is only diminished to an extent at which the gases still contain sufficient heat energy when arriving at the gas turbine to develop the necessary power for driving the compressor.

The back pressure of the gas turbine must be a few metres water column above atmospheric pressure, in order that sufficient pressure is available to give the gases in the second heat-exchanger (tubes 142) high velocities. The pressure drop that is available for work in the gas turbine is therefore equal to the pressure developed by the compressor reduced by the pressure losses in the burner 105 and the sets of heating tubes 133 and 142.

Since the temperature of the heating gases before the turbine is still high and, in fact, much higher than the final temperature of the air after the compression the available pressure drop for expansion in the turbine driving the compressor may be made at least 20% lower than the compression ratio. In order to ensure that the turbine works satisfactorily at high gas temperatures all gas pipes and blades are cooled by circulating water taken, for instance, from the pipe 112. The gas turbine and the compressor are independent of the load and the drives thereof, and may be regulated as desired.

The heat converted into mechanical energy by the gas turbine is taken from the gases and is not available for the immediate generation of steam. This heat, however, is transferred to the air which is heated by the compression. The heat energy utilized in compressing the air is therefore almost completely recuperable in the firing of the steam generator, and the compression is effected without requiring additional power. It is important that no heat is lost from the compressor. The compressor should accordingly not be cooled, and the operation should be adjusted to make it unnecessary to cool the compressor. These conditions are met by making the charging pressure of the combustion chamber approximately 2.5 to 3.5 kg/cm^2 absolute. This pressure gives the gas turbine a heat drop that can be expanded in a single turbine wheel. In operation, the compressor continuously delivers a combustible charge to the combustion chamber under a substantial high pressure. The charge is subjected to continuous combustion in the chamber producing therein hot combustion gases having a pressure head equal to the compression pressure. Under the action of this pressure head, the combustion gases are discharged through a set of high-pressure heat-exchange ducts, a gas turbine and a set of low-pressure heat-exchange ducts connected in series between the chamber and the atmosphere. The gas turbine is impelled by an intermediate portion of the pressure head of the hot combustion gases to drive the compressor with power sufficient to produce the required charging pressure, the expansion ratio of the gases being $\frac{8}{10}$ or less of the compression ratio of the compressor. A portion of the pressure head, at the high end before the turbine, is applied to impart to the combustion gases flowing through the high-pressure ducts a high velocity of more than 150 m/sec. to secure large heat transfer to the surrounding steam generating fluid; and another portion of the pressure head, at the low end after the turbine, is applied to impart to the combustion gases flowing through the low-pressure ducts a high velocity, preferably of more than 150 m/sec. to secure additional large heat transfer to the surrounding steam generating fluid. This arrangement utilizes the various pressure and temperature ranges of the combustion gases in a way which is very effective in the steam generation and highly efficient in producing the pressure for imparting to the gases the high velocity with which the high rate of steam generation is secured.

The invention is not limited to the specific details of the methods of operation, arrangements, and details of construction referred to in exemplifying and explaining the principles of the invention, and many modifications and equivalents thereof will suggest themselves to those skilled in the art. The terms steam, steam generating fluid and steam generation as used in describing the practical exemplifications of my invention refer not only to steam generated by heating water which is chiefly employed in all vapor power plants at present, but as used in the specification and claims are intended to include broadly all other equivalent vaporizable liquids suitable for vaporization by heat conveyed thereto and for utilization as a power medium.

I claim:—

1. The method of generating steam which comprises, initially compressing a gaseous body in a compressor and forming therewith a combustible charge of a substantial pressure head, subjecting said charge to continuous combustion under pressure, utilizing the upper part of the pressure head of the combustion gases for imparting to them a velocity of the order of one hundred fifty meters per second or more along a heat-exchange surface separating the gases from a steam generating fluid to transfer heat thereto and generate steam, utilizing the next lower part of the pressure head of the combustion gases leaving said first heat-exchange surface for impelling a gas turbine driving said compressor and applying the power developed in said gas turbine for initially compressing said gaseous body, utilizing the remaining part of the pressure head of the gases leaving the gas turbine for imparting to said gases a velocity above one hundred meters per second along a second heat-exchange surface separating the gases from a steam generating fluid to transfer thereto remnant heat of the gases, and maintaining the expansion ratio in the gas turbine sufficiently less than the compression ratio of the compressor to provide in the combustion gases before and after the turbine pressure drops sufficient to impart to said gases said high velocities.

2. The method of generating steam which comprises, initially compressing a gaseous body in a compressor and forming therewith a combustible charge of a substantial pressure head, subjecting said charge to continuous combustion under said pressure head, utilizing the upper part of the pressure head of the combustion gases for imparting to them a velocity of the order of one hundred fifty meters per second or more along a heat-exchange surface separating said gases from a steam generating fluid to transfer thereto and generate steam, utilizing the next lower part of the pressure head of the combustion gases leaving said heat-exchange surface for impelling a gas turbine driving said compressor and applying the power developed in said gas turbine for initially compressing said gaseous body, utilizing the remaining part of the pressure head of the gases leaving the gas turbine for imparting to said gases a velocity above one hundred meters per second over a second heat-exchange surface separating said gases from a steam generating fluid to transfer thereto the remnant heat of the gases, and main-

taining the expansion ratio in the gas turbine at 0.8 or less of the compression ratio of the compressor to provide in the combustion gases before and after the turbine pressure drops sufficient to impart to said gases said high velocities.

3. The method of generating steam which comprises, initially compressing a gaseous body in a compressor and forming therewith a combustible charge of a substantial pressure head, subjecting said charge to continuous combustion under said pressure head, utilizing an intermediate part of the pressure head of the combustion gases with an expansion ratio of 0.8 or less of the compression ratio of the compressor for impelling a gas turbine driving said compressor, applying the power developed in the gas turbine for initially compressing said gaseous body, and utilizing a sufficient upper part of the pressure head of the combustion gases before they enter the gas turbine, and a sufficient lower part of the pressure head of the combustion gases after they leave the gas turbine for imparting to said combustion gases a velocity of the order of one hundred fifty meters per second or more along heat-exchange ducts that are in contact with a steam generating fluid to transfer thereto the heat of the gases for steam generation.

4. A vapor generator comprising a pressure-proof combustion chamber, means including a compressor for supplying to said chamber a compressed combustible charge and producing therefrom hot combustion gases of high pressure head having a predetermined range in said chamber, heat-exchange means for holding a vaporizable liquid and having heating surfaces constituting a set of ducts having at one end inlet nozzles connected to said chamber having a cross section and length proportioned and constructed to apply the upper portion of the pressure head in said chamber for driving the hot gases from the chamber through said inlet nozzles into the ducts at a velocity of about 150 meters per second or more to heat said liquid and generate vapor, a gas turbine connected in series with said ducts proportioned and constructed to apply an intermediate portion of the pressure head of said gases discharged from said ducts with an expansion ratio less than the compression ratio of said compressor within said turbine into mechanical power for driving said compressor, and additional heat-exchange means for holding a liquid having heating surfaces constituting a second set of ducts connected to the outlet of said gas turbine having a cross section and length proportioned and constructed to apply the lower portion of said pressure head for driving the gases discharged from said gas turbine through the ducts at a velocity above 100 meters per second transferring remnant heat thereof to said liquid.

5. A vapor generator comprising a pressure-proof combustion chamber, means including a compressor for supplying to said chamber a compressed combustible charge and producing therefrom hot combustion gases having a high pressure head of predetermined range in said chamber, heat-exchange means for holding a vaporizable liquid and having heating surfaces constituting a set of ducts having at one end inlet nozzles connected to said chamber having a cross section and length proportioned and constructed to apply the upper portion of the pressure head in said chamber for driving the hot gases from the chamber through said inlet nozzles into the ducts at a velocity of about 150 meters per second or more to heat said liquid and generate steam, a gas turbine connected in series with said ducts proportioned and constructed to apply an intermediate portion of the pressure head of said gases discharged from said ducts with an expansion ratio less than 0.8 of the compression ratio of said compressor within said turbine into mechanical power for driving said compressor, and additional heat-exchange means for holding a liquid having heating surfaces constituting a second set of ducts having inlet nozzles connected to the outlet of said gas turbine having a cross section and length proportioned and constructed to apply the lower portion of said pressure head for driving the gases discharged from said gas turbine through said inlet nozzles into the ducts at a velocity above 100 meters per second transferring remnant heat thereof to said liquid.

6. A steam generator comprising a pressure-proof combustion chamber, means including a compressor for supplying to said chamber a compressed combustible charge and producing therefrom hot combustion gases having a high pressure head of a predetermined range in said chamber, heat-exchange means for holding a steam generating fluid and having heating surfaces constituting a set of ducts having at one end inlet nozzles connected to said chamber having a cross section and length proportioned and constructed to apply the pressure head in said chamber for driving the hot gases from the chamber through said nozzles into the ducts at a velocity of about 150 meters per second or more to heat said fluid and generate steam, a gas turbine connected in series with said ducts proportioned and constructed to apply a portion of the energy of said gases discharged from said ducts within said turbine into mechanical power for driving said compressor, and additional heat-exchange means for holding a steam generating fluid having heating surfaces constituting a second set of ducts having at one end inlet nozzles connected to the outlet of said gas turbine having a cross section and length proportioned and constructed to apply the energy of the gases discharged from said gas turbine for driving said gases through said nozzles into the second set of ducts at a velocity above 100 meters per second transferring remnant heat thereof to said fluid.

WALTER GUSTAV NOACK.