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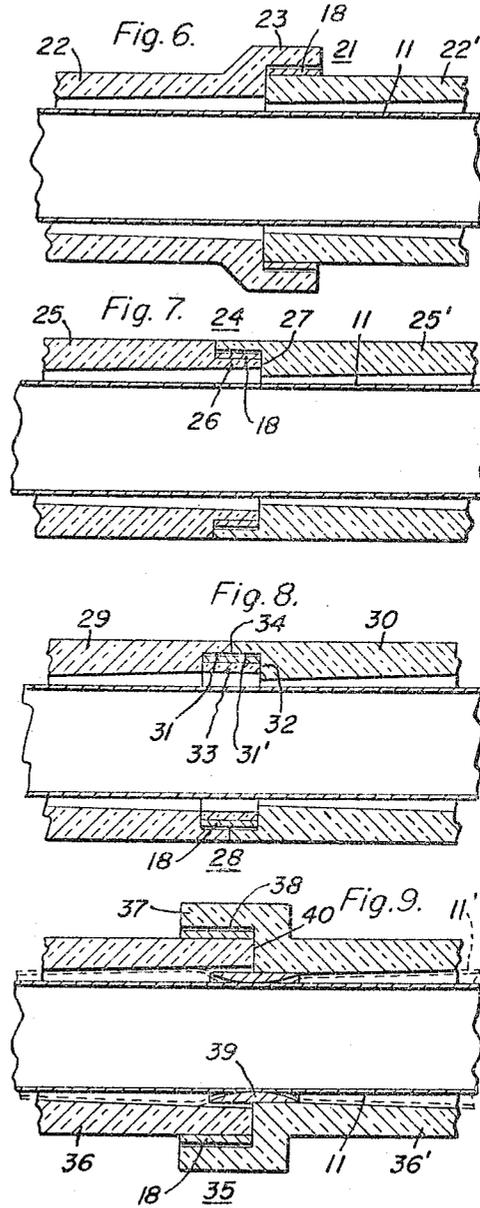
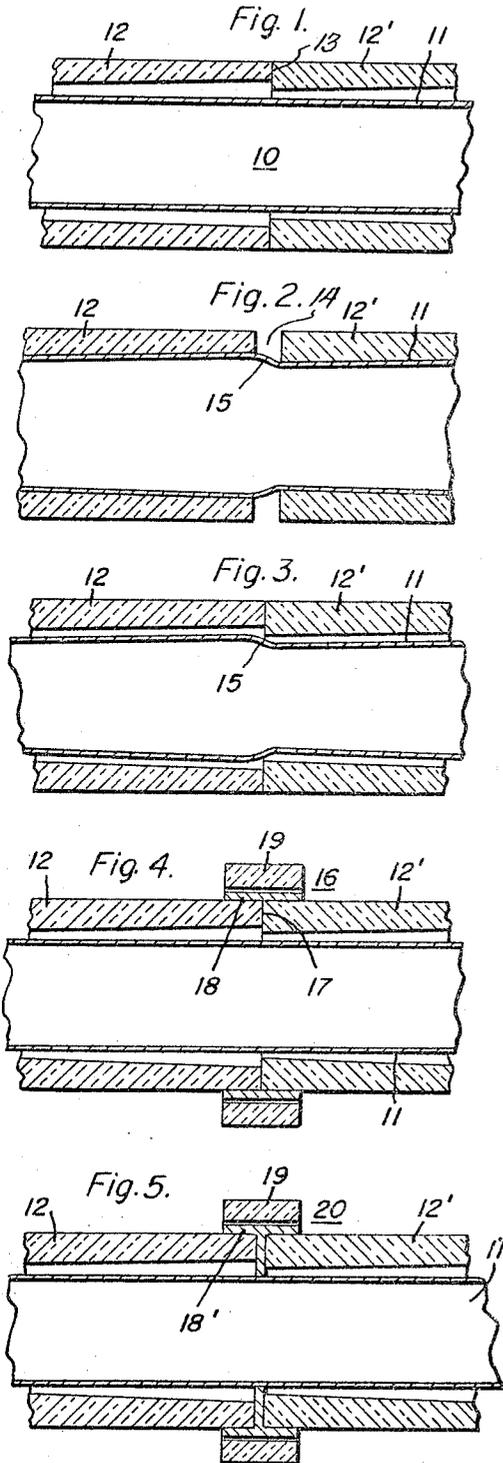
P. H. KYDD ETAL

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COMPOSITE HEAT EXCHANGER TUBE STRUCTURE

Filed April 26, 1963

2 Sheets-Sheet 1



Inventors:
Paul H. Kydd;
George J. Mullaney,
by James J. Lichiello
His Attorney.

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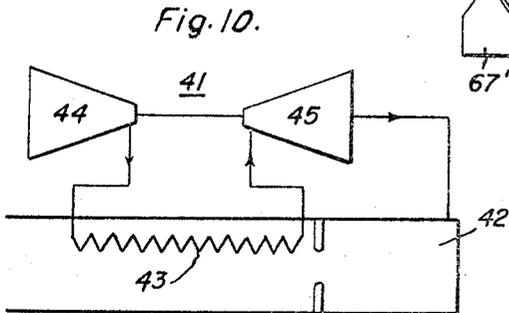
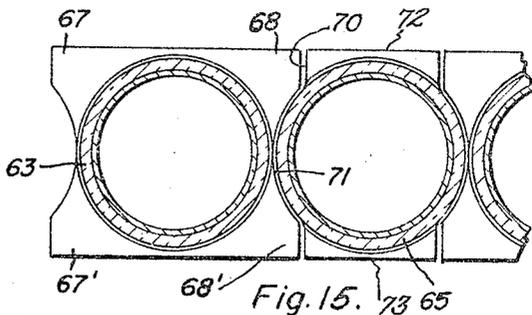
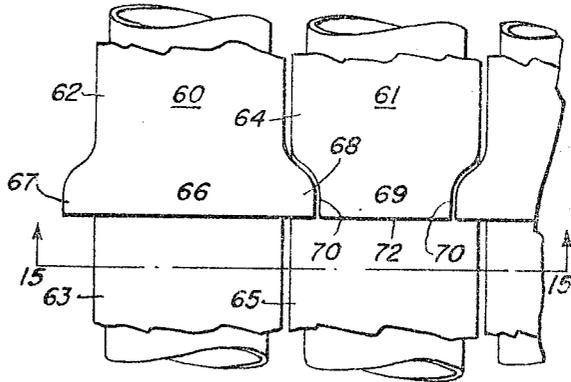
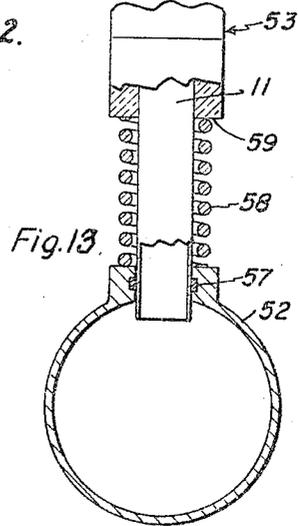
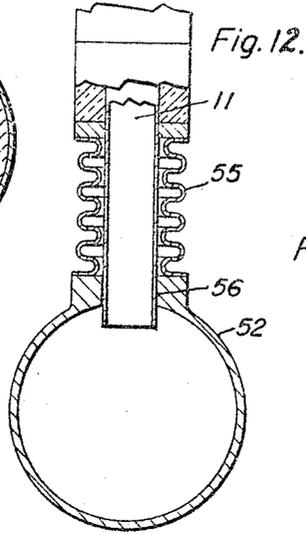
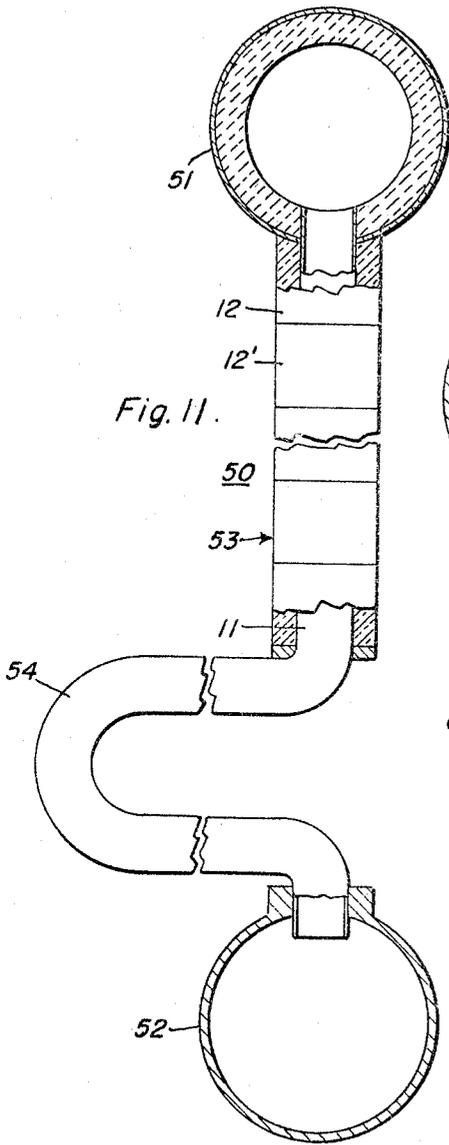
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COMPOSITE HEAT EXCHANGER TUBE STRUCTURE

Filed April 26, 1963

2 Sheets-Sheet 2



Inventors:
 Paul H. Kydd;
 George J. Mullaney,
 by James J. Lichiello
 His Attorney.

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3,270,780
**COMPOSITE HEAT EXCHANGER TUBE
 STRUCTURE**

Paul H. Kydd, Scotia, N.Y., and George J. Mullaney,
 Seattle, Wash., assignors to General Electric Company,
 a corporation of New York
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 10 Claims. (Cl. 138-148)

This invention relates to heat exchanger structure, and more particularly to a composite heat exchanger tube structure comprising an inner metal tube provided with an outer wall spaced therefrom in the unheated condition in the form of a ceramic casing.

The general requirements of heat exchangers have been increasing towards those heat exchangers operable at higher temperatures and pressures. This increase is in keeping with the trend of utilizing higher temperatures in various thermal power apparatus where higher thermal efficiencies are desired. However, such practices require certain heat exchanger parts, for example the channels, tubes, or flow passages therein, to be exposed to high temperatures greater than that which ordinary heat exchanger metals may satisfactorily withstand. In many instances, high temperatures are combined with deteriorating atmospheres with respect to the metals which result in substantially reduced life.

Accordingly, it is an object of this invention to provide an improved heat exchanger channel structure.

It is another object of this invention to provide an improved heat exchanger tube structure incorporating supporting and shielding means surrounding an inner tube.

It is another object of this invention to provide an improved heat exchanger structure comprising an inner tube having a supporting and shielding means thereabout which is operable as a high temperature creep resistant structure.

It is another object of this invention to provide an improved heat exchanger tube structure having a central metal tube and a surrounding refractory casing section or tube, of a material such as silicon carbide. The casing is spaced from the metal tube at room temperature, and tightly grips the metal tube at operating temperatures.

Another object of this invention is to provide an improved joint structure between adjacent short lengths of ceramic casing sections.

It is yet another object of this invention to provide improved joint structures, for adjacent lengths of silicon carbide casing sections, which employ sacrificial metal structures in the exposed portions of the joint.

It is a further object of this invention to provide a ceramic casing joint structure which supports the ceramic casings while at the same time permitting expansion and contraction of the casings.

Briefly described, this invention comprises, in one form, a heat exchanger tube structure which includes an inner metal tube and an outer ceramic casing. The outer ceramic casing is positioned in concentric relationship with the inner metal tube and spaced therefrom circumferentially, so that, during exposure to high temperature gases, the metal tube expands to tightly fit inside the silicon carbide casing tube which then acts as supporting and shielding means for the inner tube. The outer ceramic section is exposed to hot gases to transfer heat to a gas such as air flowing through the inner metal tube.

This invention will be better understood when taken in connection with the following description and drawings in which:

FIG. 1 is a cross sectional view of one preferred em-

bodiment of this invention illustrating an inner metal heated tube and outer butt joined ceramic casing sections upon initial assembly;

FIG. 2 is an exaggerated illustration of the assembly of FIG. 1 under operating high temperature conditions;

FIG. 3 is an exaggerated illustration of the FIG. 2 assembly under cold conditions;

FIG. 4 is a cross sectional view of another preferred joint structure to be employed for the casing sections of FIG. 1;

FIG. 5 is a cross sectional view of still another preferred joint structure;

FIG. 6 is an illustration of a bell type joint modification of FIG. 4;

FIG. 7 is an illustration of a lap joint structure for the casing sections of FIG. 4;

FIG. 8 is an illustration of a modification of the joint structure of FIG. 5;

FIG. 9 is a cross sectional illustration of a split ring type of joint structure;

FIG. 10 is one exemplary gas turbine cycle wherein this invention is specifically applicable;

FIG. 11 is an illustration of the composite tube of this invention in a vertical position and utilizing a biasing support means;

FIG. 12 is a modification of the invention of FIG. 11 illustrating a bellows support as the biasing means;

FIG. 13 is a modification of the tube assembly of FIG. 12 utilizing a spring support as the biasing means;

FIG. 14 is an illustration of bracing or interlock means employed between adjoining tubes; and

FIG. 15 is a vertical cross sectional view of the interlock means of FIG. 14.

One example of an application for this invention is the combination of a gas turbine with a waste heat steam turbine in a combined power plant. The gas turbine with its high inlet temperature of about 1600° F. efficiently utilizes high temperature enthalpy produced by combustion and rejects the enthalpy not converted into work, at sufficiently high temperatures to be used for steam generation. Such a gas turbine is an especially desirable topping device because it is a proven machine with considerable technical background. One obstacle to the successful utilization of a gas turbine in the described manner is the problem of firing it with coal or residual fuel oil, which are fuels sufficiently economical for large scale steam power generation. In coal firing, the particular problem is avoiding damage to the turbine wheel and related parts by erosion or deposition thereon of molten ash containing alkali sulfates and some vanadium oxide. In oil firing, complex vanadium containing residues cause severe corrosion at high temperature. One solution to this problem is to utilize a heat exchanger of the radiant type to transfer heat from the atmospheric pressure flame of combustion of coal or oil, to high pressure air which is utilized in the gas turbine. The heat exchanger can serve as a primary source of cycle heat and also as a regenerator to recover waste heat in the exhaust. The use of a heat exchanger also permits the construction of closed cycle gas turbines which have additional advantages in many applications.

In such a heat exchanger, the output temperature is required to be on the order of about 1600° F. to match the currently available turbines, and should be potentially as high or higher than 1800° F. Conventional stainless steel exchangers are generally limited to temperatures about 1200° F. Only the super alloys which contain large additions of critical materials such as cobalt and columbium resist creep at such extreme temperatures, and these materials are not economical for general heat exchanger application. Since the size of the heat exchanger must be minimized to keep costs low, the tem-

perature difference between the tube wall and the air to be heated must be large. Thus, tube temperatures of 2000° F. to 2200° F. are desired. In order to withstand these extreme temperatures, the only reasonably economical materials which do not creep, and are resistant to oxidation and attack by the products of combustion of coal, are super refractories such as alumina, magnesia, mullite and silicon carbide which, however, are porous and very difficult to fabricate into practical and efficient heat exchanger structures by presently known means.

These and other problems are overcome by the practice of this invention as shown in FIG. 1. Referring now to FIG. 1, a heat exchanger tube structure 10 is illustrated which will withstand the extreme conditions as above described. Apparatus 10 includes a metal tube 11 which is of a high strength, oxidation resistant material such as stainless steel or Inconel alloy. Concentrically positioned about tube 11 are one or more casing sections or tubes 12, 12', etc., usually of a ceramic material, for example the various forms of silicon carbide, such as clay bonded, nitride bonded, or self-bonded silicon carbide.

The ceramic casing 12 provides strength at high temperatures to prevent the inner tube 11 from bursting under internal pressure due to creep rupture. The inner tube 11, which contains and transports the working fluid to be heated, serves as a leak proof liner which is easily joined to conventional manifolds. The defined structure combines the complementary properties of metals and ceramics in that, (1) metals are easily fabricated and welded into leak tight structure but are relatively weak at higher temperatures, and (2) ceramics are difficult to fabricate and join in leak tight structures but have high strength at high temperatures. Another advantage of using the combination of an inner metal tube and an outer ceramic casing is that it provides for the utilization of various metals for heat exchanger tube purposes under conditions such that without support they would suffer creep rupture. The combination described serves this purpose by utilizing the ceramic casing 12 to effectively support metal tube 11 against internal pressure and protect it from corrosion and erosion by the products of combustion. Additionally, casing 12, by supporting the metal liner tube 11, lessens the required wall thickness of metal tube 11 below the thickness that would be required therefor, if used without a casing because the metal liner need only serve to isolate the working fluid from the hot combustion gases.

One preferred composite tube of this invention includes Inconel metal alloy for tube 11 and silicon carbide for casing 12. Inconel metal is an alloy of the composition 77% nickel, 15% chromium, 7% iron, and minor amounts of copper, tin, manganese, and carbon. Inconel metal has a short time tensile strength of about 11,000 p.s.i. and an elongation of about 67% at 2000° F. This metal can be used in nonsulfidizing atmospheres at temperatures from 2000° F. to 2200° F. Other suitable alloys are Nichrome alloy, 80% nickel and 20% chromium, 310 stainless steel, 25% nickel, 20% chromium and 55% iron, and 446 stainless steel, 27% chrome, and 63% iron. The wall thickness of the exemplary Inconel alloy tube 11 was about $\frac{1}{16}$ inch. Casing 12 may be of the various forms of silicon carbide for example clay bonded, self-bonded, and nitride bonded. In this one preferred composite tube casing 12 was clay bonded silicon carbide of about $\frac{1}{2}$ inch wall thickness.

In order to provide an operative combination of a metal tube 11 and a ceramic casing 12, a working relationship between the temperature expansion characteristics of the two materials must also be established. The coefficient of expansion of a ceramic such as silicon carbide is 2.6×10^{-6} per ° F. and for a metal such as Inconel alloy is 8.4×10^{-6} per ° F. Therefore, a predetermined radial cold gap setting is necessary between the metal tube 11 and the silicon carbide casing 12. This gap setting must be based on the mentioned differences

in expansion characteristics so that the metal tube 11, when expanding on heating, will not burst casing 12 but will only creep under pressure to fill the ceramic casing rather tightly excluding the air gap and providing improved heat transfer. Accordingly, casing 12 supports tube 11 at operating temperature and when cool, tube 11 contracts from casing 12 without stress on either part. At a peak operating temperature of the metal and carbide composite tube, of about 2000° F., the radial expansion of the metal tube relative to the ceramic casing is 1.2% of the radius of the metal tube. This should be the minimum radial clearance provided between the metal tube 11 and casing 12 and the maximum radial clearance should be about 2.4 percent of the radius of the metal tube.

Whether the construction be such that the inner component be metal and the outer component be ceramic or vice versa, the important relationship that must be established is that the inner component must have a coefficient of expansion greater than the outer component in order that by the time the two-component construction will have reached the operating temperature the initial clearance between components will have vanished and the outer surface of the inner component will be in tight physical contact with the inner surface of the outer component. The components so unified by expansion at the operating temperatures thereby combine their complementary properties so that one component contributes the attribute of leak-tightness to the composite and the other component contributes the attribute of high strength thereto. Although in the application described in detail herein resistance to internal pressure is encountered, applications do arise in which the greater fluid pressure applied is external to the composite tube. In such an instance the arrangement of components would be the reverse of the exemplary construction. An example of such composite tube construction would be that in which the inner component is the ceramic, magnesite (coefficient of expansion 7.2×10^{-6} from 70 to 1800° F.), and the outer component is a ferritic stainless steel, the type 446 stainless steel (coefficient of expansion 6.6×10^{-6} from 70 to 1200° F.).

Casing pieces 12 are mold produced with a necessary internal axial taper so that the mold core may be easily withdrawn. As one example, this taper is about $\frac{1}{16}$ inch in bore diameter in about 30 inches axial length. Therefore, maximum clearance at the large end of the taper should not exceed about 2.5% to avoid excessive stretching of the metal. This provides a minimum clearance of 0.30 inch and, for example, a taper of 0.30 inch per foot for $2\frac{1}{2}$ inch bore casing pieces 12 inches long.

In considering the high operating temperatures involved, in combination with the fact that silicon carbide tubes are limited in length, a suitable joint must be provided between adjacent pieces of casing which will protect tube 11 under adverse high temperature conditions and also provide for relative axial expansion of the tube and of casing 12. At the same time, a joint arrangement is preferred which will prevent undue scuffing of the metal tube longitudinally in the ceramic tube.

In FIG. 1, a common and well known type of butt joint 13 is illustrated which comprises merely the use of several short sections of casing 12, 12', etc. which are butted together at joint 13. In the assembly of the composite tube 10 the casing sections 12, 12', etc. are placed in contiguous relationship as illustrated. Thereafter, under high temperature operating conditions, tube 11 axially expands much more than the casing sections, and an axial gap between casing sections occurs. It is preferred that this axial gap be maintained as small as possible so that the thin walled metal tube 11, under moderate pressures, is able to bridge the gap. In general it has been found that the axial gap which occurs with casing sections 12, 12', etc. of 1-foot length is about 0.15 inch. Thin walled tubes as described satisfactorily bridge this gap with up to about 100 p.s.i. internal pressure.

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The use of a large number of ceramic tubes 12, 12', etc. eliminates the need of complicated joints and reduces axial scuffing as described. However, casing sections 12, 12', etc. must be prevented from sliding along tube 11 so that the described axial gaps remain generally equivalent for each joint. Irregular gap openings may lead to some joints having gaps too wide for successful bridging by tube 11. In one practice of this invention equivalent gap clearances are obtained by taking advantage of the internal taper of the casing sections 12, 12', etc. in combination with the metal tube 11. This practice, as well as a working description of the FIG. 1 apparatus, is described in connection with FIGS. 1-3 as follows. In the assembly of apparatus 10 of FIG. 1, joint 13 is defined by a smaller end of one section 12 and the larger end of an adjacent section 12'. During operation under high temperature conditions, the FIG. 1 assembly changes to that of FIG. 2 illustrating an axial gap 14 between adjacent casing members. Metal tube 11 has also expanded radially to tightly fit in casing sections 12, 12', etc. and to bridge the gap 14. It can be seen that the wall of metal tube 11 adapts itself to a taper corresponding with the taper of the bore of casing sections 12, 12', etc. with a curved section 15 bridging the gap 14. After cooling, the FIG. 2 assembly changes to that of FIG. 3. In FIG. 3 the creep deformation resulting from high temperature operation provides a permanent taper in the metal tube 11 in individual casing sections 12. This taper prevents casing sections 12, 12', etc. from moving axially along tube 11. Various other types of joints may also be employed in the practice of this invention. Representative examples of these joints in initial cold assembly are illustrated in FIGS. 4-10.

Referring now to FIG. 4, there is disclosed a joint structure 16 between a pair of adjacent casing members 12 and 12'. Joint structure 16 is referred to as a sleeve butt joint. Surrounding the joint 17 between casing members 12 and 12' is a thin metal cylinder 18 which may be of the same metal as tube 11 or of a different metal. Metal cylinder 18 is utilized as a sacrificial element which is initially exposed to the hot products of combustion attempting to enter joint 17. Metal cylinder 18 not only prevents the products of combustion from reaching tube 11 and causing corrosion and erosion of tube 11 but also neutralizes the corrosive elements in these gases. However, the use of a sacrificial element is optional depending on environmental conditions. A further cylinder 19, usually of the same material as sections 12, surrounds metal cylinder 18, in concentric relationship, and with proper radial clearance. Ceramic cylinder 19 is employed to limit dissipation of sacrificial cylinder 18.

Where the axial gap between adjacent ceramic sections may be large, or where the portion of the metal tube 11 bridging the gap needs additional support, the joint structure 20 of FIG. 5 may be employed. In FIG. 5, the sacrificial metal element 18' is formed with a T cross section so that the tang of the T peripherally engages tube 11. This configuration essentially divides a larger gap to two smaller gaps, and provides additional support for tube 11 across the gap.

The ceramic sleeve 19 may also be an integral portion of one of the sections 12. For example, in the joint structure 21 of FIG. 6, one casing member 22 is provided with an enlarged projecting lip portion 23. Lip 23 then overlaps the end of an adjacent casing member 22' or receives the end of casing member 22' in a sleeve-like arrangement. A suitable clearance is provided between the outside diameter of the end of casing 22' and the inside diameter of lip 23 to position sacrificial metal cylinder 18 therein.

In FIG. 7, there is illustrated a joint 24 which is a modification of the well known form of a lap joint. In FIG. 7, one casing member 25 includes a smaller outside diameter projecting lip portion 26. Correspondingly, casing member 25' includes a counterbore type portion

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27 which is adapted to axially receive projecting lip portion 26 of casing member 25. If desirable, a radial gap is provided between projecting lip 26 and counterbore portion 27 so that a thin cylinder 18 of a sacrificial metal may be employed in the defined gap for the same purpose as cylinder 18 of FIG. 4.

In FIG. 8, there is illustrated a joint 28 between two casing members 29 and 30. Each of the casing members 29 and 30 contains an end portion having a larger diameter or counterbore opening, 31 and 31' respectively. Thus when two such members are positioned, as illustrated in FIG. 8, a generally cylindrical chamber 32 is defined. Chamber 32 includes a first ceramic cylinder 33 which is coaxially positioned therein to surround tube 11. Thereafter a sacrificial metal cylinder 18 is positioned concentrically about cylinder 33 and bridges the hot gap appearing at joint line 34 between adjacent ceramic tube members 29 and 30. The purpose of the composite washer (33 and 18) is to grip the metal tube 11 at the joint 34 and divide the span of the gap into two smaller gaps which the tube wall can bridge more readily.

An alternative way of strengthening the tube wall at the gap is illustrated in FIG. 9 where there is disclosed a joint 35 between two casing members 36 and 36'. Casing member 36' includes a diametrically enlarged projecting lip portion 37 which projects over one end of casing 36 in sliding relationship. This assembly also provides, if desirable, a radial clearance 38 in which there is positioned a sacrificial cylinder 18 as described with respect to FIG. 4. A suitable short metal or ceramic cylinder 39 is concentrically positioned between tube 11 and casing 36 to bridge the joint line 40. The inside of surface of short cylinder 39 is a smooth arcuate or curving surface. In the operation of this invention with joint 35, inner tube 11 creeps from its cold dimension as illustrated by numeral 11' to the hot expansion state, indicated by numeral 11', which is adjacent casing sections 36 and 36'. Alternatively, a depression in tube 11 may be formed by spinning or swaging. Then, support ring 39 made in two halves as a split ring, is clamped over the depression in the tube wall and held in place by the casing sections 36 and 36' which are slid over it. The purpose of the support ring 39 is to bridge the hot gap between adjacent casing sections and provide support for tube 11 across the whole span of the gap by effectively thickening the tube wall at that point. This construction can be used with longer casing sections giving larger gaps or at higher pressures than the joints illustrated in FIGS. 1-6. The principle of all joints as described in FIGS. 4-9 is to provide a tortuous path, between the corrosive atmosphere and the metal tube 11 in which there may also be a sacrificial metal ring to intercept corrosive agents.

As mentioned, one particular application of this invention is as a heat exchanger in a coal fired gas turbine power plant. An exemplary arrangement as described is illustrated in FIG. 10 as gas turbine cycle 41. Cycle 41 represents a coal fired plant wherein coal is burned in a combustor 42 as in an ordinary steam power plant furnace, and the products of combustion then pass through a heat exchanger 43, incorporating the principles and practices of this invention, and from there to a waste heat boiler or to other apparatus. Air or other fluid is passed through a compressor 44 and into the heat exchanger 43 of this invention where the temperature thereof is greatly increased. From heat exchanger 43 the air or other fluid passes through a turbine 45 for useful work output. The exhaust from turbine 45 then passes to combustor 42. In such an exemplary power plant as described, one preferred method of utilizing the composite tubes of this invention is in the form of straight metal tubes 11 up to about 40 feet length, placed side by side to form a wall with casing sections 12, 12', etc. of about 1 or 2 ft. in length. It has been found advantageous to utilize a large number of casing sections in order to better provide for the axial mismatch of thermal expansion and permit the use of single butt joints as

illustrated in FIG. 1. Casing members of 3-5 feet in length may be employed, if joints as described in FIGS. 5, 8, and 9 are used to support metal tube 11 at the gaps between sections.

The composite tubes may be installed horizontally, with support means being provided every 3-5 feet to prevent sagging or vertically as in a conventional boiler. The vertical arrangement should be employed in conjunction with a counterbalancing arrangement to support most of the weight of the casing members, and to prevent stretching or compressing of the metal tube at the hot end. One such arrangement is shown in FIG. 11. Referring to FIG. 11, there is disclosed an assembly 50 comprising a hot manifold 51 and a cold manifold 52 and an interconnecting composite tube assembly 53 which is exposed to the heat of combustion in a furnace and thus heats air passing from the cold manifold through composite tube 53 to hot manifold 51. Tube assembly 53 is that as shown in FIG. 1, and includes a metal tube 11 and a plurality of surrounding casing sections 12, 12' etc. Tube assembly 53 also includes a curved portion or loop 54 which is similar to the well known expansion loop found in various piping installations exposed to wide temperature variations. Loop 54, however, serves additional purposes in the present invention, such as providing for expansion of tube assembly 53 and for supporting the weight of tube assembly 53. Loop 54 may also be utilized to heat air as a pre-heater arrangement whereby cooler furnace exhaust gases are directed by the loop to preheat air therein. If the weight of the tube assembly (about 5 lbs. per ft.) is supported in tension from the top manifold 51 when cold, and the spring rate of the loop 54 is such that it is all supported in compression from below when hot, stress on the hot end of the tube will be small under operative conditions and no stretching should take place.

Other expansion and supporting means may be employed in lieu of loop 54. For example, in FIG. 12 a bellows assembly 55 is illustrated in combination with a slip joint 56. Because of the use of slip joint 56, the pressure in bellows 55 is the same as in manifold 52 and to prevent leakage, bellows 55 is joined to manifold 52 and to tube 11 thus permitting tube 11 to expand in slip joint 56. The connection of bellows 55 to tube 11 is facilitated by the use of a metal collar abutting the last casing section, which collar is affixed to tube 11 at its inner periphery and affixed to bellows 55 at its outer periphery. Operation of the bellows is the same as that of loop 54.

An alternate method of providing the described result is shown in FIG. 13. In FIG. 13, the tube 11 of assembly 53 passes through a sliding seal joint, equipped with a suitable packing member 57, into cold manifold 52. A suitable calibrated spring 58 is provided between the joint 57 and the casing end 59 so that the entire weight of the assembly is supported by spring 58.

The composite tubes of FIGS. 12 and 13, in their longer lengths, may require some form of bracing between tubes to prevent bending. Various mechanical braces, wedges, inserts, etc., may be employed for this purpose. One exemplary method may be incorporated in the casing structure as illustrated in FIG. 14. Referring to FIG. 14, there is shown a pair of the composite tubes of this invention 60 and 61. The individual ceramic casings 62 and 63 and 64 and 65 respectively are joined by bell or sleeve type joints similar to the joint of FIG. 6. In order to prevent bending or buckling of long parallel tubes, an interlocking lug arrangement incorporated in the joint structure is employed. For example, the bell housing or sleeve 66 of casing 62 is provided with laterally extending lug portions 67 and 68 which define a concave section to receive the adjacent casing 64. Accordingly, the sleeve part 69 of casing 64 is cut back at 70 to receive lug 68. This interlocking arrangement is better shown in FIG. 15 in cross section. In FIG. 15, the lugs 68 and 68' define the concave section 71 which fits about adjacent casing 64. Sleeve 69 of casing 64 is cut

back or is much narrower laterally to include a pair of opposed projections or lugs 72 and 73. As illustrated, lugs 72 and 73 are oppositely positioned along an axis which is 45° removed from the direction in which lugs 67, 67', 68, and 68' are positioned. When a plurality of tubes are assembled with alternate types of lugs for alternate tubes, a structure is defined which prevents buckling and twisting of individual tubes.

The composite tube of this invention has been utilized in various forms and under different conditions. For example, 2 to 4 ft. lengths of composite tubing with joint structures as described have been subjected to high temperatures, in an electrical furnace, while under internal pressure. These composite tubes included Inconel metal tubes of 1½ to 2½ inches diameter encased by clay bonded silicon carbide casing sections of ½ inch wall thickness. Internal pressures ranged from 45 p.s.i.g. for the larger tubes to 75 p.s.i.g. for the smaller tubes. These tubes were tested up to 1500 hours and at temperatures up to about 2000° F. In additional tests the exemplary composite tubes of this invention were placed in a coal fired furnace, pressurized at 100 p.s.i.g. and heated for long periods with temperature cycling of several hundred degrees C. No serious corrosive attack was found.

In another series of tests, a composite tube consisting of an inner Inconel liner tube with a silicon carbide jacket as before described was heated to 2100° F. externally, while air at atmospheric pressure and 80° F. was blown through the liner at 65 feet per second. The temperature of the Inconel tube was 1900° F. and the exit air temperature was 280° F. for a temperature rise of 200° F. in a length of 3 feet. The test showed that the casing members would not crack with a radial temperature gradient caused by heat flow to the cold air.

All of the materials utilized in the practice of this invention for the tube materials, sacrificial metal, and refractory carbides for the casing material, were found to be chemically compatible below about 2000° F. No adverse chemical reaction was found between metal-ceramic combinations, for example Inconel and clay bonded silicon carbide. It appears that the ceramic jacket inhibits scaling of the metal tube by preventing the loose scale from falling off.

This invention is particularly adaptable for heating gases to temperatures and pressures higher than those achieved with conventional recuperators, although it can be used to heat liquids as well. The invention is intended to be more specifically applicable to a coal fired power plant where the exchanger is preferably receiving all heat by radiation from the flame, and thus there is no necessity for direct contact of the flame gases with the tubes. One important application for the composite structure of this invention relates to power plants utilizing a metal vapor as the working fluid, such as mercury, cesium, zinc, etc., where severe corrosion of heat exchanger tubes is a problem. Further applications of this invention include, (a) open and closed cycle gas turbines, and particularly open cycle gas turbines utilizing dirty fuels, (b) MHD power generators, (c) steam superheaters and reheaters for power plants, (d) heat exchangers for regeneratively raising the temperature of a flame in an industrial process which requires it, for example a blast furnace, open hearths, glass melting tanks, and chemical synthesis by partial combustion of natural gases, and (f) heating of chemicals and various processes for example oil and gas, or nitrogen and hydrogen in ammonia synthesis. A still further application for the composite tube of this invention is as a simple transfer conduit for very high temperature fluids.

In some of these applications, the inner tube may be made of other materials such as quartz and high silica glass, which, if supported and protected as set forth in this invention, permits higher operating temperatures to be reached than with metals. For use with reducing gases, such as hydrogen or hydrocarbons, it may be de-

sirable to have a double metal tube with the inner tube resistant to reducing atmospheres and the outer tube resistant to oxidizing atmospheres, both supported by a carbide jacket.

While a specific method and apparatus in accordance with this invention is described and shown, it is not intended that the invention be limited to the particular description nor to the particular configurations illustrated, and it is intended by the appended claims to cover all modifications within the spirit and scope of this invention.

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

1. In a composite tube type heat exchanger which is subjected to high temperatures to transfer heat to a fluid flowing therethrough, a composite tube comprising in combination:

- (a) an inner metal tube having a predetermined temperature coefficient of expansion,
- (b) a plurality of ceramic casing members peripherally enclosing said inner tube and arranged in endwise juxtaposition therealong,
- (c) said casing members having a predetermined temperature coefficient of expansion less than that of said inner tube,
- (d) said casing members being spaced from said inner tube in the unheated condition with a total cold clearance therebetween at least as large as and substantially equal to the differential expansion occurring between said inner tube and said casing members by being heated from the unheated condition to the operating temperatures,
- (e) said casing members having tapered bores therethrough which under high temperature conditions permanently deform the expanding inner tube in a tapering configuration so that sliding of said casing members along said inner tube is minimized, and
- (f) a joint structure between the ends of adjacent sections of said casing members to protect any gap remaining therebetween at operating temperatures.

2. In a tube type heat exchanger employing a plurality of composite tubes which are subjected to high temperatures in a corrosive environment to transfer heat to a fluid flowing through said composite tubes, each of said composite tubes comprising in combination:

- (a) an inner metal tube having a predetermined temperature coefficient of expansion,
- (b) a plurality of ceramic casing members peripherally enclosing said inner tube and arranged in endwise juxtaposition therealong,
- (c) said casing members having a predetermined temperature coefficient of expansion less than that of said inner tube,
- (d) said casing members being spaced from said inner tube in the unheated condition with a total cold clearance therebetween at least as large as and substantially equal to the differential expansion occurring between said inner tube and said casing members during heating from the unheated condition to the operating temperatures, whereby at operating temperatures the inner metal tube is tightly gripped and supported by said casing members,
- (e) a joint structure between the ends of adjacent sections of said casing members to protect any gap remaining therebetween at operating temperatures, and
- (f) lug means formed on said joint structure for interlocking with complementary lug means formed on the joint structure of an adjacent composite tube to brace said tubes against movement in a direction lateral to the central axes of said tubes.

3. A composite tube construction comprising:

- (a) longitudinally-extending impermeable metallic means for containing a fluid confined therein for transportation under pressure therethrough,

(1) said containing means being in the shape of a right circular cylinder and having sufficient wall thickness and strength to withstand the internal fluid pressure without additional external support at temperatures below and approaching the operating temperatures for said composite tube,

(b) ceramic means for simultaneously protecting said containing means and supporting the internal fluid pressure transmitted thereto by said containing means at operating temperatures after the expansion of the containing means thereagainst during temperature increase thereof to the operating temperatures,

(1) said protecting and supporting means having an opening therethrough of circular cross-section encircling said containing means,

(2) said containing means and said protecting and supporting means having a total cold radial clearance therebetween at least as great as and substantially equal to the differential radial expansion of said containing means and protecting and supporting means during heating thereof to the operating temperatures.

4. The composite tube construction substantially as recited in claim 3 wherein the total cold radial clearance is equal to about 1.2 to about 2.4 percent of the radius of the containing means.

5. The composite tube construction of claim 3 wherein the joint structure comprises in combination:

- (a) a first one of the casing members having an enlarged periphery portion on one end thereof to receive therein the end of an adjacent casing member,
- (b) said enlarged periphery portion and said end of an adjacent casing member defining a peripheral space therebetween, and
- (c) a short sacrificial metal cylinder disposed in said space and radially spaced from said enlarged peripheral member.

6. In a heat exchange device wherein a pressurized fluid receives heat by transfer thereto of the heat from hot gaseous products of combustion, the composite wall construction comprising in combination:

(a) longitudinally extending metallic means for isolating the pressurized fluid from the hot products of combustion,

(1) said isolating means receiving the pressurized fluid in contact with one surface thereof, and

(b) longitudinally extending ceramic means for simultaneously supporting and protecting said isolating means,

(1) said supporting and protecting means receiving the hot products of combustion in contact with one surface thereof and having the opposite surface thereof adjacent said isolating means,

(2) said isolating means and said supporting and protecting means each being of similar cylindrical configuration and each having a different coefficient of thermal expansion and said means being arranged with the cylinder having the greater coefficient of expansion located within the cylinder having the lesser coefficient of expansion,

(3) said cylinders having a pre-selected cold clearance between walls thereof such that at some pre-selected elevated operating temperature the inner cylinder will expand to contact the outer cylinder,

whereby a strong unified leak-proof composite tube is provided the wall area of which has a high rate of heat transfer.

7. Composite wall construction substantially as recited in claim 6 wherein the isolating means is the inner cylinder of the combination.

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8. Composite wall construction substantially as recited in claim 6 wherein the supporting and protecting means is made of silicon carbide, both the isolating means and the supporting and protecting means provide opposed surfaces of revolution and the pre-selected cold clearance between cylinders is equal to about 1.2 to 2.4 percent of the radius of said isolating means.

9. Composite wall construction substantially as recited in claim 6 wherein the isolating means is made of Inconel alloy and the supporting and protecting means is made of silicon carbide.

10. Composite wall construction substantially as recited in claim 6 wherein the supporting and protecting means comprises a plurality of cylindrical members, each member being shorter in length than the isolating means and arranged in endwise juxtaposition along said isolating means with a joint structure interconnecting the ends of each pair of adjacent members.

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LAVERNE D. GEIGER, *Primary Examiner.*

CHARLES SUKALO, *Examiner.*

V. M. PERUZZI, T. MOORHEAD, *Assistant Examiners.*