United States Patent [19]

Ruhe et al.

[11] **3,916,990**

[45] **Nov. 4, 1975**

[54] **GAS TURBINE REGENERATOR**

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[73] Assignee: **Foster Wheeler Corporation,** Livingston, N.J.

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[21] Appl. No.: **485,643**

Related U.S. Application Data

[63] Continuation-in-part of Ser. No. 445,521, Feb. 25, 1974, abandoned.

[52] **U.S. Cl.** **165/158;** 165/162; 122/32

[51] **Int. Cl.**^{2} **F28G 9/02**

[58] **Field of Search** 165/157–162, 165/60, 115, 118; 122/32, 34; 261/153

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[57] **ABSTRACT**

A heat exchanger in which a plurality of tubes are supported in a spaced parallel relationship between two tube sheets. A conduit is provided in a parallel relation to the tubes for supplying a fluid to the tubes, and the arrangement is such that one of the tube sheets is fixed relative to the conduit and the other tube sheet moves relative to the conduit to accommodate thermal expansion and contraction of the tubes. A support unit is provided for supporting the tubes in a spaced parallel relationship while allowing an additional fluid to pass between the tubes in a heat exchange relation to the first fluid. A cooling liquid may be mixed with the first fluid prior to the heat exchange with the additional fluid.

11 Claims, 7 Drawing Figures

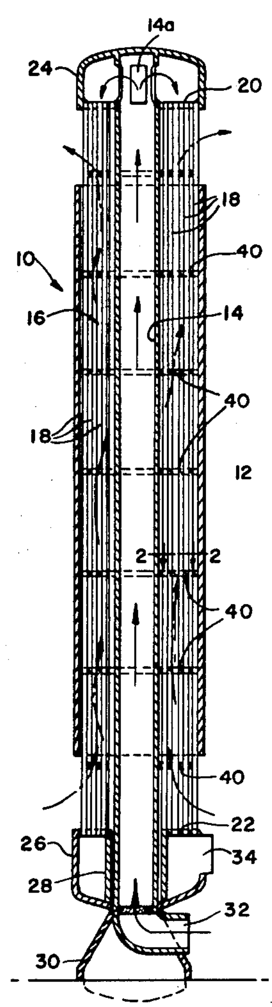

FIG. 1.

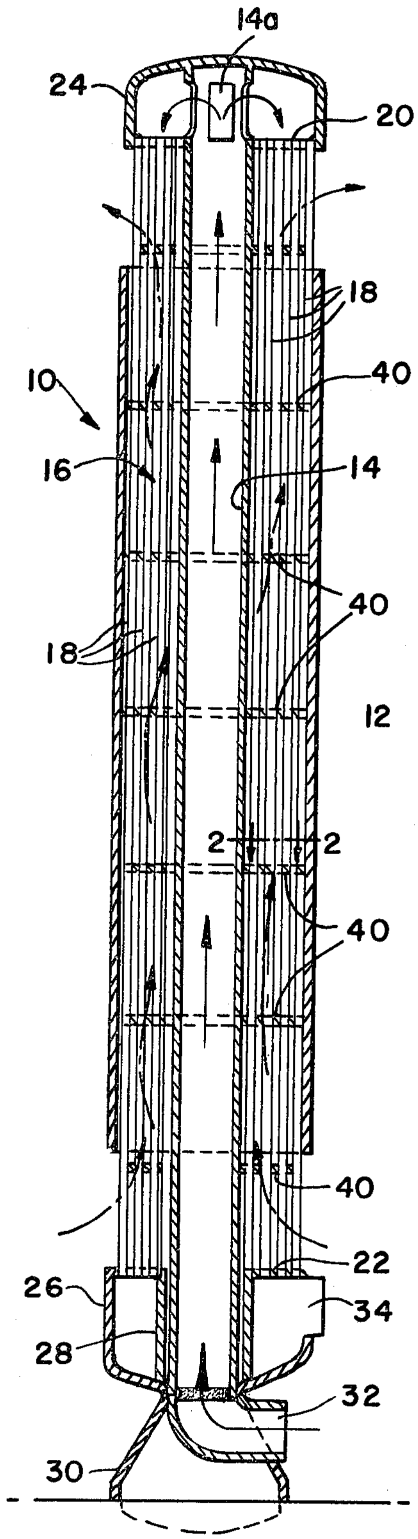

FIG. 2.

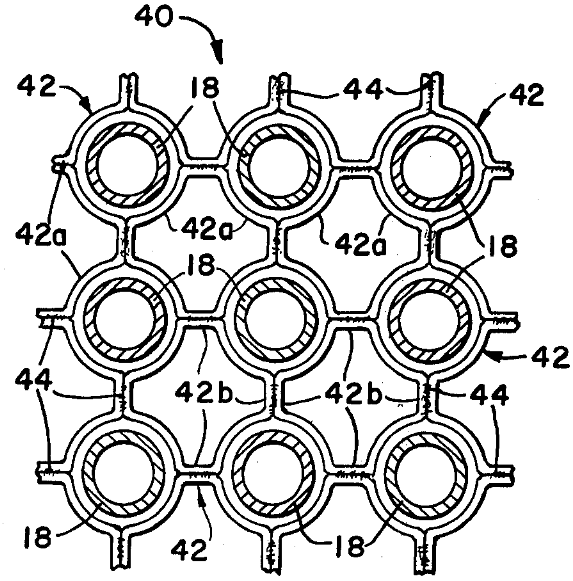

FIG. 3.

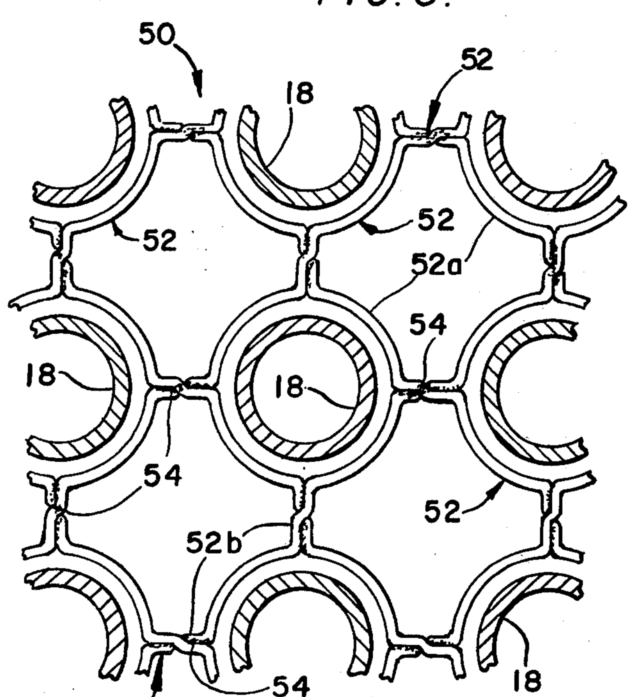

FIG. 4.

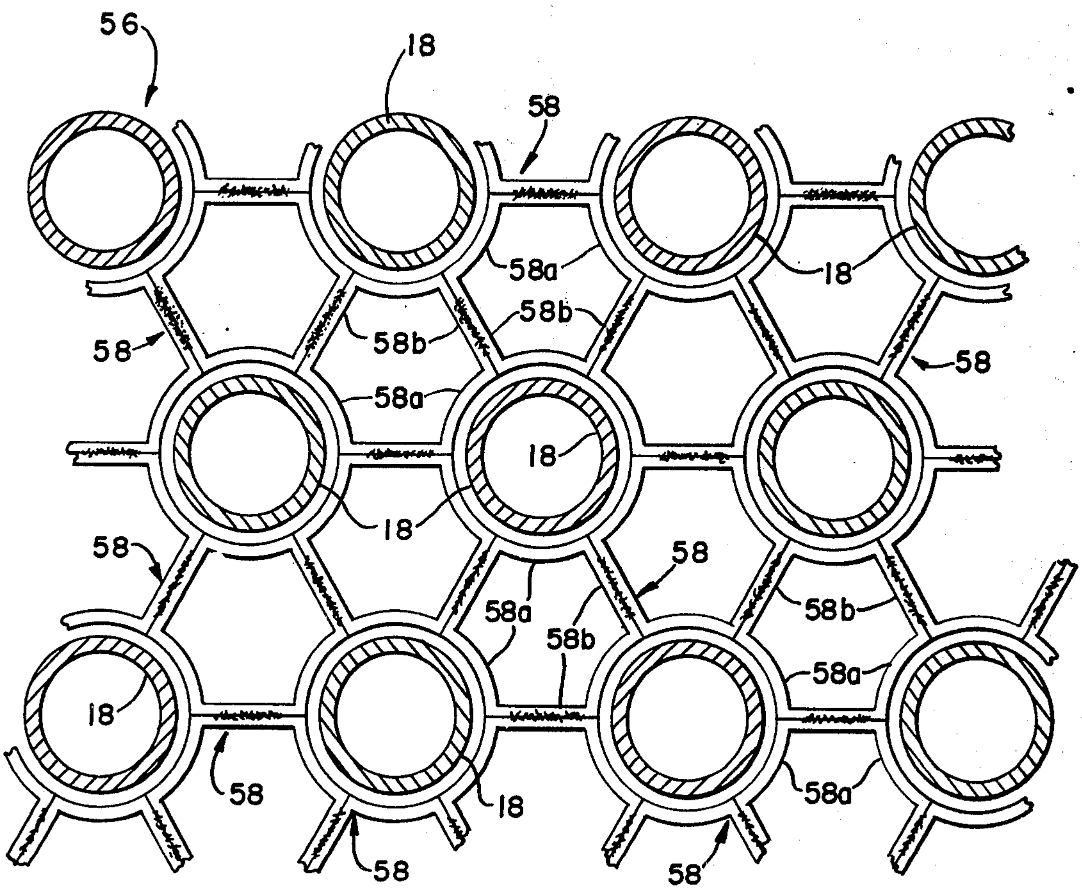
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FIG. 6.

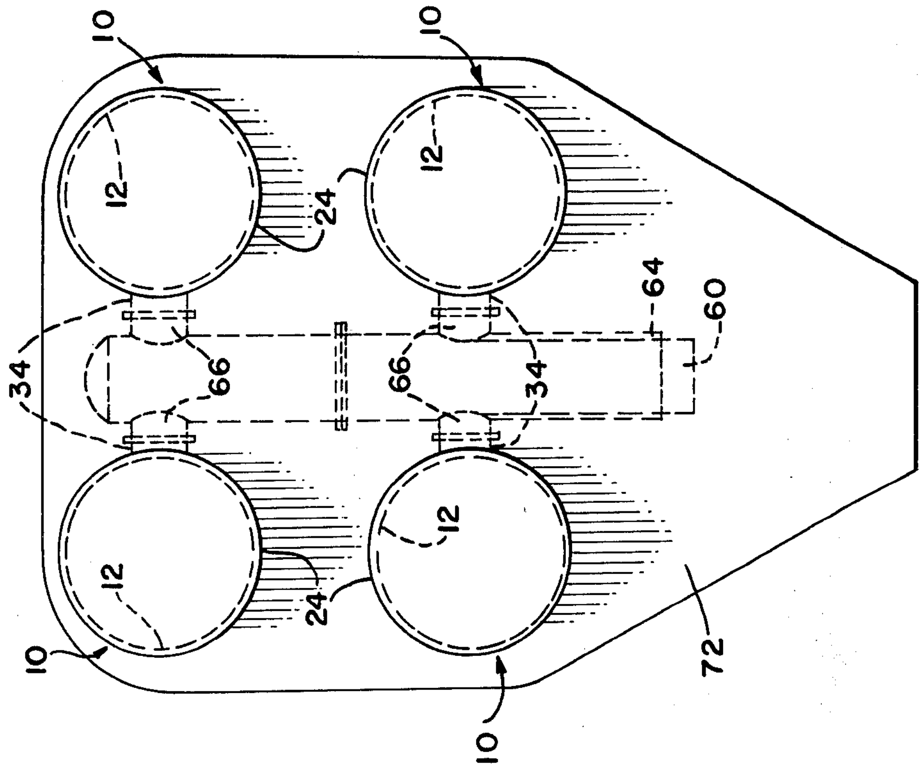


FIG. 5.

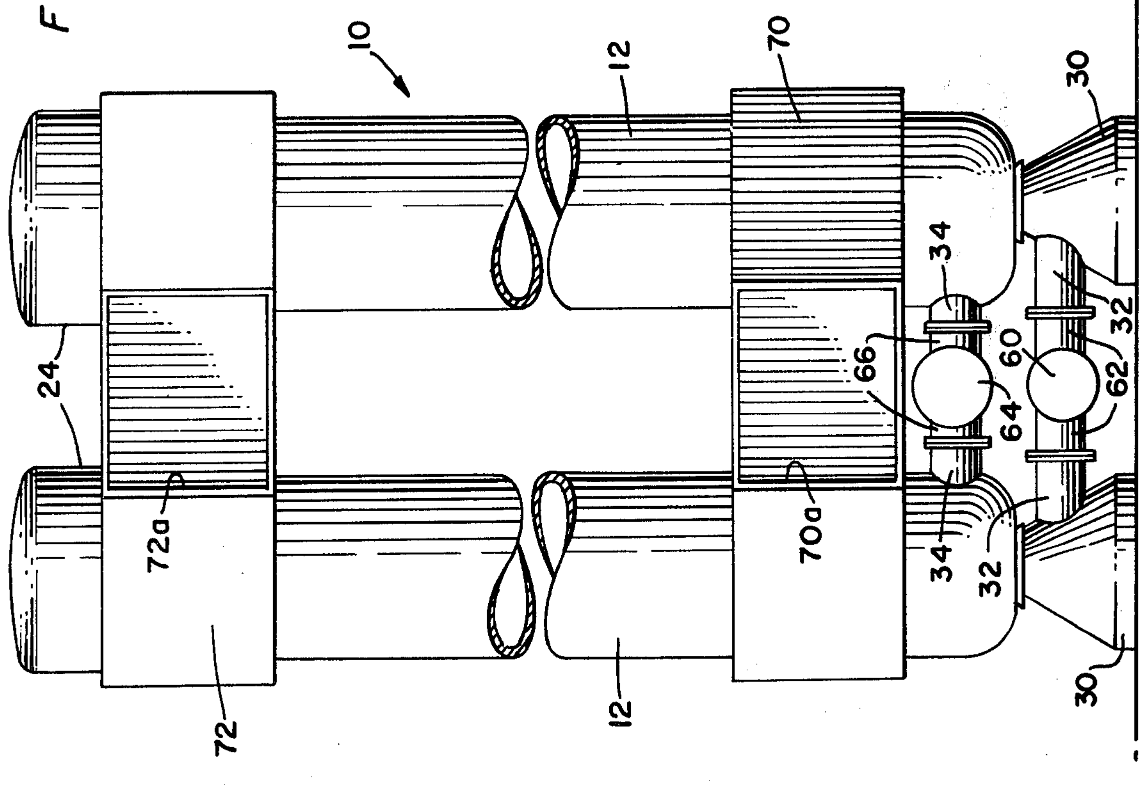
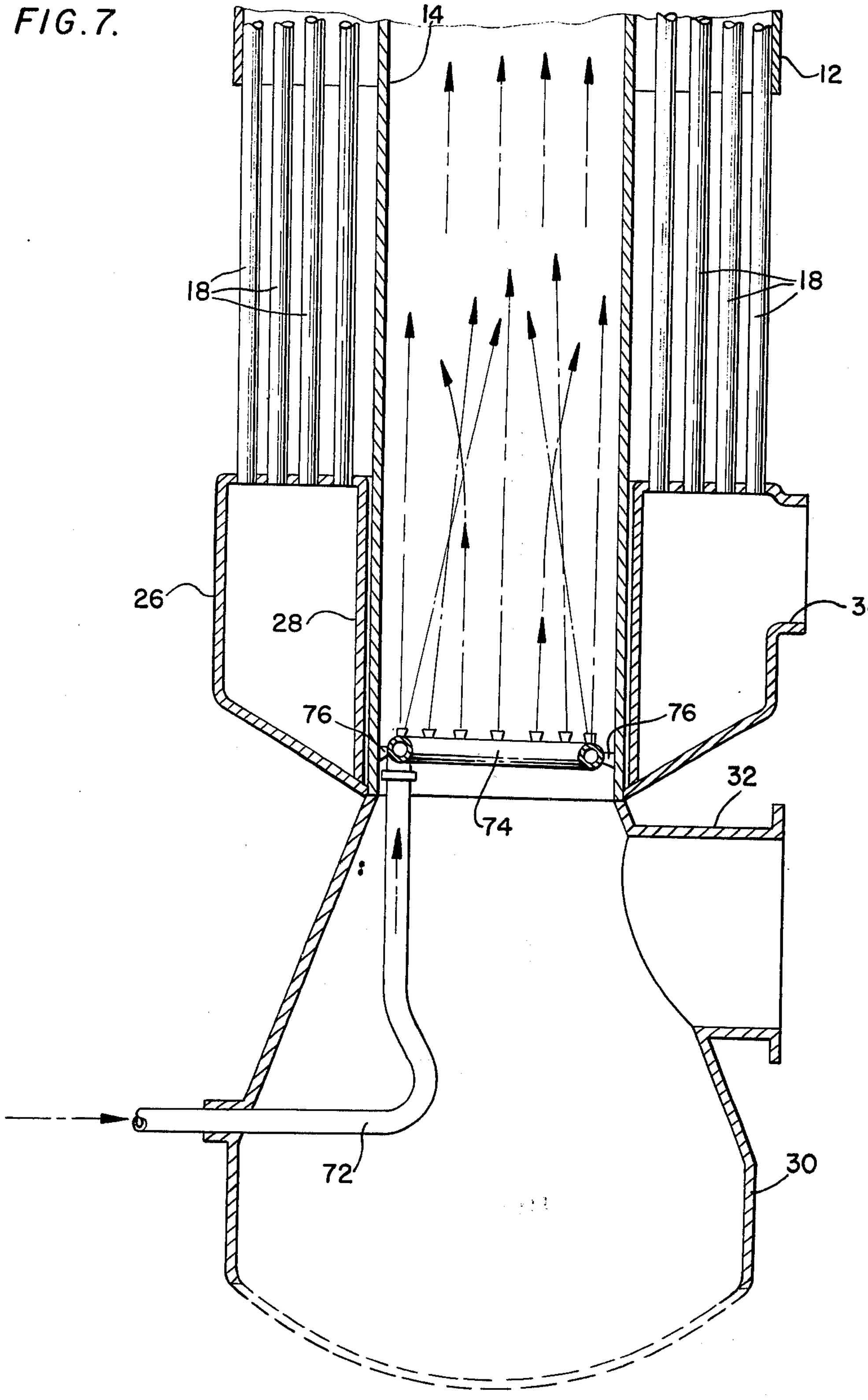


FIG. 7.



GAS TURBINE REGENERATOR

CROSS-REFERENCE TO RELATED APPLICATION

This application is a continuation-in-part of a co-pending application for a GAS TURBINE REGENERATOR, Ser. No. **445,521,** filed Feb. **25, 1974** now abandoned.

BACKGROUND OF THE INVENTION

This invention relates to a heat exchanger and, more particularly, to a heat exchanger which effects a heat exchange between two fluids flowing in a counter-flow relationship.

Several heat exchangers are now in existence, such as gas turbine regenerators, vapor generators, feedwater heaters, and the like, in which a first fluid is passed through a plurality of tubes in a counter-flow relation to a second fluid to effect a heat exchange between the fluids. For example, in a gas turbine regenerator, exhaust gas at a relatively high temperature from a turbine is passed in a heat exchange relation to air from an air compressor to heat the air before the air is passed into a combustion chamber. This, of course, reduces the amount of fuel required in the combustion chamber to raise the temperature of the air to a level sufficient to drive the turbine. Many existing gas turbine regenerators of this type have either been in the form of what is commonly referred to as a plate-type unit or a hexagonal-shaped unit, both of which, although effecting an adequate heat exchange between the gas and the air, caused other problems.

For example, the plate-type units were subject to thermal fatigue failure and internal cracking which resulted in a large amount of leakage from the compressed air side to the exhaust side of the regenerator, resulting in considerable loss of power output on the gas turbine. Also, repair of the plate-type units was difficult, resulting in expensive replacement with new units.

The hexagonal-shaped units, although curing some of the difficulties of the plate-type units, led to other disadvantages such as the requirement of a relatively large amount of field work to assemble the various components of the units which, of course, increased the cost of the units. Another disadvantage of the hexagonal shaped units was the fact that the flow pattern of the exhaust gases passing through the unit required an appreciable amount of open space inside the unit for the exhaust gas to reverse flow direction. This necessary empty space resulted in the units having relatively large overall outside dimensions which prevented the units from being shipped in one piece. Also, the use of hexagonal-shaped units required clean non-fouling exhaust gases such as natural gases and were not suitable for oil fired gas turbines which produced a dirtier exhaust gas.

SUMMARY OF THE INVENTION

It is, therefore, an object of the present invention to provide a heat exchanger which overcomes the above-mentioned disadvantages of the prior art type heat exchangers while being relatively easy to assemble and relatively low in cost.

It is a more particular object of the present invention to provide a heat exchanger of the above type in which thermal stresses, structural stresses, and pressure stresses are relatively low resulting in the various com-

ponents of the unit enjoying a relatively long, trouble-free life.

It is a still further object of the present invention to provide a heat exchanger of the above type which can be assembled with a relatively low amount of field work.

It is a still further object of the present invention to provide a heat exchanger which minimizes the amount of space required and, therefore, results in more compact units which can be easily shipped.

It is a still further object of the present invention to provide a heat exchanger of the above type which can be used with relatively dirty exhaust gases such as gases from oil fired gas turbines or the like.

It is a still further object of the present invention to provide an improved support unit for supporting the tubes of the heat exchanger while permitting the flow of fluid through the heat exchanger housing.

It is a still further object of the present invention to provide a heat exchange system in which a plurality of heat exchangers are connected to a common fluid inlet conduit, a common fluid outlet conduit and a supply and exhaust manifold for an additional fluid.

It is a still further object of the present invention to provide a heat exchanger of the above type in which a cooling liquid is mixed with one of the fluids before its heat exchange with the other fluid.

Toward the fulfillment of these and other objects, the heat exchanger unit of the present invention comprises a plurality of tubes which are supported in a spaced parallel relationship between two spaced tube sheets. A conduit is provided for supplying fluid to the tubes and one of the tube sheets is fixed relative to the conduit while the other tube sheet moves relative to the conduit to accommodate thermal expansion and contraction of the tubes. The support unit is formed by a plurality of interconnected strips formed into a grid pattern defining a first series of openings for receiving the tubes and a second series of openings for permitting the passage of a heat exchange fluid therethrough.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a vertical sectional view of a gas turbine regenerator incorporating features of the present invention;

FIG. **2** is an enlarged cross-sectional view taken along the line **2—2** of FIG. **1**;

FIGS. **3** and **4** are views similar to FIG. **2** but depicting alternate embodiments of the support unit of the present invention;

FIG. **5** is a front elevational view depicting a gas turbine regenerator system incorporating four of the units of FIG. **1**;

FIG. **6** is a plan view of the system of FIG. **5**; and

FIG. **7** is an enlarged, partial vertical sectional view of an alternate embodiment of a gas turbine regenerator incorporating features of the present invention.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Referring specifically to FIG. **1**, the reference numeral **10** refers in general to a gas turbine regenerator incorporating features of the present invention. The regenerator **10** comprises an outer tubular housing **12** partially enclosing an air conduit **14** extending coaxially with the housing with an annular space **16** being defined between the conduit and the housing.

A plurality of spaced parallel tubes **18** extend in the annular space **16** with both ends of each tube projecting from the housing **12**. An upper tube sheet **20** and a lower tube sheet **22** receive the tubes with the ends of the tubes being mechanically expanded and welded in the sheets in a conventional manner. Both ends of the conduit **14** project outwardly from the housing **12** and extend through a central opening formed in the tube sheets **20** and **22**, respectively.

An upper header **24** is secured to the outer circumference of the upper tube sheet **20** and receives the upper end portion of the conduit **14**, which has a plurality of slots **14***a* extending therethrough for reasons that will be explained in detail later. The upper tube sheet **20** is attached to the conduit **14** and the upper header **24** is attached to the upper tube sheet in any conventional manner.

A lower header **26** is attached to the lower tube sheet **22** and the latter in turn is attached to a sleeve **28** which extends within the lower header and over a lower portion of the conduit **14**. It is noted that the diameter of the sleeve **28** is slightly greater than the diameter of the conduit **14** to permit relative movement therebetween for reasons that will be discussed later.

The lower tube sheet **22** may be attached relative to the sleeve **28**, and the lower header **26** may be attached relative to the lower tube sheet in a conventional manner such as by welding or the like.

A conical base **30** is provided which is attached to the lower end of the conduit **14** by welding or the like and which thus supports the entire structure. The base **30** is provided with an air inlet **32** which registers with the conduit **14**. As a result, air entering the inlet **32** passes upwardly through the conduit **14** before discharging through the slots **14***a* into the upper header **24**, from which it passes into the upper ends of the tubes **18**. An air outlet **34** is provided through the lower header **26** to permit discharge of the air after it has passed through the tubes **18**.

Hot gases are introduced into the lower end of the housing **12** and pass upwardly between the tubes **18** in the space **16** before exiting from the upper end of the housing, for reasons to be described later.

A plurality of annular support units **40** are disposed at spaced intervals throughout the length of the tubes **18** for supporting same with a portion of one of the support units **40** being shown in detail in FIG. **2**.

In particular, each support unit **40** is formed by a plurality of metal strips **42** which are generally octagonallyshaped with one series of alternating sides **42***a* of each strip being curved inwardly and the other series of alternating sides **42***b* being straight. Each straight side **42***b* of each strip **42** is connected to a corresponding side **42***b* of another strip by welding or the like as shown by the reference numeral **44**, to form a grid pattern with the curved sides **42***a* defining a plurality of openings for receiving the tubes **18**. The remaining openings defined by the grid pattern provide a free flow area for the gases passing through the housing with a minimum of resistance.

In operation, air from an air compressor or the like is introduced into the conical base **30** through the inlet **32** and passes upwardly through the conduit **14** whereby it discharges into the upper header **24**, as shown by the solid flow arrows in FIG. **1**. From the header **24** the air passes downwardly through the tubes **18** and exits through the outlet **34** formed through the lower header **26** for further passage to a combustion chamber for the turbine. Gases from the turbine exhaust at a relatively high temperature are passed into the lower end of the housing **12** and pass upwardly through the annular space **16** and between the various tubes **18**, as shown by the dashed arrows, whereby they exit through the upper end of the housing **12** and are directed to an exhaust stack, or escape freely into the atmosphere from each individual regenerator. As a result of the above counter-flow between the gases and the air, a heat exchange is effected therebetween to raise the temperature of the air and thus reduce the fuel requirements in the combustion chambers of the turbine.

It can be appreciated that thermal expansion of the tubes **18** in a longitudinal direction is accommodated by movement of the lower tube sheet **22**, and therefore the sleeve **28** and the lower header **26**, relative to the conduit **14** which is fixed relative to the upper tube sheet **20** and the upper header **24**.

A first alternate form of the support unit is shown in general by the reference numeral **50** in FIG. **3** and comprises a plurality of strips **52** which have a series of alternating curved sides **52***a* and straight sides **52***b*, similar to the strips **42** of the previous embodiment. The straight side **52***b* of each strip **52** is interlaced with a straight side of another strip with one or both of the strips being slotted to provide an interlock between the strips before they are welded together at an area shown by the reference numeral **54**. As in the previous embodiment, the strips **52** define a grid pattern including a plurality of openings for receiving the tubes **18**, with the remaining portion of the grid pattern permitting a relatively unimpeded flow of gases through the housing **12**.

A second alternate form of the support unit is shown in general by the reference numeral **56** in FIG. **4** and is designed to accommodate a series of rows of tubes **18** in an offset, or staggered, relationship. Each unit **56** comprises a plurality of strips **58** in hexagonal form and having a series of alternating curved sides **58***a* and straight sides **58***b*. Each straight side **58***b* of each strip **58** is connected to a straight side of an adjacent strip by welding, or the like, with the adjacent curved sides **58***a* defining a plurality of openings for receiving the tubes **18** and the remaining portion of the grid pattern permitting a relatively unimpeded flow of gases through the housing **12**.

Referring specifically to FIGS. **5** and **6**, a regenerator system is shown which consists of four regenerators **10** which are connected to a common air inlet, air outlet, gas inlet and gas outlet, and are thus able to service a relatively large gas turbine.

In particular, the regenerators **10** are disposed in two spaced rows of two regenerators per row and a horizontally extending air inlet conduit **60** is provided between the two rows which is connected to the air inlet **32** of each regenerator **10** by means of branch conduits **62**.

In a similar manner, a common air outlet conduit **64** is provided which extends horizontally between the two rows and which is connected to the air outlets **34** of each regenerator **10** by means of branch conduits **66**. In this manner, air introduced into the air inlet conduit **60** from the air compressor is routed into the air conduit **14** of each regenerator **10** through the branch conduits **62** and the air inlets **32** of each regenerator, before passing upwardly through the respective conduits

14 of each regenerator. As discussed in connection with the previous embodiments, the air collects in the upper header 24 of each regenerator 10 and passes downwardly through the respective tubes 18 before exiting through the respective air outlets 34 and, through the branch conduits 66, to the air outlet conduit 64 for passage to the combustion chambers of the turbine.

A supply manifold 70 is provided which surrounds the gas inlet area between the housing 12 and the lower header 26 of each regenerator 10. As a result, gases introduced from the turbine exhaust into the inlet 70*a* of the manifold 70 are passed into the lower end of the housing 12 of each of the regenerators 10, from which they pass upwardly through the annular space 16 in each regenerator 10 and exhaust through an upper manifold 72 having an outlet 72*a* or escape freely into the atmosphere from each individual regenerator.

Although not shown in the drawings, it is understood that an access opening may be provided in the base 30 and that an internal rung ladder may be provided along the conduit 14 to provide access to the upper header 24.

It can be appreciated that, as a result of the foregoing arrangement, the compactness of each individual regenerator can be maintained while the regenerators can be adapted for much larger capacity in order to service a relatively large type gas turbines. Of course, the regenerators 10 can be connected in a different manner than that shown in FIGS. 5 and 6, such as, for example, in one row of several regenerators, or the like.

According to the regenerator embodied in FIG. 7, a cooling fluid is injected into the air stream passing through the regenerator. Since the regenerator of FIG. 7 is otherwise similar to that of FIG. 1, identical portions thereof will be referred to by the same reference numerals. In particular, an inlet pipe 72 extends through the base 30 of the regenerator of FIG. 7 and into the conduit 14, and is connected at one end to a multinozzle toroidal spray ring 74 supported within the conduit 14 by a bracket assembly 76. The other end of the pipe 72 is coupled to a suitable source of fluid, preferably demineralized water. As a result, the spray water is discharged through the ring 74 and into the conduit 14 where it mixes with the air entering the regenerator 10 through the inlet 32 which, for the purposes of this embodiment, does not extend into the conduit 14. The resulting air-water mixture passes upwardly through the conduit 14 and into the upper header 24, where its flow direction is reversed before it passes downwardly through the tubes 18 as discussed in connection with the regenerator of FIG. 1. This relatively long flow path permits the total vaporization of the water and provides several benefits.

For example, when the inlet 32 of the regenerator of FIG. 7 is coupled to the output of an air compressor preceding the turbine, and the hot gases passed through the housing 12 in the spaces between the tubes 18 are from the turbine exhaust, the compressed air is generally at a relatively low temperature compared to the turbine exhaust gases but still at a substantially high temperature, such as 500°–600°F. By virtue of the air being cooled by the liquid prior to its heat exchange with the turbine exhaust gases while being maintained at the same pressure, more heat is absorbed from the turbine exhaust gases and therefore a more efficient cycle to the turbine is achieved. Furthermore, the vaporization of the liquid added to the air stream provides an improved heat exchange and if the air-liquid mixture at the outlet 34 is directed to the input of a gas turbine, a higher mass flow is provided. As a result, a greater amount of fuel consumption is required in order to maintain the temperature profile of the turbine exhaust temperature, which substantially increases the horsepower generated by the turbine relative to the fuel consumption.

It is noted that the embodiment of FIG. 7 also avoids one of the main disadvantages normally associated with fluid injection in this type of environment, which is the possibility that the injected fluid may not sufficiently vaporize resulting in the fluid droplets entering the turbine causing severe damage. In order to remedy this situation, many prior art arrangements have included long heated inlet pipes to insure that the injected fluid is fully vaporized. The regenerator of the present invention has the inherent benefit that the distance between inlet 32 and outlet 34 is sufficiently long to insure full vaporization under controlled fluid injection and temperature conditions. This construction therefore eliminates construction of costly auxiliary equipment for the injection of fluids.

It is emphasized that, although the fluid injected into the conduit 14 is preferably water because of its high latent heat value, other fluids may be injected, such as waste products from other processes and the like which could contain a combustible material and thus serve as a supplementary fuel as well as a cooling agent.

It should be understood that the fluid injection system illustrated in FIG. 7 may be adapted for any of the different embodiments described herein.

It is also understood that several variations may be made in the foregoing embodiments without departing from the scope of the present invention. For example, the features of the present invention are not limited to the use of gas turbine regenerators but can be equally applicable to other heat exchangers, such as vapor generators, feedwater heaters, waste heat boilers, air heaters, nuclear steam generators, fossil fired steam generators, and the like.

Of course, other variations of the specific construction and arrangement of the regenerator disclosed above can be made by those skilled in the art without departing from the invention as defined in the appended claims.

What is claimed is:

1. A gas turbine regenerator through which the exhaust gasses of a gas turbine are adapted to pass in heat exchange relation with combustion air of the gas turbine for injecting cooling fluid into; and heating, the combustion air enteringing said gas turbine comprising:

a conduit having an inlet for receiving the combustion air and an outlet for discharging same, a tube sheet connected to and supported by said conduit, a header connected to said tube sheet, a plurality of tubes extending parallel to said conduit, one end of each of said tubes being supported by said tube sheet in communication with said header, whereby said header reverses the fluid flow from said conduit and passes said combustion air into said tubes, an additional tube sheet supporting the other ends of said tubes, a sleeve connected at one end to the conduit close to the inlet thereof and to said additional tube sheet at a free end thereof spaced from said conduit inlet and surrounding a portion of said conduit with the inner wall of said sleeve extending in a spaced relation to the outer surface of said conduit to permit relative movement therebetween, an additional header connected to said additional tube sheet and to said sleeve at the end thereof close to the conduit inlet, said additional header adapted to receive said combustion air from said other ends of said tubes and discharge same from the outlet formed therethrough, and a housing having a circular cross-section located coaxially with respect to said conduit the tubes enclosed in an annular space defined between said housing and conduit having an inlet for receiving the exhaust gases of said gas turbine and an inlet for discharging said same in a counterflow relation to said combustion air in said tubes, said exhaust gases being at a relatively high temperature than said combustion air with the resultant thermal expansion of said tubes being accommodated by movement of said sleeve and therefore said additional tube sheet and additional header relative to said conduit; at least one support unit for supporting tubes in a spaced relation within the housing, said unit comprising a plurality of interconnected strips formed into a grid pattern defining a first series of openings for respectively receiving said tubes said openings spaced uniformly about the exterior surface of the tubes forming a spaced sleeve thereabout, and a second series of openings for permitting the passage of the combustion air therethrough, said strips being interlaced with at least one side being slotted to facilitate said interconnection, and a fluid injection means for injecting of cooling fluid into the conduit near the inlet for mixing with said combustion air, the heat exchange between the combustion air gases being sufficient to vaporize the cooling fluid.

2. The gas turbine regenerator of claim **1** wherein said conduit, said tubes and said housing extend primarily vertically, with said tube sheet and said header being disposed at the upper portion thereof, and with said sleeve, said additional tube sheet and said additional header being disposed at the lower portion thereof, said combustion air passing from the lower portion of said conduit upwardly and then downwardly through said tubes, and said exhaust gases passing upwardly through said housing.

3. The gase turbine regenerator of claim **1** wherein said conduit, said tubes and said housing extend primarily horizontally, with said tube sheet and said header being disposed at the upper portion thereof, and with said sleeve, said additional tube sheet and said additional header being disposed at the lower portion thereof, said combustion air passing from the lower portion of said conduit upwardly and then downwardly through said tubes, and said exhaust gases passing upwardly through said housing.

4. The heat exchanger of claim **1** wherein said first fluid is air at a relatively low temperature from an air compressor and wherein said second fluid is a gas at a relatively high temperature from the exhaust of a gas turbine.

5. The gas turbine regenerator of claim **1** wherein said cooling fluid is water in liquid form when injected and wherein the heat exchange between said combustion air and exhaust gases is sufficient to heat said combustion air and vaporize said cooling water.

6. The gas turbine regenerator of claim **5** wherein said water injection means comprises a toroidal spray nozzle having a plurality of holes and an inlet for communicating a water supply thereto for injection into said conduit.

7. The gas turbine regenerator of claim **6** further comprising bracket means for supporting said toroidal spray nozzle within said conduit.

8. The gas turbine regenerator of claim **1** wherein said cooling fluid is a liquid, at least a portion of which is combustible.

9. The gas turbine regenerator of claim **1** wherein said combustion air is at a relatively low temperature from an air compressor and wherein said exhaust gas is at a relatively high temperature from the exhaust of the gas turbine.

10. The gas turbine regenerator system of claim **1** comprising a plurality of heat exchangers, a supply conduit for the combustion air, means connecting said supply conduit to each of said heat exchangers, an outlet conduit for said combustion air means connecting said outlet conduit to each of said heat exchangers, a supply manifold connected to each of said heat exchangers for supplying the exhaust gases to said heat exchangers, and an exhaust manifold connected to each of said heat exchangers for receiving said exhaust gases.

11. The gas turbine regenerator system of claim **10** wherein; said supply conduit is connected to an air compressor, said outlet conduit is connected to a combustion chamber, and said supply manifold is connected to the gas turbine.

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