Jan. 7, 1969 R. C. SHELDON 3,420,054

COMBINED STEAM-GAS CYCLE WITH LIMITED GAS TURBINE

Filed Sept. 9, 1966

FIG.1

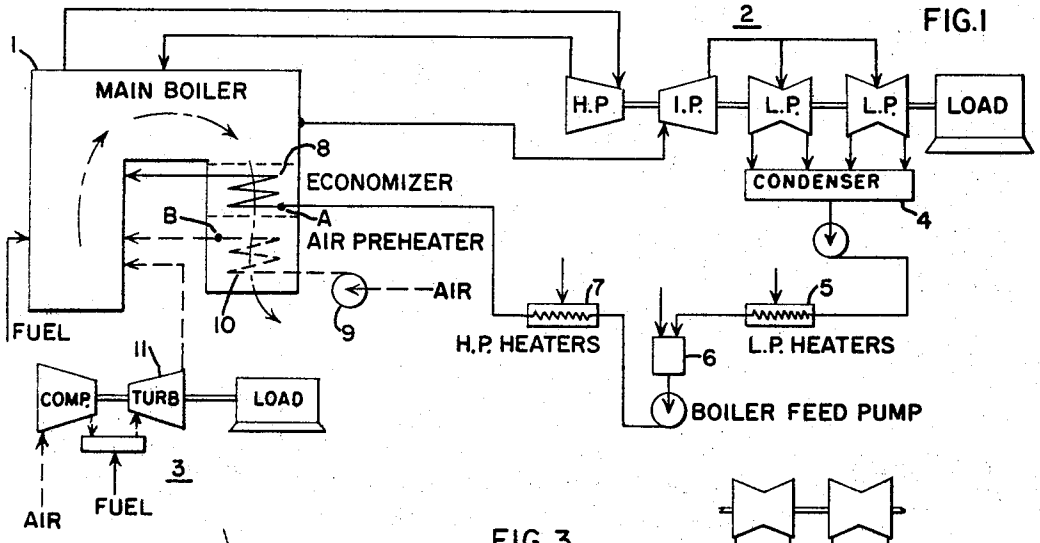


FIG.3 (PRIOR ART)

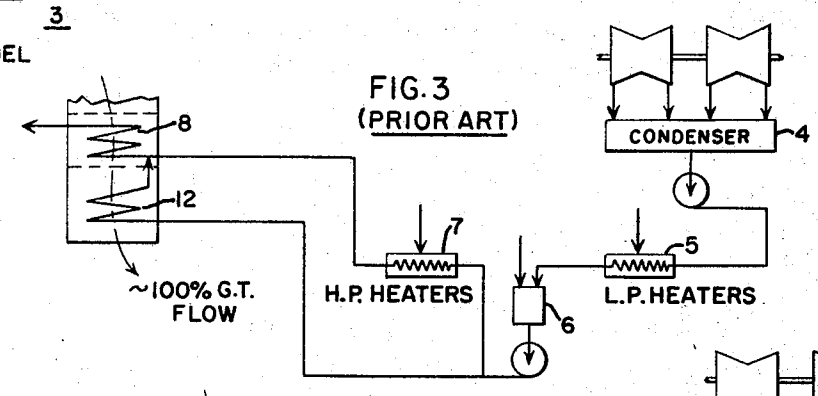
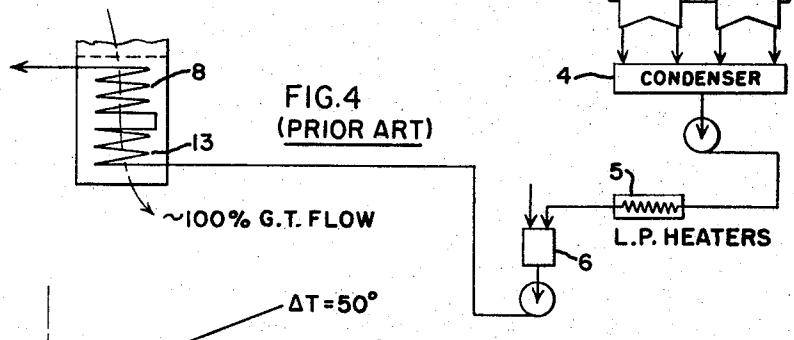


FIG.4 (PRIOR ART)



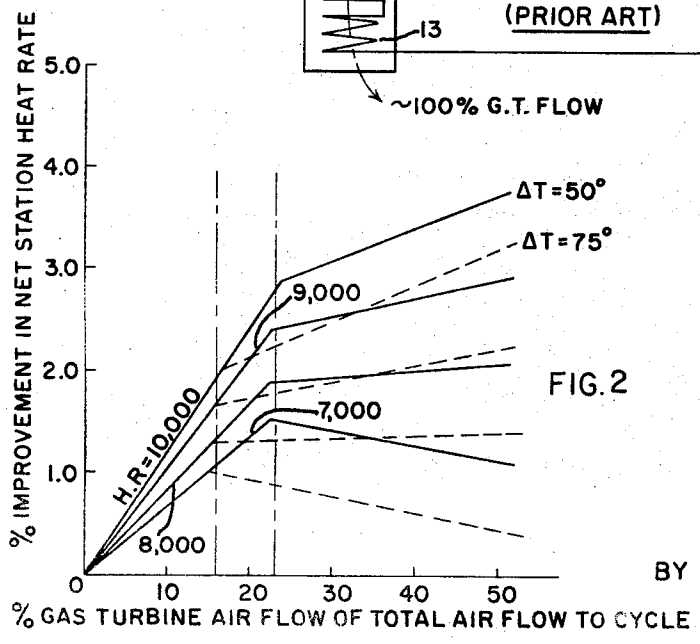


FIG.2

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COMBINED STEAM-GAS CYCLE WITH LIMITED GAS TURBINE

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ABSTRACT OF THE DISCLOSURE

A combined steam turbine-gas turbine cycle, where the combustion-supporting air for the main boiler is supplied both from an air preheater in the stack and by gas turbine exhaust, the latter being limited to a flow on the order of 15 to 25 percent of the total flow to the boiler.

This invention relates to an improved combined steam-gas cycle of the type where gas turbin exhaust supplies combustion-supporting air for supplementary firing of fuel in a steam turbine boiler.

One of the problems in designing powerplants using combined cycles, wherein steam turbines and gas turbines are utilized together to improve the station heat rate over a conventional steam cycle, lies in optimizing the design so that the additional cost of the gas turbine and other equipment will not offset the substantial thermodynamic gains to be had from combined cycles. Generally speaking, in prior art combined cycles of the type wherein the gas turbine exhaust supplies combustion-supporting air for supplementary firing in a steam turbine boiler, the net gas turbine power is about 12% to 15% of the total plant output. The various plant costs associated with this gas turbine output are usually significantly greater than the costs required to obtain the same incremental output in the steam turbine. Therefore, the cost of adding the gas turbine topping power must be justified by substantial improvements in net station heat rate.

Conventional modern steam plants have widely exploited the regenerative feedwater heating cycle wherein steam is bled from various extraction points in the steam turbine to heat the feedwater before it is further heated in the economizer of the boiler. Since the regenerative cycle raises the temperature of the feedwater at the economizer inlet and since it is desirable to cool the stack gases as much as practicable to return heat to the cycle, air preheaters have been used in modern steam cycles to perform final cooling of the stack gas. The preheated air is supplied to the boiler for combustion with a suitable fuel.

Combined steam-gas cycles are known where a gas turbine supplies the combustion-supporting air for the boiler, since it is well known that gas turbines employ substantial excess air in their combustion process and that the exhaust gases leaving the gas turbine will support further combustion. In all of these prior art combined steam-gas cycles, virtually all of the combustion-supporting air for the boiler comes from the gas turbine, with perhaps slight amounts of additional air for cooling. Cycle designers have had great difficulty in combining the regenerative feedwater heating concept with the gas turbine without compromising the great benefits to be had from the regenerative cycle. Therefore, the net economic gains to be had from combined steam-gas cycles with combustion-supporting air supplied entirely from the gas turbine exhaust have been somewhat disappointing.

Accordingly, one object of the present invention is to provide an improved combined steam-gas cycle which receives the full benefits of a conventional steam regenerative cycle as well as the additional topping power provided by the gas turbine.

Another object of the invention is to provide an improved combined cycle wherein an existing regenerative cycle plant can be modified and improved without upsetting the heat balance, simply by adding a gas turbine and additional heat exchange equipment.

Still another object of the invention is to provide an improved steam-gas cycle wherein a modest and limited investment in gas turbine equipment can provide substantial incremental improvement in heat rate over that of a conventional steam regenerative cycle.

The subject matter which is regarded as the invention is particularly pointed out and distinctly claimed in the concluding portion of the specification. The invention, however, both as to organization and method of practice, together with further objects and advantages thereof, may best be understood by reference to the following description, taken in connection with the accompanying drawing in which:

FIG. 1 is a simplified schematic diagram of the improved steam-gas cycle,

FIG. 2 in a graph illustrating the criticality of the gas turbine flow in relation to total air flow in the boiler, and

FIGS. 3 and 4 are two partial schematic views similar to FIG. 1 but illustrating prior art combined cycles.

Briefly stated, the invention comprises employing a steam turbine powerplant using a regenerative feedwater heating cycle and economizer and furnishing combustion-supporting air to the boiler from two sources in a selected flow ratio to one another. The major portion of combustion-supporting air is supplied from the atmosphere and preheated in a heat exchanger located downstream of the economizer. The remaining portion is taken from the gas turbine exhaust and is a critically limited percentage of the total boiler flow.

Referring now to FIG. 1 of the drawing which illustrates the invention in simplified form, a main boiler **1** supplies steam to a tandem reheat four-flow steam turbine **2**. A gas turbine **3** furnishes a limited percentage of the total combustion-supporting air in boiler **1** from its exhaust.

Turning first to the conventional elements of a typical regenerative feedwater heating cycle, condensate from steam condenser **4** is pumped through a cascade of low pressure heaters **5** (illustrated for simplicity as a single unit), a deaerator **6**, and a cascade of high pressure heaters **7** (again shown for simplicity as a single element). Heaters **5**, **7** and deaerator **6** are supplied with extraction steam bled from various points in the steam turbine at suitable pressures as is well known in the art. The feedwater is further heated in an economizer element **8** disposed in the path of the stack gas from boiler **1** where it serves to partially cool the gas. The other elements of the steam turbine are not described, since they represent a conventional reheat turbine cycle, but other steam cycles would be equally suitable as would different arrangements of the turbine elements.

Turning to the novel features of the present invention, combustion-supporting air is supplied to the boiler **1** from two sources. The first source comprises a fan **9** pumping air at ambient temperature into a preheater **10** disposed in the stack downstream of economizer **8**. From the preheater the air is introduced into the boiler to burn fuel in a conventional manner. In accordance with the invention, this air flow is on the order of 75 to 85 percent of the total air flow through the boiler.

The other source of combustion-supporting air is supplied from a conventional gas turbine **3**. Exhaust gases from the turbine element **11** contain substantial oxygen to support combustion and are at the same time significantly hotter than air supplied through the air preheater, typical gas turbine exhaust temperatures being on the order of 950° F. Although the exhaust contains products of combustion, and is a mixture of air and other gases,

it will be sometimes referred to herein as combustion-supporting air.

The gas (or air) flow through a gas turbine is an indication of its size and rating. In accordance with the present invention, the gas turbine flow is only on the order of 15 to 25 percent of the total flow in the boiler. In terms of the power supplied by the gas turbine in relation to the total plant power in steam units of the type likely to be encountered, the gas turbine contribution to total power is relatively small, perhaps on the order of 1 to 5 percent. This can be compared with conventional prior art combined cycles wherein virtually all of the combustion-supporting air came from the gas turbine and wherein the percentage of total power contributed by the gas turbine was as high as 20 percent, in extreme cases.

Reference to FIG. 2 illustrates the criticality of selecting the proper fraction of total steam boiler air flow which is supplied by the gas turbine. On the abscissa is plotted the percentage of total air or combustion gas flow through boiler **1** which is supplied from the gas turbine exhaust. The ordinate indicates the percent improvement in net station heat rate. A family of curves is shown for a range of steam turbine cycle heat rates, 7000 through 10000 Btu/kw. hr.; these heat rates do not include the effects of boiler efficiency and auxiliary power. For values of gas turbine air flow (relative to total air flow) from 0% to about 23%, the indicated percent improvements in net station heat rate imply a constant stack temperature for both the convenional and combined cycles. Also implied in this first section of the curves is a decreasing temperature difference between the stack gas entering the air heater and the air leaving, point B in FIG. 1, and between the gas entering the air heater and the final feedwater temperature, point A in FIG. 1. At about 23% of gas turbine air flow these temperature differences are 50° F., and are maintained constant at increasing proportions of air flow through the gas turbine. The dashed lines delineate the cycle performance when the temperature differences are maintained at 75° F.; note that this is at values of percent gas turbine flow greater than about 16%. Lower terminal differences, while requiring more expensive heat exchangers, result in more efficient utilization of the available heat as shown by the higher level of improvement in net station heat rate. As can be seen, the curves break sharply at the 16% and 23% points just described, and from then on the net gain is much less, and even decreases for very efficient steam plants.

The temperature differences of 50° F. and 75° F. represent reasonable figures encountered in practice. However, these temperature differences cannot be decreased below a minimum economical value and, for all practical purposes, gas turbine air flow percentages greater than about 25% will produce gains at substantially lower or ever decreasing rates.

The operation of the present invention will be better understood by a brief discussion of the problems encountered by prior combined cycles when gas turbine exhaust was used as the sole combustion-supporting air for supplementary firing in the boiler. FIGS. 3 and 4 show two prior art arrangements wherein the gas turbine exhaust supplied virtually all of the air flow through the boiler. Conventional air preheaters cannot be used in these cycles, so that economical levels of stack gas temperature must be attained by means of feedwater regeneration.

One prior art solution appears in the partial view of FIG. 3 wherein elements equivalent to those of FIG. 1 are illustrated with the same reference numerals. In order to reduce the stack gas temperature, a supplementary economizer or feedwater cooler **12** was placed downstream of the main economizer **8** and connected in parallel with the high pressure feedwater heaters **7**. The

reduction in steam turbine extraction to the high pressure heaters, degrades the performance of the steam turbine regenerative cycle.

A second prior art solution is shown in FIG. 4, wherein the conventional economizer surface was extended by an additional economizer **13** downstream thereof. Here it will be noted that the high pressure feedwater heaters were not used at all, and even greater degradation of the steam regenerative cycle occurs.

For modern steam cycles utilizing steam conditions in the order of 2400 p.s.i.g./1000 F. at the throttle with reheat to 1000 F., or 3500 p.s.i.g./1000 F./1000 F., combined cycles utilizing arrangements like FIGS. 3 and 4 will result in cycle heat rate improvements only 1 to 2% greater than those attainable by the present invention; however, the required gas turbine capacity is 4 to 5 times greater.

The present invention enables the full regenerative feedwater heating cycle to be employed without effect thereon by utilizing a limited size gas turbine to supply combustion-supporting air. The heat rate improvement is dramatically improved up to a critical or limiting value, and after that, gains are made at substantially greater expense in gas turbine and heat exchange equipment, and for very efficient steam stations there is a loss rather than a gain.

The critical temperatures in the economizer and air heater resulting in the sharp break in the curves of FIG. 2 are inherently set for a given station heat rate and assumed temperature difference in the final heat exchange elements. These critical values occur at gas turbine flows in the order of 15 to 25 percent of total air flow and can be calculated by conventional techniques. On the curves shown in FIG. 2, it will be apparent that gains are quite rapid until this range of limited gas turbine flows takes place, and after that, the gains are relatively modest or even may be negative.

The invention results in combined steam-gas cycles in which the gas turbine is relatively small as compared to conventional combined cycles. Thus, significant improvements can be made by relatively modest investment in gas turbine and associated heat exchange equipment through the use of the invention.

While there has been shown what is considered to be the preferred embodiment of the invention, it is understood that various modifications may be made therein, and it is intended to cover in the appended claims, all such modifications as fall within the true spirit of scope of the invention.

What I claim as new and desire to secure by Letters Patent of the United States is:

1. In a combined cycle, the combination of:

a boiler having steam generating and superheating elements therein and including an exhaust stack,

a steam turbine receiving steam from said elements,

a plurality of regenerative feedwater heaters connected to receive condensate from the steam turbine and to heat the condensate with extracted steam,

an economizer disposed in the exhaust stack and connected to receive heated condensate from the feedwater heaters and supply same to the generating elements,

air preheating means disposed in the exhaust stack downstream of said economizer and connected to supply combustion air to the boiler,

a gas turbine having an exhaust conduit connected to supply the remainder of combustion air to the boiler,

the gas turbine and air preheating means being so adapted relative to one another so that the flow of combustion-supporting air through the boiler which is supplied by the gas turbine exhaust is only in the order of 15 to 25 percent of the total flow.

2. In a combined cycle wherein exhaust from a gas turbine and air from the atmosphere simultaneously sup-

port combustion in a boiler, said boiler generating steam for a turbine cycle with regenerative feedwater heaters, the improvement comprising:

an economizer disposed in the boiler stack connected to further heat feedwater from said regenerative heaters,

an air preheater also disposed in the stack connected to receive air from the atmosphere and to supply heated air to the boiler combustion zone,

means connected to conduct substantially all of the exhaust gas from the gas turbine to the boiler combustion zone,

said gas turbine being of a size and flow capability relative to the preheater such that the gas turbine exhaust furnishes between 15 and 25 percent of the total flow to the boiler combustion zone.

References Cited

UNITED STATES PATENTS

1,911,501	5/1933	Grady	122—1
3,053,049	9/1962	Blaskowski	122—7 XR
3,118,429	1/1964	Hochmuth	122—7
3,203,175	8/1965	Michalicka et al.	60—39.02
3,304,712	2/1967	Pacault et al.	60—39.18

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60—39.02; 122—1, 7