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POWER PLANT WITH STEAM INJECTION

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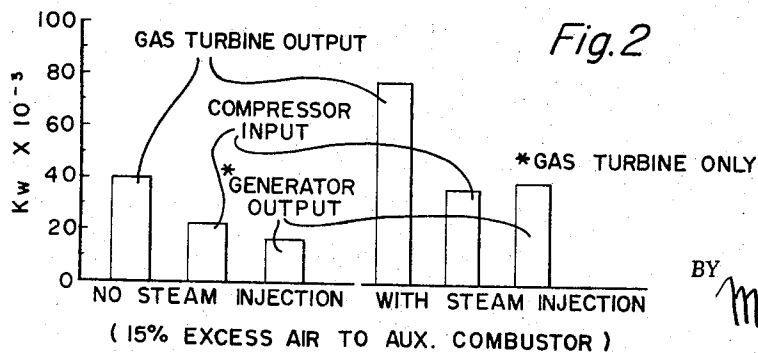
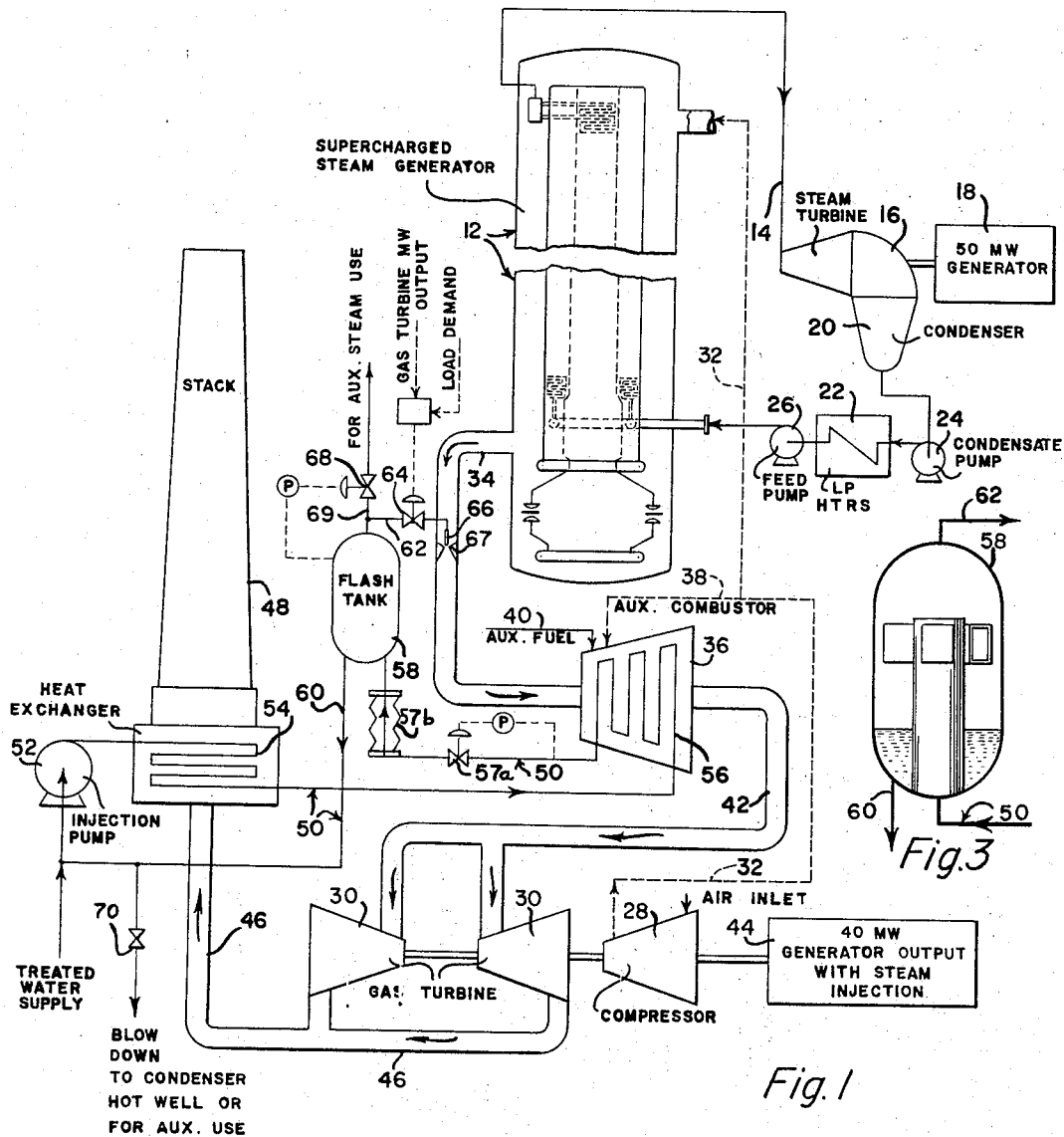


Fig. 1

Fig. 2

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POWER PLANT WITH STEAM INJECTION

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ABSTRACT OF THE DISCLOSURE

A power plant with steam injection having an auxiliary combustor to produce added combustion products along with a supercharged combustor and utilizing a portion of the heat within the auxiliary combustor to produce the steam for injection into the combustion products supplied to a gas turbine means.

A gas turbine power unit comprises a combustor which burns fuel sending the hot combustion gases directly to the gas turbine for generating power. When peak loads are required, the introduction of additional fluid into the combustor, which is heated therein, passing to the turbine provides additional working fluid for driving the turbine at increased peak rates.

In the past, the additional fluid was supplied as a liquid, cold or preheated solely by the turbine outlet gases, or was supplied to the combustor as a vapor produced in a boiler. When a considerable quantity of liquid is supplied into the combustor, unstable performance and damage to the combustor can occur. Vapor provides better peak power because of a relatively even expansion when superheated and because it avoids potential damage to the combustor parts. However, the cost of producing the vapor may be substantial, especially where the vapor is supplied directly from an independent peaking boiler. In steam injection peaking units it is also important that the peak loads be attained as quickly as possible. Present steam injection systems are relatively slow in this respect. With steam injection systems, time delay occurs in bringing the independent steam supplying unit or boiler up to power.

Consequently, it is an object of the present invention to provide an improved steam injection gas-turbine peaking system having reduced capital cost for producing the vapor to be injected.

It is another object of the present invention to provide an improved steam injection gas-turbine peaking unit which can produce readily available vapor for injection and faster peak load power.

Accordingly, the present invention provides in a fuel fired gas turbine-generator unit having a combustor for producing hot combustion gases, a steam injection means for passing a supply of liquid in indirect heat exchange with the hot combustion gases and for producing vapor, and nozzle means for injecting the vapor into the combustion gases for driving the turbines therewith. In this manner, combustion gas heat recovery provides decreased capital costs for the injection system.

Also provided in accordance with this invention is a flash tank separator in the steam injection means operating during normal conditions (and during peaking) to permit flashing of the heated liquid into vapor, and a separating means therein for separating the vapor from the liquid. In this manner vapor is inexpensively provided during normal operation for immediate availability for injection upon peak load demands into the combustion gases. In a further aspect, the liquid portion in the flash tank is recirculated to the heat exchanger and flash tank for subsequent flashing. Heat losses consist only of the injection vapor lost to atmosphere at stack

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temperature and blown down required to maintain desired water conditions in the circulating loop (with blow down the vapor injected into the combustion gases passing to the combustor and gas turbine can be maintained at high purity).

Further provided in accordance with the present invention is a specific heat exchanger arrangement for the injection system. The fluid circulates through the circulating loop first through a turbine exhaust gas heat exchanger and then through a heat exchanger disposed in the combustor. The combustor heat exchanger cools specific combustor parts to reduce maintenance, and also provides a portion of the enthalpy rise in the circulating loop fluid.

The invention and other objects and advantages thereof will become apparent from a description of the specification and accompanying drawings, in which:

FIGURE 1 is a circuit diagram of a combined steam generator-gas turbine peaking system according to the present invention;

FIGURE 2 is a bar graph showing the increase in gas turbine generator output with steam injection in accordance with the present invention; and

FIGURE 3 is an enlarged schematic view of the flash tank separator showing the internal separating equipment.

Referring now to FIG. 1 for a combined steam generator-gas turbine steam peaking system, a vapor generator 12 by the combustion of fuel (not shown) produces steam which passes from the generator through line 14 to a steam turbine 16, driving a generator 18 for producing electricity during normal operation. The steam expands in the turbine and passes into condenser 20. From the condenser, the condensate is passed through low pressure heaters 22 via condensate pump 24. The preheated water is next pressurized in feed pump 26 and sent into the generator for conversion to steam.

The vapor generator or supercharged combustion means 12 is supercharged by a compressor 28 which is driven by gas-turbines 30 furnishing pressurized air to the generator through line 32. Hot flue combustion gases issuing from the generator at high pressure pass through conduit 34 into auxiliary combustor 36. Compressor 28 also supplies combustion air into the auxiliary combustor 36 via lines 32 and 38, which mixes with auxiliary fuel passing into the combustor through line 40 burning therewith in the combustor and mixing with the flue gases in conduit 34 from the generator. The mixed heated gases then pass through conduit 42 to the gas turbines 30, at a predetermined temperature, e.g., 1500° F. (i.e., preferably at a maximum turbine inlet temperature), driving the turbines and supplying excess power (over that required by the compressor) to drive a generator 44, from which the gases pass to the atmosphere via conduit 46 and stack 48.

A steam injection system is provided to increase the gas turbine-generator terminal output for peak load demands including, a heated fluid circulating loop 50 comprising, in order, an injection pump 52, a stack heat exchanger 54, an auxiliary combustor heat exchanger 56 (disposed in the walls of the auxiliary combustor 36), pressure reducing means (including control valve 57a and capillary tubes 57b), a flash tank 58 and a flash tank drain line 60. From the vapor space of the flash tank is a steam injection line 62 having a control valve 64 therein leading into the flue gas conduit 34 upstream of the auxiliary combustor through a spray nozzle 66 for injecting steam into the throat of a venturi section 67.

During normal operation the supercharged generator-gas turbine combined unit drives generators 18 and 44. At this time the auxiliary combustor 36 is in operation at a reduced firing rate. Treated water (perhaps from the condensate pump 24) is circulated through the liquid

circulating loop 50 picking up heat from the flue gases passing through the stack 48 in the stack heat exchanger 54 and from the auxiliary combustor 36 in the combustor heat exchanger 56. The injection pump 52 is driven at constant speed (determined so as to furnish sufficient circulating loop flow at peak auxiliary combustor firing) and provides liquid at a high pressure, for example, 2000 p.s.i. in the stack and combustor heat exchangers. Pressure reducing valve 57a in loop 50 between the combustor heat exchanger and the flash tank is on pressure control (indicated by dashed P line) to hold the upstream pressure high enough (about 2000 p.s.i.) to always maintain subcooled fluid in the heat exchangers so that no steam is produced in the heat exchangers which would reduce the heat transfer. The pressure reducing valve 57a and the capillary tubes 57b reduce the pressure of the heated liquid flowing therethrough into the flash tank (which is held at 200 p.s.i. by a control valve 68 (indicated by dashed P line) in line 69 leading from the vapor space of the flash tank) causing a vapor content to be flashed in the flash tank. The liquid-vapor mixture is separated in the flash tank in centrifugal separators (FIG. 3), the liquid portion passing through the drain line 60 to the injection pump 52 and is recycled back through the recirculating loop 50. Steam injection vapor control valve 64 in line 62 leading to the conduit 34 is closed and separated vapor generated in the flash tank during this period is furnished for other uses through the auxiliary steam control valve 68 and line 69 (e.g., for powering turbine drive for the injection pump 52, or for bleeding steam for the low pressure heaters 22 increasing the capacity of the generator 12). Except for the auxiliary steam through line 69 and blow down liquid exiting from the drain line through a fixed opening valve 70 in the blow down line (which is provided for continuous blow down to hold a permissible level of dissolved solids in the recirculating fluid), all the liquid is recirculated through loop 50 maintaining a level of heat in the recirculating liquid at a desired high pressure for immediate availability of injection steam for peaking. The available vapor content in the flash tank during normal operation provides a continuously available source of vapor for immediate injection into conduit 34 when demanded. A steady state condition is always maintained in the flash tank during normal operation as well as during peaking.

For peak load generation, valve 64 opens in response to a load increase control signal and the auxiliary combustor is fired at full firing rate, producing still additional vapor in the flash tank for injection into the conduit 34. The injection pump continues to supply liquid at a pressure, for example, of 2000 p.s.i. (maintained thereat by control valve 57a), which is heated in the stack exchanger 54 and in the auxiliary heat exchanger 56. Pressure reducing valve 57a and capillary tubing 57b in loop 50, between the combustor heat exchanger and the flash tank, reduce the pressure of the heated liquid to the flash tank (still maintained at 200 p.s.i. by control valve 68) continuing to flash vapor in the flash tank, the pressure reducing capillary tubing and valve permitting the vapor generation in the flash tank 58. The liquid and vapor mixture is separated in the flash tank separators (FIG. 3), the liquid separated portion passing through the drain line 60, as during normal operation, back into the circulating loop 50 for recirculation. Valve 64 between the flash tank and injection nozzle is opened and the separated vapor passes through line 62 into the conduit 34 through nozzle 66. A steady state condition is continued to be maintained in the flash tank; when peaking, a specific rate (e.g., $\frac{1}{3}$ lb. steam per lb. of flue gas) of vapor is injected into the flue gases. Control of steam injection quantity for peaking is achieved by control regulation of steam injection valve 64. The final control signal to this valve, is the resultant error signal of a comparison between gas turbine megawatt output and imposed load demand. The vapor is injected into the con-

duit 34 from a 200 p.s.i. flash tank source into the throat of venturi section 66 which promotes intimate mixing of the flue gases and injected steam.

The flue gas-injected steam mixture then passes into the auxiliary combustor where it is heated to a 1500° F. level for admission to the gas turbine, the increased firing rate and steam injection maintaining constant the fluid temperature entering the gas-turbines. By admitting the injection steam, and burning increased amounts of fuel in the auxiliary combustor, the gas turbine generator terminal output is increased a considerable amount, providing for peak load demands.

For example, FIG. 2 shows an input-output comparison for the compressor, gas turbine, and gas turbine generator with and without steam injection. In this example, $\frac{1}{3}$ lb. of steam is injected per lb. of flue gas and the auxiliary combustor burns about three times the normal amount of fuel during peak loads. Also, the gas turbine output is 16 megawatts during normal operation. During steam injection the gas turbine generator terminal output is increased by a factor of approximately 2.5.

As shown in FIG. 3, the separator internals are preferably of the vertical centrifugal type, for example, of the type described in patent application for Vapor-Liquid Separator, Serial No. 350,066, filed on Mar. 6, 1964, now Patent No. 3,296,779.

Another advantage of the present system is that with a supercharged steam generator, even without a peaking system, it is desirable to use a flue gas turbine-compressor-generator to recover additional power from the boiler flue gases, in addition to that needed to compress the air for combustion. By adding an auxiliary combustor in the flue gas stream upstream of the gas turbine, the flue gas temperatures may be boosted to economically desired levels to produce increased net power output from the gas turbine. Since gas turbine peaking units also require gas turbine combustors, both a supercharged-gas turbine base power plant and a gas turbine peaking unit may be provided together in one system with a single combined duty gas turbine or auxiliary combustor, properly sized for the peaking requirement.

Although the invention has been described in accordance with a preferred embodiment thereof, other changes may be made and complete portions of the combined three-unit system (supercharged boiler; gas turbine unit for net power generation; steam injection peaking system) may be eliminated for a particular purpose as will be apparent to those skilled in the art in accordance with the invention as defined in the appended claims.

What is claimed is:

1. A power plant with steam injection comprising:
 - a supercharged combustion means including burner means for burning fuel in the presence of pressurized air to produce combustion gases;
 - an auxiliary combustor;
 - a compressor for supplying the pressurized air to the supercharged combustion means, said compressor including a power input shaft means;
 - means for conveying the pressurized air from the compressor to the supercharged combustion means and to the auxiliary combustor;
 - conduit means for conveying the combustion gases from the supercharged combustion means to the auxiliary combustor, a venturi section located within said conduit means;
 - means for injecting steam into the conduit means adjacent the venturi section to form a mixture of steam and combustion gases being supplied to the auxiliary combustor;
 - means for injecting fuel into the auxiliary combustor to ignite in the presence of the mixture of air from the compressor, combustion gases from the supercharged combustion means, and steam from the means for injecting steam;

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- a gas turbine means including a power output shaft means, said power output shaft means being coupled to the power input shaft means of said compressor; and
- means for conveying the mixture of combustion gases and steam from the auxiliary combustor to the gas turbine means to drive the gas turbine means. 5
2. A power plant according to claim 1 further including:
- a stack heat exchanger; 10
- means for conveying the spent mixture of the combustion gases and steam from the gas turbine means across the stack heat exchanger;
- an auxiliary combustor heat exchanger located within said auxiliary heat exchanger; 15
- a flash tank to flash steam, said flash tank including liquid-vapor separating means;
- means for supplying water through said stack heat exchanger and then through said auxiliary combustor heat exchanger and then to said flash tank; 20
- means for connecting said flash tank to said means for injecting steam into the conduit means.
3. A power plant according to claim 2 wherein: said supercharged combustion means is a supercharged steam generator; 25
- and further including:
- a steam turbine; and
- means for conveying the steam produced by the supercharged steam generator from the supercharged steam generator to the steam turbine to drive the steam turbine. 30
4. A power plant according to claim 2 further including pressure reducing means disposed in said means for supplying water located between the auxiliary combustor heat exchanger and the flash tank. 35
5. A power plant according to claim 4 further including an auxiliary steam line connected to the flash tank and having a flash tank pressure control means disposed therein for maintaining a predetermined flash tank pressure.
6. A power plane with steam injection comprising: 40
- a supercharged steam generator;
- an auxiliary combustor;
- a compressor for supplying pressurized air, said compressor including a power input shaft means; 45
- means for conveying the pressurized air from the compressor to the supercharged steam generator and to the auxiliary compressor;
- burner means located within said supercharged steam generator for burning fuel in the presence of the pressurized air to form hot combustion gases within the supercharged steam generator which produce steam in the supercharged steam generator;
- a steam turbine; 50
- means for conveying the steam produced by the supercharged steam generator from the supercharged steam generator to the steam turbine to drive the steam turbine;
- means for conveying the combustion gases after passing through the supercharged steam generator from the supercharged steam generator to the auxiliary combustor; 55

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- means for injecting steam into the combustion gases being supplied to the auxiliary combustor;
- means for injecting fuel into the auxiliary combustor to ignite in the presence of the mixture of air from the compressor, combustion gases from the supercharged steam generator, and steam from the means for injecting steam;
- a gas turbine means including a power output shaft means, said power output shaft means being coupled to the power input shaft means of said compressor; 60
- means for conveying the mixture of combustion gases and steam from the auxiliary combustor to the gas turbine means to drive the gas turbine means;
- a stack heat exchanger;
- means for conveying the spent mixture of combustion gases and steam from the gas turbine means across the stack heat exchanger;
- an auxiliary combustor heat exchanger located within said auxiliary heat exchanger;
- a flash tank to flash vapor, said flash tank including liquid-vapor separating means;
- means for supplying water through said stack heat exchanger and then through said auxiliary combustor heat exchanger and then to said flash tank, said means for supplying water including pressure reducing means located between the auxiliary combustor heat exchanger and the flash tank;
- means for connecting said flash tank to said means for injecting steam including a control valve responsive to load demand as compared to the power output of the gas turbine means for varying the amount of separated steam injected; and
- an auxiliary steam line connected to the flash tank pressure control means disposed therein for maintaining a predetermined flash tank pressure.
7. A power plant according to claim 6 wherein: said pressure reducing means includes a pressure reducing valve and capillary tubing, the capillary tubing being located downstream of the pressure reducing valve; and
- said means for supplying water includes a constant speed pump for furnishing sufficient quantities of water.

References Cited

UNITED STATES PATENTS

2,656,677	10/1953	Peterson	60—39.55	X
2,869,323	1/1959	Van Nest	60—39.55	
2,911,789	11/1959	Baker	60—39.18	
3,238,719	3/1966	Harslem	60—39.55	

FOREIGN PATENTS

401,148	10/1933	Great Britain.
642,118	8/1950	Great Britain.
675,583	7/1952	Great Britain.

60 CARLTON R. CROYLE, *Primary Examiner*,