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J. K. LA FLEUR

3,258,067

HEAT EXCHANGER

Filed June 1, 1964

Fig. 1

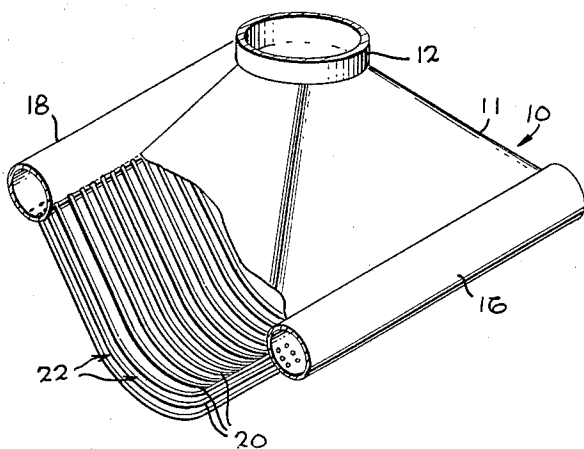


Fig. 2

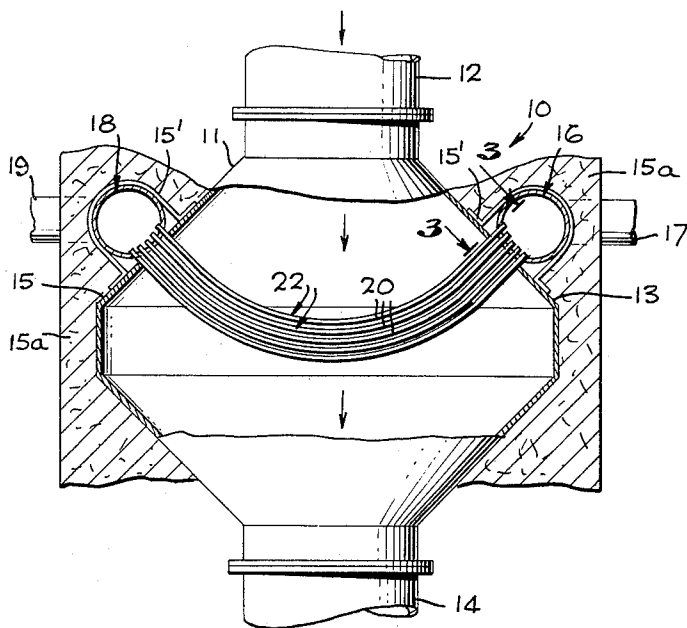


Fig. 4

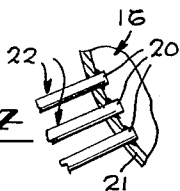


Fig. 3

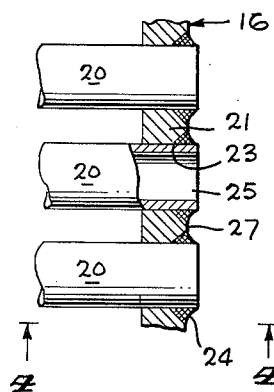
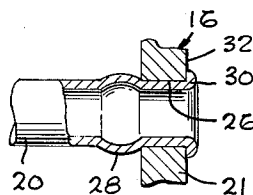


Fig. 5



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3,258,067

HEAT EXCHANGER

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13 Claims. (Cl. 165—81)

This invention relates to a gas heater and is particularly directed to a compressed gas heater or heat exchanger designed especially for the heating of compressed propulsive gas, such as helium, especially useful for driving a turbine in a closed cycle gas turbine power plant.

In a closed cycle gas turbine power system utilizing helium as a working fluid, e.g., as described in my copending applications, Serial No. 87,311, filed February 6, 1961, now abandoned, and Serial No. 318,564, filed October 24, 1963, now Patent No. 3,194,026, helium is first compressed, is then heated in a hot regenerator, and passed to a heat exchanger. In the heat exchanger the helium is further heated to a high temperature for introduction into a hot turbine which functions to supply power to the compressor. In such heat exchanger hot combustion gases are passed into heat exchange relation with the helium.

Thus, for example, according to one mode of procedure for operation of a closed cycle gas turbine power system utilizing helium as a working fluid, helium gas enters the compressed gas heater or heat exchanger at approximately 1000° F. and is heated therein to about 1200° F. by hot combustion gases. According to the improved process described and claimed in my copending application, Serial No. 371,428, entitled Heat Transfer Process, filed of even date herewith, the hot combustion gases employed as heat transfer medium for heating the compressed helium in the heat exchanger are reduced in temperature from the stoichiometric combustion gas temperature of about 3500° F. down to approximately 1700° F. before being passed into the exchanger and across the high pressure gas, e.g., helium, being heated therein.

A major advantage of the system and procedure described in my copending application filed of even date herewith is that due to the lowered temperature of the combustion gas used to heat the compressed gas, that is, helium, in the heat exchanger, the size of the heat exchanger can be greatly reduced because of such lower temperature, making it possible to construct compact heat exchange surfaces using thin-walled tubing, and the cost of construction material employed in fabricating heat exchange surfaces is greatly reduced due to the greater strength of the conventional metals and alloys used for such construction, at temperatures below about 1700° F., while at the same time further reducing the danger of deterioration or burning out of the heat exchanger tubes. Thus, the process of my copending concurrently filed application avoids the necessity for the use of special heat exchange equipment necessary to prevent direct impingement of the previously employed hot combustion gases at temperatures of the order of 3000° F. to about 3500° F. directly against the tubes, for example, baffle systems which causes heat transfer from the combustion gases to take place essentially by radiation rather than by sweeping the gases directly across the tubes (convection).

It is an object of the invention to design a heat exchanger of simple, efficient construction, avoiding the conventional heat exchanger constructions employing special means, such as baffle systems, to avoid burning out of the tubes.

In conventional heat exchangers, the ends of the tubes are held in fixtures designed so as to absorb end loads or

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thrusts to hold the ends of the tubes in position when the tubes expand during heating. Of necessity, in such constructions, an end portion of the tubes is often unavailable for heat transfer purposes. It is accordingly an object of the instant invention to provide heat exchangers of compact, simple design, and particularly adapted for heating compressed gases, such as helium, which makes available substantially all of the tube surface for heat exchange purposes.

Still another object is the design of a heat exchanger containing thin-walled tubes of relatively small diameter for passage of a compressed gas to be heated, the ends of the tubes being supported in a simple manner without requiring any special means of connection to the supporting walls or headers of the exchanger.

A still further object is the provision of a compact heat exchanger, particularly designed for heating compressed gas such as helium by means of hot combustion gases, such that for a given heat flux or rate of heat transfer the overall size of the exchanger is substantially smaller as compared to conventional heat exchangers.

The invention provides a novel heat exchanger embodying as the main feature of construction a plurality of tubes, preferably thin-walled tubing of relatively small diameter, which are suspended across the interior of the heat exchanger in the form of a catenary curve, and are supported at their opposite ends by headers mounted adjacent the opposite side walls of the heat exchanger. Preferably the tubes are arranged in a plurality of vertically spaced layers or banks within the exchanger. The ends of the tubes are fixedly connected in a simple suitable manner, as by welding, to the walls of the opposite headers for support thereby.

The tubes can hang in the form of a curve, that is, a catenary, having a large radius of curvature or relatively small radius of curvature, that is, from a curve which is nearly straight to a curve in the form of substantially a complete semi-circular loop. Because of the manner in which the tubes are supported and the curved configuration of the tubes, thinner construction metals can be employed to provide thinner walled tubing and having a smaller diameter than that which is ordinarily employed, since in ordinary heat exchanger construction the tubes must be sufficiently rigid and have sufficient thickness to absorb end loads due to expansion of the tubes on heating.

Since small diameter tubing has a greater ratio of heat exchange surface to volume, as compared to larger diameter tubing, smaller, more compact, exchangers can be constructed, utilizing the invention principles of suspending the tubes in the form of a catenary, to produce a given heat flux (rate of heat transfer or units of heat transfer per unit of time) as compared to conventional heat exchangers. Thus, for a given size heat exchanger, the invention construction provides a greater heat flux than do conventional exchangers.

Also, the compact heat exchanger of the invention employing thin-walled tubes supported in the form of a catenary has substantially lower thermal losses to the atmosphere as compared to larger size, conventional heat exchangers since, for a given amount of heat flux, the heat exchanger with the smallest volume will have the lowest thermal losses to the atmosphere.

The invention will be more clearly understood by reference to the description below of a preferred embodiment, taken in connection with the accompanying drawing wherein

FIG. 1 is a perspective view of a heat exchanger according to the invention, with a portion of the outer wall broken away to show banks of tubes having the curved configuration of the heat exchanger tubes of the invention;

FIG. 2 is an elevational cross-section of a heat exchanger of the type shown in FIG. 1;

FIG. 3 is a detail taken on line 3—3 of FIG. 2, showing a plan view of the tubes as arranged in each layer or bank of tubes, and the connection of the ends of the tubes to the headers by welding;

FIG. 4 is a detail taken on line 4—4 of FIG. 3, showing the vertically spaced tubes in the respective banks of tubes; and

FIG. 5 illustrates a modification of the manner of attachment of the ends of the tubes to the headers employing aflaring and rolling type connection.

Referring particularly to FIGS. 1 and 2 of the drawing, numeral 10 represents the heat exchanger of the invention comprising an outer casing or housing 11 having a gas inlet 12 connected to its upper end and a gas outlet 14 connected in conventional manner to the lower end of the heat exchanger.

Supported on opposite side walls 13 and 15 of the heat exchanger housing 11 by suitable means in the form of brackets 15', and preferably surrounded by wall insulation 15a, are headers 16 and 18 of generally cylindrical shape, as seen more clearly in FIG. 1. The header 16 mounted on the heat exchanger wall 13 has a gas inlet 17, and the header 18 mounted on the exchanger wall 15 has a gas outlet 19.

Suspended across the interior of the heat exchanger and supported from headers 16 and 18 is a multiplicity of thin-walled small diameter tubes 20 in the shape of a catenary curve, and arranged in a series of vertically spaced arcuate banks or layers 22 of such tubes, as seen in FIGS. 1, 2 and 4. The respective tubes 20 of each such arcuate bank or layer are mounted in closely spaced parallel relation to each other at substantially the same level within the heat exchanger, progressing from the front to the rear of the exchanger, viewing FIGS. 1 and 2, as illustrated in FIG. 3. Such tubes can be constructed of any suitable metal such as Inconel, stainless steel or any other heat resistant metal.

The tubes 20 of the exchanger, which preferably hang in the form of a curve which is a catenary, can have a large radius of curvature or a relatively small radius of curvature.

The opposite ends of each of the tubes 20 are fixedly connected to the wall 21 of each of the heat exchangers 16 and 18. Viewing FIG. 3 of the drawing showing one form of attachment of the ends of the tubes to be headers, e.g., 16, the tubes are passed completely through apertures 23 in the wall 21 of the headers, and extend a short distance, as indicated at 25, into the interior of the header beyond the inner surface 27 of the wall thereof. The tube ends are then seal-welded at their inner ends around the periphery of the aperture 23, as indicated at 24.

According to the modification shown in FIG. 5, the ends of the tubes 20 also pass completely through suitable apertures 26 in the wall 21 of the headers, e.g., 16, and the tubes are flared at 28 adjacent the outside surface of the header wall 21, and the ends of the tubes are rolled as indicated at 30 against the inner surface 32 of the header wall 21, thus maintaining the ends of tubes 20 in fixed position in each of the headers 16 and 18.

In a preferred mode of utilization of the heat exchanger shown in FIGS. 1 and 2, a compressed gas such as helium, and which may be at an elevated temperature, e.g., of the order of about 1000° F., is fed through inlet 17 into the header 16, and the gas then passes through the banks 22 of catenary tubes 20 and across the heat exchanger in heat exchange relation with, for example, a hot combustion gas, e.g., at a temperature of the order of about 1700° F. introduced via the pipe 12. The hot combustion gases sweep downwardly, as indicated by the arrows, across the heat exchanger tubes 20 carrying the compressed helium, and then pass down-

wardly through the heat exchanger and into the discharge outlet 14. The compressed helium which is now heated to a temperature, for example, of about 1200° F., as result of being heated by the downward sweeping flow of hot combustion gases, passes into the opposite header 18 and through the discharge outlet 19 therein. Such compressed and heated helium gases can then be fed directly to a turbine used for driving a compressor, as described in my above copending applications, Serial Nos. 87,311 and 318,564.

If desired, the tubes 20 in the respective arcuate layers or banks 22 can be positioned either directly in vertical alignment, as illustrated in FIG. 1 of the drawing, or the tubes in one bank can be staggered in relation to the tubes of an adjacent bank or layer.

It will be seen from the construction of the heat exchange tubes 20, including their mode of attachment to the opposite headers and the manner of suspension of such tubes in the form of a catenary curve, that not only is substantially all of the surface area of each tube available for heat exchange purposes, but the amount of heat exchange surface per tube is increased over the use of conventional straight tubes. Due to the manner in which the tubes are supported and the curved configuration of the tubes, thinner construction metals can be employed to provide thin-walled tubing and of smaller diameter than is ordinarily employed. This is because in ordinary heat exchange construction, the tubes must be sufficiently rigid and have sufficient thickness to absorb end loads due to expansion of the tubes on heating.

In the heat exchanger of the invention, the tubes, e.g., 20, are sufficiently rigid so that they maintain their original curvature when hanging in the exchanger. But the tubes are flexible from the standpoint that they will deflect without damage either by expansion as result of heating or by physical displacement without damage. However, the ends of the tubes remain rigidly attached to the respective headers during any such displacement of the tubes.

Giving a specific example of the dimensions of a heat exchanger according to the invention used for heating compressed helium, but without intending to limit the invention by such example, the distance between headers 16 and 18 can be, for example, 13 feet, the length of each of the headers being six feet, the arcuate length of the catenary tubes, such as 20, being 18 feet, and employing about 19 arcuate tube banks 22 having a total of 1,050 tubes, each $\frac{3}{16}$ " in diameter and $\frac{1}{32}$ " in wall thickness.

A configuration for a conventionally heat exchanger having approximately the same heat flux will require about five times the weight of tubing of the invention exchanger described directly above, and the overall size of such conventional exchanger would be much greater, e.g., using 250 tubes each approximately 2" in diameter and 200 feet in overall length, such dimensions would be about 20 feet x 10 feet x 45 feet.

It will accordingly be seen that the size and weight of the invention heat exchanger are much less than for a conventional heat exchanger for a given heat flux.

In view of the foregoing, it is seen that the invention provides a novel heat exchanger construction in which the tubes are self-supporting and therefore smaller diameter and less expensive tubing may be used. No mechanical supports for the tubes are required, and the gas flow over the tubes is substantially uniform and is not disturbed by sudden changes in flow direction due to use of conventional tube supports. Further, the invention structure results in a more compact arrangement of the heat exchanger, thereby reducing thermal heat losses to the atmosphere.

While I have described particular embodiments of my invention for the purpose of illustration, it should be understood that various modifications and adaptations thereof may be made within the spirit of the invention, as set forth in the appended claims.

I claim:

1. A heat exchanger which comprises a housing, a first header mounted on one side of said housing, a second header mounted on the opposite side of said housing, a plurality of essentially flexible tubes mounted in said housing, said tubes each suspended in the form of a catenary across said housing, one end of each of said tubes connected to said first header and the other end of each of said tubes connected to said second header, a gas inlet to said housing and a gas outlet from said housing, spaced from said gas inlet.

2. A heat exchanger which comprises a housing, a first header mounted on one side of said housing, a second header mounted on the opposite side of said housing, a plurality of essentially flexible tubes mounted in said housing, said tubes each suspended in the form of a catenary across said housing, one end of each of said tubes welded to said first header and the other end of each of said tubes welded to said second header, a gas inlet to said housing and a gas outlet from said housing, spaced from said gas inlet.

3. A heat exchanger which comprises a housing, a first header mounted on one side of said housing, a second header mounted on the opposite side of said housing, a plurality of essentially flexible tubes mounted in said housing, said tubes each suspended in the form of a catenary across said housing, one end of each of said tubes connected to said first header and the other end of each of said tubes connected to said second header, a gas inlet to said housing and a gas outlet from said housing, spaced from said gas inlet, the ends of each of said tubes being connected to said headers by a flared and rolled connection.

4. A heat exchanger which comprises a housing, a first header mounted on one side of said housing, a second header mounted on the opposite side of said housing, a plurality of essentially flexible tubes mounted in said housing, said tubes each suspended in the form of a catenary across said housing, forming arcuate banks of tubes across said housing between said headers, one end of each of said tubes connected to said first header and the other end of each of said tubes connected to said second header, a gas inlet to said housing on one side of said arcuate banks of tubes and a gas outlet from said housing on the other side of said arcuate banks of tubes.

5. A heat exchanger which comprises a housing, a first header mounted on one side of said housing, a second header mounted on the opposite side of said housing, a plurality of essentially flexible tubes mounted in said housing, said tubes each suspended in the form of a catenary across said housing, forming arcuate banks of tubes across said housing between said headers, with the tubes in each bank spaced horizontally from each other, one end of each of said tubes fixedly connected to said first header and the other end of each of said tubes fixedly connected to said second header, a gas inlet to said housing on one side of said arcuate banks of tubes and a gas outlet from said housing on the other side of said arcuate banks of tubes.

6. A heat exchanger which comprises a housing, a first header mounted on one side of said housing, a second header mounted on the opposite side of said housing, a plurality of essentially flexible tubes mounted in said housing, said tubes each suspended in the form of a catenary across said housing, forming a plurality of arcuate banks of tubes, said banks positioned in vertically spaced relation across said housing between said headers, one end of each of said tubes connected to said first header and the other end of each of said tubes connected to said second header, the tubes of each of said banks being spaced horizontally from each other, a gas inlet to said housing on one side of said arcuate banks of tubes and a gas outlet from said housing on the other side of said arcuate banks of tubes.

7. A heat exchanger which comprises a housing, a first header mounted on one side of said housing, a sec-

ond header mounted on the opposite side of said housing, a plurality of essentially flexible tubes mounted in said housing, said tubes each suspended in the form of a catenary across said housing, forming a plurality of arcuate banks of tubes, said banks positioned in vertically spaced relation across said housing between said headers, one end of each of said tubes welded to said first header and the other end of each of said tubes welded to said second header, the tubes of each of said banks being spaced horizontally from each other, a gas inlet to said housing on one side of said arcuate banks of tubes and a gas outlet from said housing on the other side of said arcuate banks of tubes.

8. A heat exchanger which comprises a housing, a first header mounted adjacent one side wall of said housing, a second header mounted adjacent the opposite side wall of said housing, a plurality of thin-walled metal tubes hanging in the form of a catenary curve across the interior of said housing and communicating with said first and second headers, said tubes being essentially flexible but sufficiently rigid to maintain said catenary configuration, one end of each of said tubes being connected to the wall of said first header and the other end of each of said tubes being connected to the wall of said second header, substantially the entire surface area of said tubes being disposed within said housing and available as heat transfer surface, a gas inlet to said housing positioned above said tubes, and a gas outlet from said housing positioned below said tubes.

9. A heat exchanger which comprises a housing, a first header mounted adjacent one side wall of said housing, a second header mounted adjacent the opposite side wall of said housing, a plurality of thin-walled essentially flexible metal tubes hanging in the form of a catenary curve across the interior of said housing and communicating with said first and second headers, said tubes forming arcuate banks of tubes across said housing between said headers, one end of each of said tubes being connected to the wall of said first header and the other end of each of said tubes being connected to the wall of said second header, substantially the entire surface area of said tubes being disposed within said housing and available as heat transfer surface, a gas inlet to said housing above said arcuate banks of tubes, and a gas outlet from said housing below said arcuate banks of tubes.

10. A heat exchanger which comprises a housing, a first header mounted adjacent one side wall of said housing, a second header mounted adjacent the opposite side wall of said housing, a plurality of thin-walled metal tubes hanging in the form of a catenary curve across the interior of said housing and communicating with said first and second headers, said tubes being essentially flexible but sufficiently rigid to maintain said catenary configuration, said tubes forming arcuate, substantially horizontally positioned banks of tubes across said housing between said headers, one end of each of said tubes being welded to the wall of said first header and the other end of each of said tubes being welded to the wall of said second header, substantially the entire surface area of said tubes being disposed within said housing and available as heat transfer surface, a gas inlet to said housing above said arcuate banks of tubes, and a gas outlet from said housing below said arcuate banks of tubes.

11. A heat exchanger which comprises a housing, a first header mounted adjacent one side wall of said housing, a second header mounted adjacent the opposite side wall of said housing, a plurality of thin-walled essentially flexible metal tubes hanging in the form of a catenary curve across the interior of said housing, and communicating with said first and second headers, said tubes forming a plurality of arcuate, vertically spaced banks of tubes across said housing between said headers, one end of each of said tubes being connected to the wall of said first

header and the other end of each of said tubes being connected to the wall of said second header, the tubes of each said bank being spaced horizontally from each other, substantially the entire surface area of said tubes being disposed within said housing and available as heat transfer surface, a gas inlet to said housing above said arcuate banks of tubes, and a gas outlet from said housing below said arcuate banks of tubes.

12. A heat exchanger as defined in claim 11, the ends of said tubes being welded to the walls of said headers.

13. A heat exchanger as defined in claim 11, the ends of said tubes being connected to said headers by flaring

and rolling the end portions of said tubes against the walls of said headers.

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