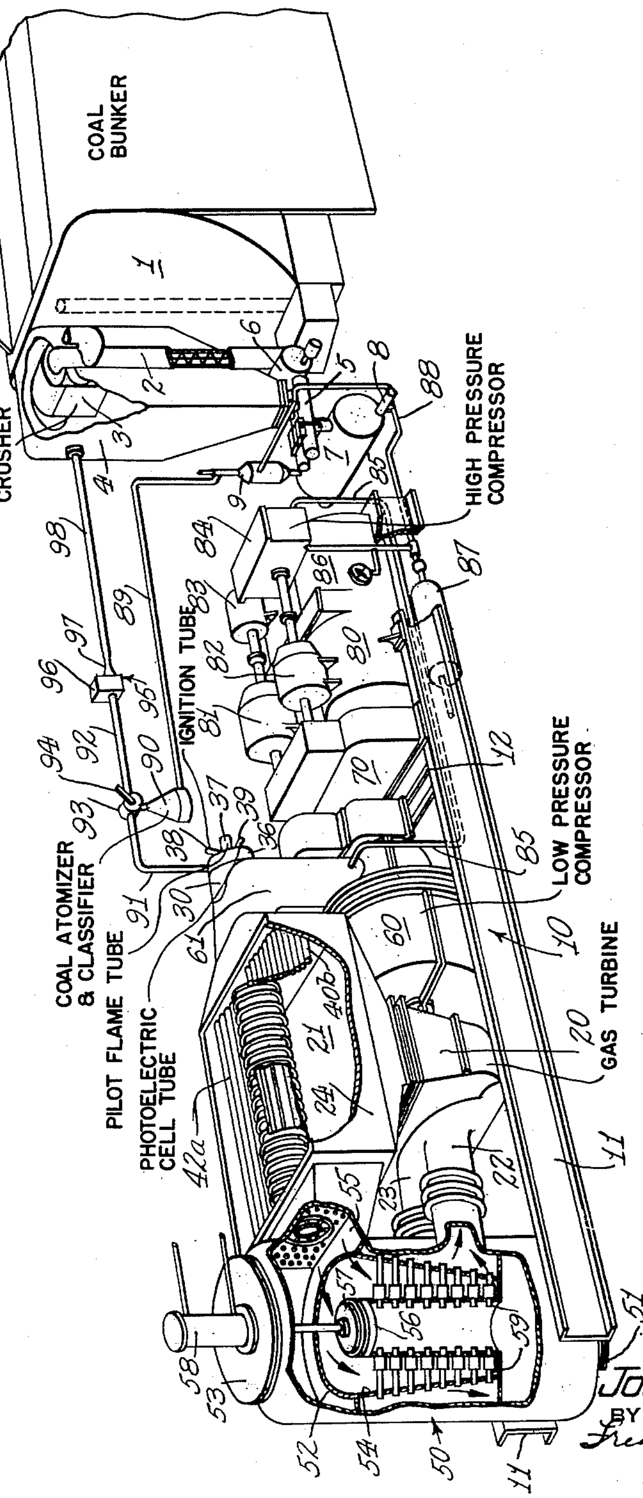
COAL FIRED COMBUSTION CHAMBER WITH REGENERATOR TUBES ON EITHER SIDE WITHIN THE TURBINE EXHAUST DUCT

Filed May 8, 1947 3 Sheets-Sheet 1

FIG.1.



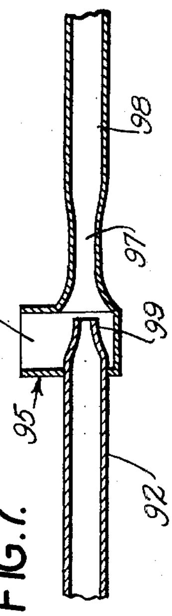


FIG.7.

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Filed May 8, 1947 3 Sheets-Sheet 2

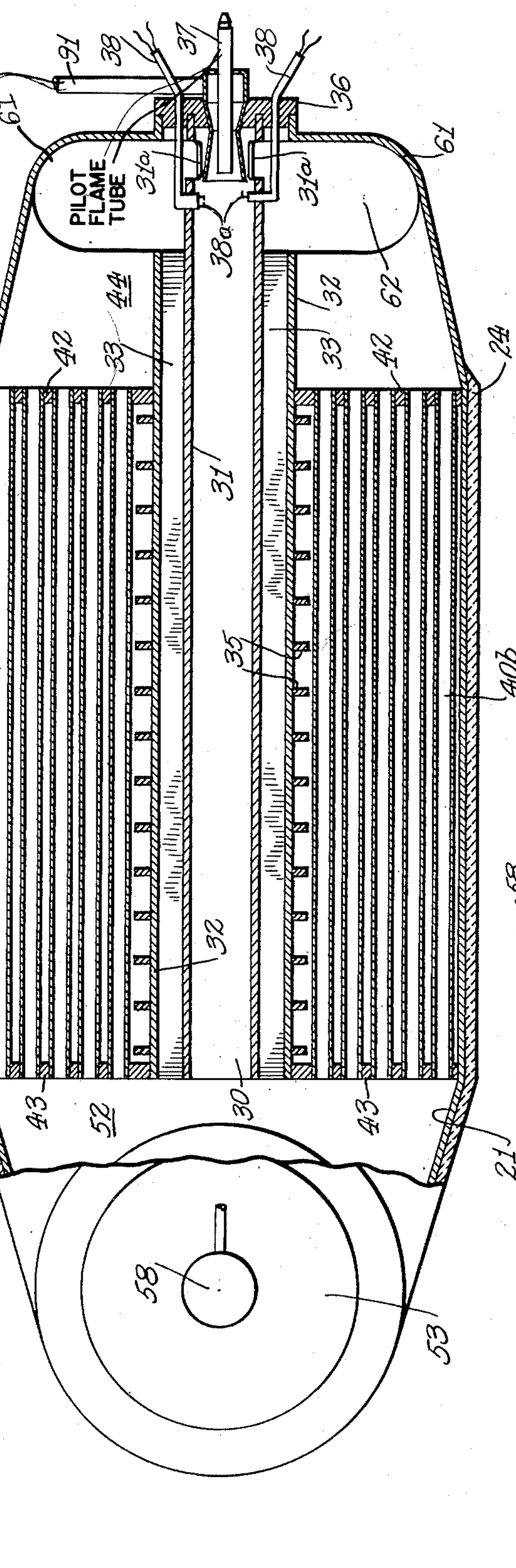

FIG.3.

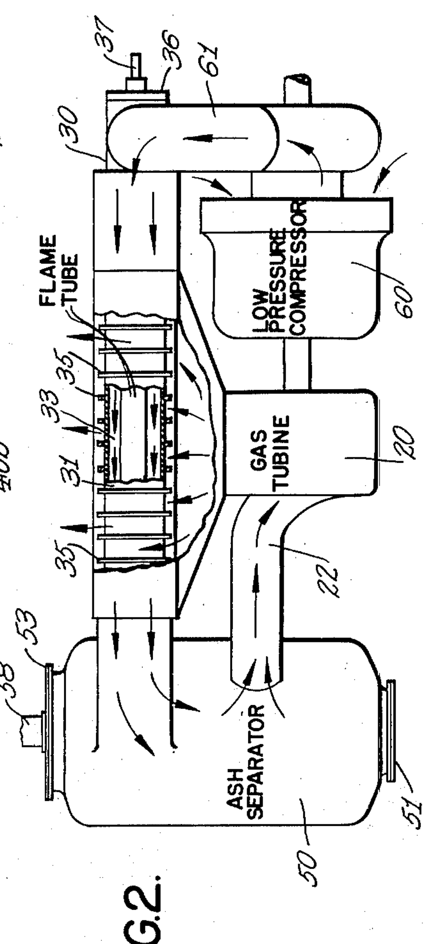

FIG.2.

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FIG. 4.

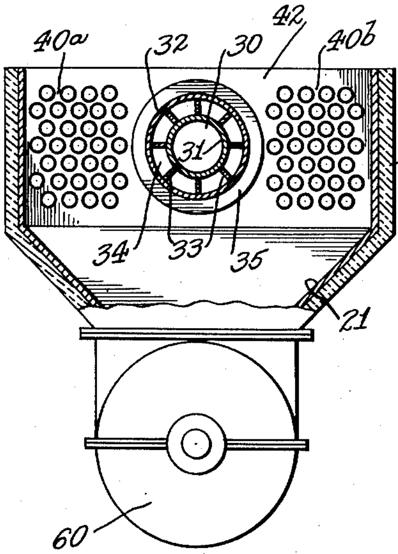


FIG. 5.

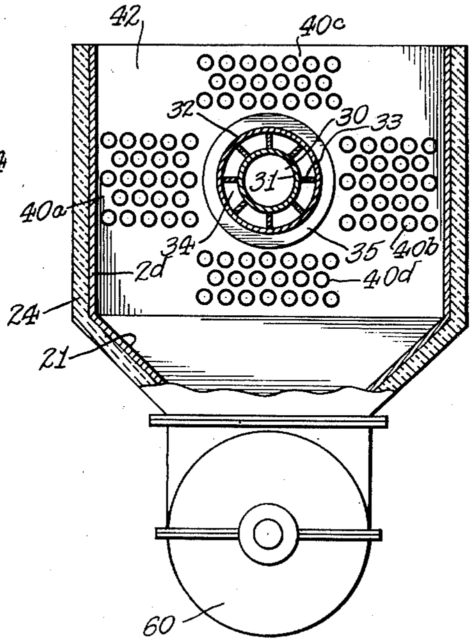
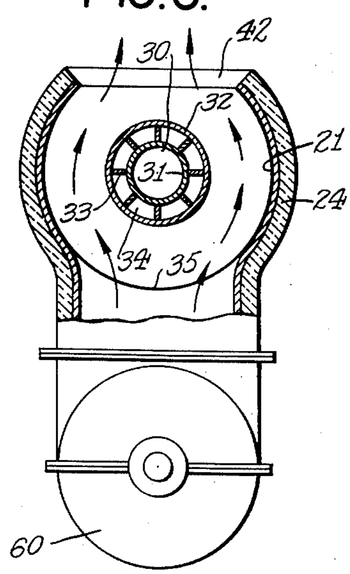


FIG. 6.



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UNITED STATES PATENT OFFICE

2,583,920

COAL FIRED COMBUSTION CHAMBER WITH REGENERATOR TUBES ON EITHER SIDE WITHIN THE TURBINE EXHAUST DUCT

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Application May 8, 1947, Serial No. 746,817

5 Claims. (Cl. 60—39.46)

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This invention relates to improvements in gas turbines and, more particularly, to a novel gas turbine system in which the turbine and air heater are housed in a single casing, the air heater comprising both combustive and regenerative elements.

In the operation of the conventional gas turbine it is customary to use a regenerator mounted on or in the turbine exhaust, through which is passed all of the air leaving the compressor. Under such conditions, the hot gases which constitute the turbine exhaust pass through the regenerator in heat-exchange relationship to the compressed air. With all of the air so heated, a maximum of thermal efficiency is obtained. However, the space requirements for such installations are large, and a pressure drop in the order of 1 p. s. i. is experienced by the air. Where a minimum of space is available for gas turbine installations, as in locomotive installations shown and claimed in my application Serial No. 691,307, filed August 17, 1946, and where it is desirable to utilize the allowable pressure drop in other parts of the system, such as in a fly-ash separator, it is desirable to reduce to a minimum the amount of space allocated to the regenerator, and also to minimize the pressure drop experienced by the air in passing through the regenerator.

The desirable features of the system proposed herein permit the attainment of the reduction of space and also the minimizing of the pressure drop experienced by the air with the allocation of a greater portion of the pressure drop to the fly-ash separator. The invention herein secures these desired results by disposing a two-part air heater in the space above the turbine exhaust. In this air heater a central combustion chamber or combustive heater tube is flanked by two banks of preheater or regenerative heater tubes for the compressed air. The parallel arrangement of the combustor and the regenerative air heater sections will cause the pressure drop in the several sections to occur in parallel instead of in series as is the usual arrangement where the combustive heater, the turbine and the regenerator are arranged in series. With the system herein, the combustive air heater will be adiabatic. With the pressure drop in the regenerative heater parallel to the combustive heater pressure drop, an equal pressure drop will be produced in the combustive air heater. With the combustive air heater directly above the turbine and in heat-exchanging relation therewith, the fly-ash separator is vertically arranged adjacent to the turbine in such a manner that a minimum of floor space is

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required and the ducts connecting the parts of the equipment are made as short as possible. Such a reduction in space requirements, coupled with the reduction in connecting ducts and auxiliary equipment, renders the novel gas turbine system herein of particular utility to locomotive and marine power plant applications, where space is highly restricted.

The above and other desirable features of novelty and advantage of the present invention will be more fully understood by reference to the accompanying drawings, in which there is illustrated, by way of example, a novel gas turbine installation. In the drawings, like numerals refer to like parts throughout the several views, of which:

Fig. 1 is a perspective drawing, partly in broken section, of a power plant utilizing a gas turbine;

Fig. 2 is a side elevation, partly in broken section, of the power unit;

Fig. 3 is an enlarged top plan view, partly in broken section, of the power unit showing the flame tube of the combustor and the regenerator tubes mounted in the exhaust stack of the turbine;

Figs. 4 and 5 are cross-sections through the regenerator showing the mounting of the combustor and tube sheets;

Fig. 6 is a view similar to Figs. 4 and 5 showing the mounting of the combustor in the exhaust stack of a turbine and without regenerator tubes; and

Fig. 7 is a cross-section of an automatic pressure reducing and gas-cooling valve.

The gas turbine-electric power units and the coal supply with pulverizing means are illustrated generally in Fig. 1, the composite power plant being illustrated in Fig. 2. As shown in Fig. 1 the thermal plant comprises a bed plate or base **10** of spaced, parallel everted channels **11**, secured by interposed cross bracing members, designated generally by the numeral **12**. The power unit comprises a gas turbine **20**, and a generator **80** coupled to the turbine shaft through gear box **70**.

Gas turbine **20** has an exhaust duct comprising a substantially elongated casing **21** in which is mounted a combustor **30** and two banks of regenerator tubes **40a** and **40b** are disposed on either side of the combustor unit and in heat-exchanging relation with the exhaust gases. A pair of inlet ducts **22**, **23** connect the turbine to a fly-ash separator **50**. The separator **50** is secured between frames **11** of base **10** in any suitable manner. An air compressor **60** is mounted on the turbine shaft and discharges low pressure air of 60 to 100 p. s. i. through ducts 61 into the combustor and regenerator tubes, as will be described more in detail hereinafter. The gear box 70 serves to couple the turbo-compressor shaft to the generator unit 80 mounting auxiliary generators 81 and 82 thereon. The auxiliary generator 81 serves to power auxiliary equipment, including a field generator or excitor 83 for the main generator 80. Auxiliary generator 82 is A. C. wound and powers the high pressure compressor 84. The high pressure compressor, or auxiliary air pump 84, is connected through line 85 to the pressure side of compressor 60, as shown in Fig. 1. This compressor discharges through line 86 and a T connection to an auxiliary high pressure air tank 87 and a separate high pressure air line 88. The pressure tank 87 will serve as a reservoir for air brake air and other equipment, such as bell ringers, sanders, and the like.

The coal utilized for combustion purposes in the apparatus herein is handled in the following manner:

The raw coal is stored in a closed hopper bunker 1, provided with a stoker, or other mechanical discharge means, discharging into a screw elevator 2, which, in turn feeds a crusher 3. The crusher 3 discharges comminuted coal of 8 mesh or smaller size into a hopper 4. The comminuted coal from hopper 4 is discharged through coal pump 5 driven by motor 6 and fed into pressure tank or container 7 from whence it is discharged by screw means through outlet 8 into the high pressure air line 88. This line feeds into a cyclone separator or valve 9 and thence through line 89 and coal atomizer 90 to feed line 91 of combustor 30. The valved separator 9 has a return to the pressure tank 7 which permits the removal of any desired quantity of coal from the air stream to the combustor 30 to vary the air/coal ratio. A second by-pass for the air-borne coal from the feed line 89, back to the storage hopper 4, is provided by line 92, which is connected to the atomizer 90 through two-way valve 93. This arrangement permits the discontinuance of the coal feed and, conversely, the initiation of the coal feed, as when the turbine is first being started, after being initially supplied with gaseous or liquid fuel. A control handle 94 is supplied for the valve 93 and is connected to the engineer's control board as well as to automatic control devices, where such are used.

In the operation of the system herein, the air delivered through conduit or duct 89 is under high pressure of the order of 140 p. s. i. and above. Under this pressure considerable heat is developed and imparted to the fluidized coal entrained in the highly compressed air stream. In emergencies, such as in the case of a crash stop, or when shutting down the engine at the end of a run or for any other reason, it is desirable to evacuate the fluidized coal into the coal hopper 4, while at the same time reducing the temperature to a point below the ignition point by means of a dump or quench device in the discharge line 92. As shown more in detail in Fig. 7, the aspirator or quench chamber 95 comprises a container having an open top 96 and a restricted outlet 97 discharging into line 98, which is essentially a continuation of line 92, and feeds directly into the hopper 4. The outlet end of the line 92 is restricted, as indicated at 99, and is so mounted in the chamber of quench device 95 as to serve as an injector discharging high pressure air containing fluidized coal at relatively high temperature through the restricted nozzle 97 and expand same into discharge line 98, which is larger than inlet line 92. Because of the relatively large size of the chamber 96 formed by the member 95, the high pressure, air-borne fluidized coal issuing from the jet 99 will aspirate air from and through the chamber 96 into discharge line 98. The aspirated air being at the ambient temperature of the surrounding air will be appreciably cooler than the pulverulent fuel-bearing pressurized air, and will serve to cool or quench it down to a point where spontaneous ignition of the flour-fine pulverized coal is prevented. This quenching or cooling effect, as noted, is enhanced by a further drop in temperature caused by the expanding effect, on the air-borne fuel stream, of the restricted throat 97 in the larger discharge line 98.

The operation of this device will be seen to be entirely automatic and provides a distinct safety factor. When a crash stop occurs, or, if for any reason the fluidized coal supply from the atomizer 90 to the combustive air heater is to be discontinued, the valve lever or throttle 94 is thrown, either manually or automatically, so as to dischange the compressed fluid from atomizer 90 through duct or line 92 and cooperating dump line 98 into the hopper 4. In passing from line 92 into line 98 the highly heated, fluidized pulverulent coal is quenched or cooled by contact with excess quantities of air drawn in through the quench device 95, which, desirably, is in open contact with the outside air and is not exposed directly to the heat of the motive and combustive heater units, if the units are mounted as part of locomotive or marine propulsion systems. Because of the discharge of the now-cooled, and therefore free from the danger of spontaneous ignition, pulverulent coal, into the hopper 4, there is no discharge of clouds of soot into the atmosphere of the engine room or of a railroad station if the valve 93 had been opened to discharge the pulverulent air-borne fuel directly into the air. It will be seen that this feature provides another and automatic device which makes for efficiency in the operation of a pressurized, pulverulent fuel combustion system, while providing absolute and automatic safety features therefor.

The combustor unit and its special mounting in the exhaust duct of the gas turbine assembly is the essential element of the invention herein and will now be described:

The combustor unit 30 comprises an inner flame tube 31 and an outer cylindrical sheath 32. Radially spaced, longitudinal fins 33, are mounted in and between the inner flame tube and the outer tube or sheath 32, and provide a plurality of longitudinal ducts 34 extending the length of the combustor and discharging directly into the plenum chamber of the fly-ash separator 50. The outer tube or sheath 32 is provided along its length with a pluraltiy of parallel, spaced fins or extended surfaces 35. The combustor unit is mounted in the exhaust stack or regenerator casing 21 of the gas turbine 20 in such a manner that the extended surfaces or fins 35 are centrally disposed. Because of this disposition, the combustor unit is placed in direct, heat-exchanging relation with the exhaust gases of the turbine.

The inner flame tube 31 is open at its discharge end, as shown in Figs. 1 and 3, and is closed at the opposite end by a cap or cover 36. The closure or cap member 36 will receive the fuel supply pipe 91, which introduces pulverized fuel into the flame tube in a pressurized, air-borne stream. The cap 36 is provided further with a fluid fuel inlet tube 37 for introducing liquid or gaseous fuel for starting the turbine, and to serve as a pilot light or igniter for the system. Electric ignition means, designated generally by the numeral 38, is provided with opposed sparking elements 38a disposed in the flame area of the burner end of the flame tube 31. A sight tube 39 (Fig. 1) is also provided adjacent to the flame area so as to permit inspection thereof. For remote inspection and control, the sight tube may be provided with a suitable alarm system. A photoelectric cell, or other flame-and-heat-responsive device may be connected thereto, suitable connections to the instrument board of the system being provided.

The fuel delivered through coal atomizer 90 and feed pipe 91 into the flame tube will be combusted in the flame tube and the products of combustion will be diluted in the upper mixing chamber 52 of fly-ash separator 50 by the extra, relatively cool air delivered through ducts 34 of the combustor casing and the tube sheets of regenerative heater banks 40.

The fly-ash separator 50 (Fig. 2) is more particularly shown and claimed in my application Serial No. 746,818, filed May 8, 1947, for Powdered Fuel Combustion Apparatus, and will be described herein only in sufficient detail to illustrate the mode of operation of the system herein. The separator comprises a generally cylindrical body portion mounted on a base and provided with a discharge opening 51 at the bottom. A top plenum chamber 52 is closed off by a cover 53, which is normally welded to the unit. As more specifically shown and claimed in my application Serial No. 746,818, the plenum or mixing chamber opens into a conical chamber formed by an outer conical wall member 54 secured by flange means 55 to the inner wall of member 50. An inner cylinder 56 is secured at the bottom to the conical wall 54, and a removable cap or cover 57 is provided to close off the top of the inner cylinder 56. The cover 57 is raised and lowered in place by a suitable mechanism, such as a power piston, indicated generally at 58. A plurality of groups of radially arranged separator tubes or miniature cyclone separators 59, are mounted in and between the separator walls 54 and 55 in such a manner as to discharge separated fly-ash to the upper part of the cylinder, and thence to the bottom of the container, while the purified air or combustion gases are delivered into a chamber or header formed between the conical wall 54 and the outer wall of the separator. This latter chamber is connected to and through ports or ducts 22, 23 leading into turbine 20. Turbine exhaust duct 21 will be required to be lagged, all as indicated generally at 24. The fly-ash separator casing 50 will also normally be lagged, or preferably internally insulated.

In the invention herein, the special mounting of the combustive heater unit 30 in the exhaust duct of the turbine and in heat-exchange relation with the exhaust gases, provides a distinct increase in the efficiency of the gas turbine cycle. With the special arrangement of extended heating surfaces exteriorly and interiorly of the combustive heater unit, a minimum temperature differential is set up and established between the flame tube and the sheath or outer tube of the combustor. Because of this, and because of the relatively high cooling effect of the forced air flow through the longitudinal ducts formed between the flame tube and the outer shell, the metallurgical requirements of the metals used are relatively simple, and carbon steels can be used to advantage. As the exhaust stack temperature may vary between 600° F. to 900° F. it is possible to use relatively cheap carbon steel, which can function satisfactorily at this temperature range. Low chromium steels are suitable for use. This does away with the use of the heavier, and more costly heat-resistant alloys, which are not as susceptible of economical fabrication, as is carbon steel.

The regenerative heating systems will be described in conjunction with the novel mounting of the combustive heater unit. The tube banks 40a and 40b of the regenerative heating units will comprise open-ended tubes 41 mounted in and between end plates 42 and 43. The units or tube banks are supported in the exhaust duct in any suitable manner and are preferably mounted for ease of removal and servicing. As noted, the tube banks may comprise laterally arranged units 40a, 40b, or laterally arranged units together with vertically arranged or superjacent and subjacent units 40c and 40d, as shown in Fig. 5.

The combustor casing 32 will be mounted in the duct in the manner shown and is arranged for ease of removal and servicing. The end walls of the exhaust duct are inwardly convergent, as shown, and these form with the combustor unit and the tube sheets a plenum chamber or space 44 at the input side of the unit, and a mixing chamber for the products of combustion from the flame tube and the heated air from the combustive heater and the regenerator tubes, the mixed gases discharging into the plenum chamber 52 of the separator 50. The opposed discharge ducts 61 of the compressor 60 define a header space, or plenum chamber 62, which supplies air to the chamber 44, the ducts 34 of the combustor, and the tubes of the regenerative heaters. The flame tube 31 is provided with apertures 31a, through which combustion air is introduced into the flame tube at the burner nozzle. The air inlets to the flame tube are so constituted and arranged with respect to the air inlets to the cooling ducts of the combustive heater and the tubes of the regenerative heating unit that 20% to 30% of the total air supply is passed through the flame tube while the balance is passed through the ducts 34 and the regenerator tubes. The products of combustion of the flame tube and the balance of the air delivered into chamber 62 are mixed in the plenum chamber 52 of the fly-ash separator. Where regenerative heater units are dispensed with, as in the form shown in Fig. 6, the entire quantity of air will pass through the combustive air heater.

In the form shown in Fig. 6, the parallel fins 35 may be extended into the entire exhaust stack area, and may in fact be directly mounted in and retained by the walls 21 of the stack. Where extra high operating preessures are to be utilized the combustive heater of Fig. 6 is particularly suited.

As noted above, 10% to 20% of the total air supply is used within the flame tube for the actual burning of the fuel. The remainder of the air, from 85% to 80% approximately, will pass through the annular space between the flame tube and the pressure retaining shell of the combustive air heater. Under these conditions, the rise in temperature of the major portion of the air which is used only for cooling the flame tube, will be quite small, and the temperature of the pressure retaining outer shell will be considerably below that of the turbine exhaust gas. It is entirely feasible to conduct the exhaust gas around the combustive air heater in such manner that the heater is completely enveloped with gas at a temperature higher than the temperature of the pressure-resisting shell. Because of this higher ambient gas temperature, no heat can be lost from the shell. It will, therefore, be unnecessary to do any insulating of the outer or pressure-resisting shell. The temperature to which the shell will be exposed will normally be in the range of 600° to 900° F., in which range, as already noted, it is entirely practical to use ordinary carbon steel or low chromium alloys. The strength of carbon steel is adequate at temperatures up to 900° F., although in order to eliminate scaling, it may be desirable to use an alloy with small percentages of chromium, nickel, copper and other well known addition agents.

Normally, the temperature of the cooling air flowing within the annular space between the outer sheath and the flame tube will be lower than the temperature of the exhaust gas. Some heat from the exhaust gas can be transferred through the outer sheath or pressure-resisting shell to the air. To promote this transfer, the outer surface of the shell can be formed with extended surfaces in the form of radial fins, pins or lugs, or other well known variations. Extended surfaces will ordinarily not be used on the inner side of the pressure-resisting shell, because the air at that point is at a pressure of 3 to 6 atmospheres (45 to 90 p. s. i.), and heat transfer is far better than in the atmospheric pressure exhaust.

The exhaust gas passages should be shaped in such a manner that the hot gases will have to sweep over all of the surface of the outer, pressure-resisting shell. The insulation required for the duct conveying the turbine exhaust gas will be lagging of conventional nature to prevent injury to personnel working near the turbine, and to minimize loss of heat by radiation.

What is claimed is:

1. A power plant comprising, in combination, a gas turbine, and an air compressor driven by the turbine, a second air compressor driven by the turbine, means for generating heated expansible motive fluid comprising a combustor unit having a central combustion chamber and an outer shell discharging through a common feed line to the turbine, said feed line including a plenum chamber; means for supplying fluidized fuel and combustion air from the second compressor to the combustion chamber, and cooling air to the said outer shell, regenerator tubes connecting the first compressor and the plenum chamber, and an exhaust duct for the turbine exhaust gases mounting both the combustor unit and the regenerator tubes in heat-exchanging relation with the hot exhaust gases.

2. A power plant comprising a gas turbine, mechanical power take off means from the turbine shaft, a source of motive fluids for the turbine comprising a combustor mounted in the exhaust stack of the turbine in heat-exchanging relation with the exhaust gases, regenerative air heating means in the duct in heat-exchanging relation with the exhaust gases of the turbine, and means for feeding aeriform fluids to said regenerative heating means and mixing the heated aeriform fluids with the products of combustion from the combustor to form a motive fluid for the turbine, said turbine, combustor and regenerative air heating means forming a unitary structure.

3. A gas turbine power plant effective to simultaneously deliver mechanical energy, low pressure air of varying temperature, high pressure air of varying temperature, and heated aeriform gases, comprising mechanical power take-off means coupled to and driven by a gas turbine, means for generating motive fluids for the turbine including a main air compressor and regenerative air heating means in fluid communication with the said compressor, a combustor for burning air-borne fluidized solid particles of fuel, a second air compressor, means for delivering air from the second compressor to the combustor as a fluid carrier of a combustible, streaming entrainment of fluidized solid particles of fuel, said combustor, main compressor and regenerative air heating means discharging into a common mixing and fly-ash separating device to form a heated motive fluid for the turbine, means for delivering heated motive fluid to the turbine, an exhaust duct for the turbine, the combustor being mounted in the duct in heat-exchanging relation with the exhaust gases, and regenerative air heating tube banks also mounted in the duct in heat-exchanging relation with the exhaust gases.

4. Power plant according to claim 3, characterized by the fact that the means for delivering air-borne fluidized solid particles of fuel to the combustor incorporates a pneumatic expansion pulverizing means in advance of the combustor.

5. Power plant according to claim 3 characterized by the fact that the regenerative air heating tube banks are respectively mounted in the exhaust duct in heat-exchanging relation with exhaust gases of progressively decreasing temperature.

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