July 7, 1964 C. R. BINNER ETAL 3,139,927

HEAT EXCHANGER

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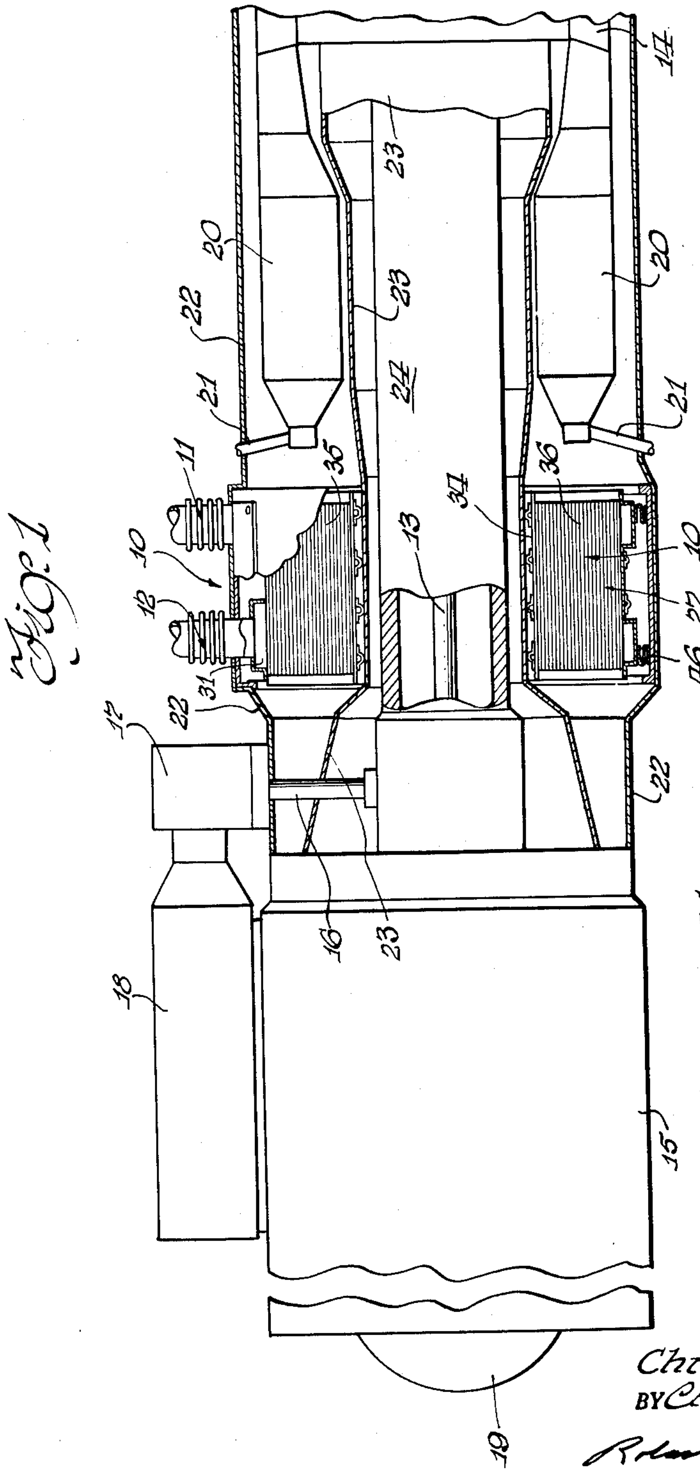

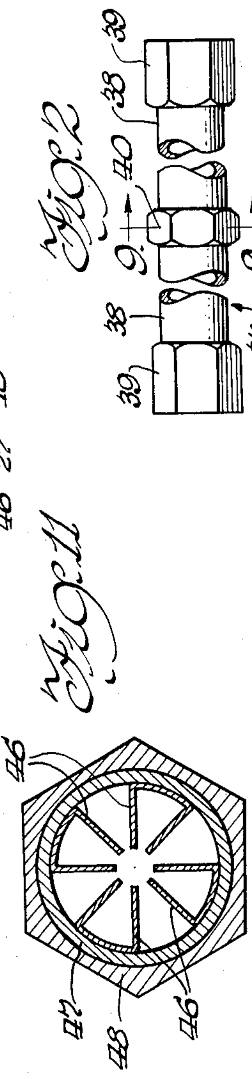

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HEAT EXCHANGER

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Fig. 3

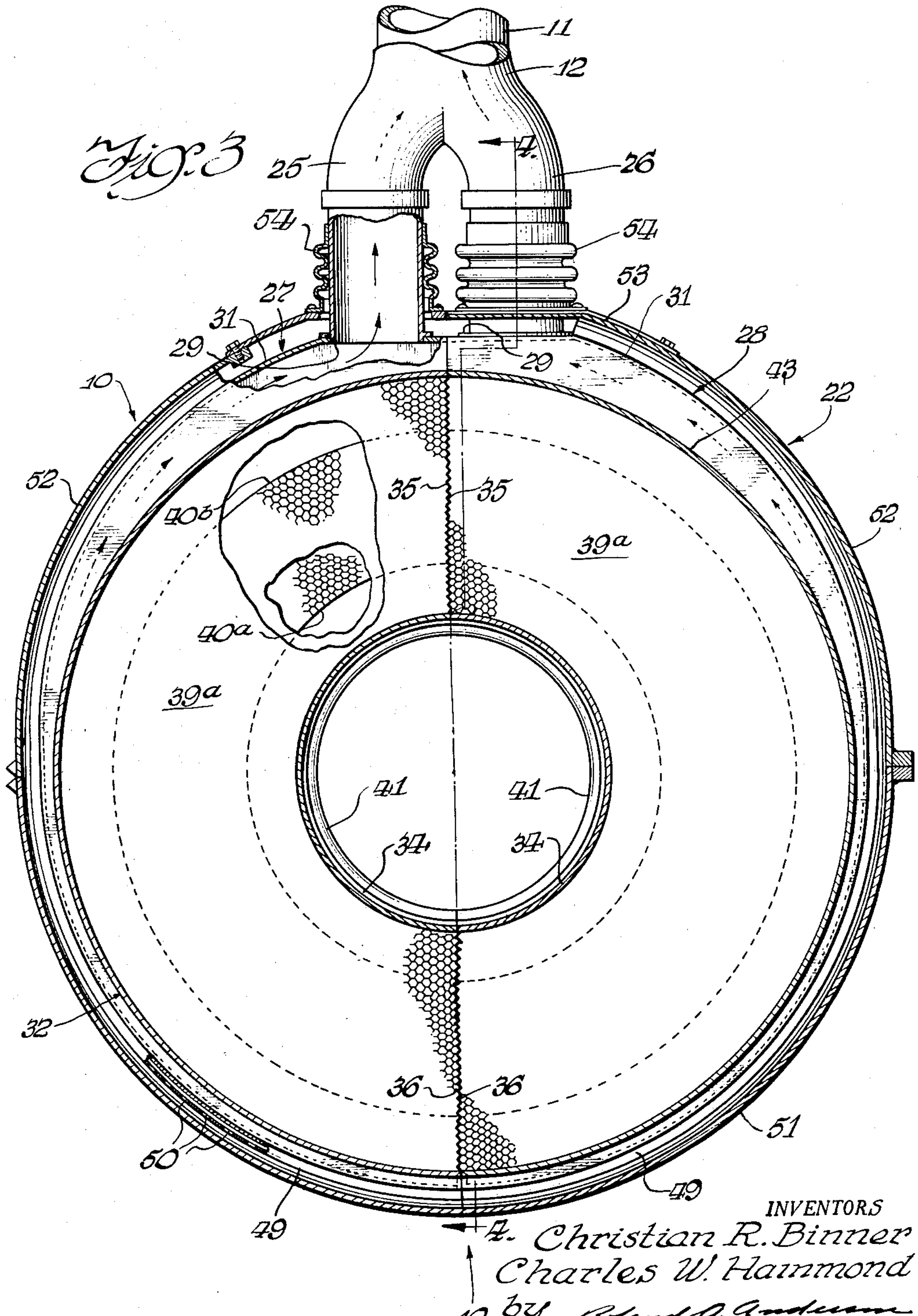

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Fig. 4

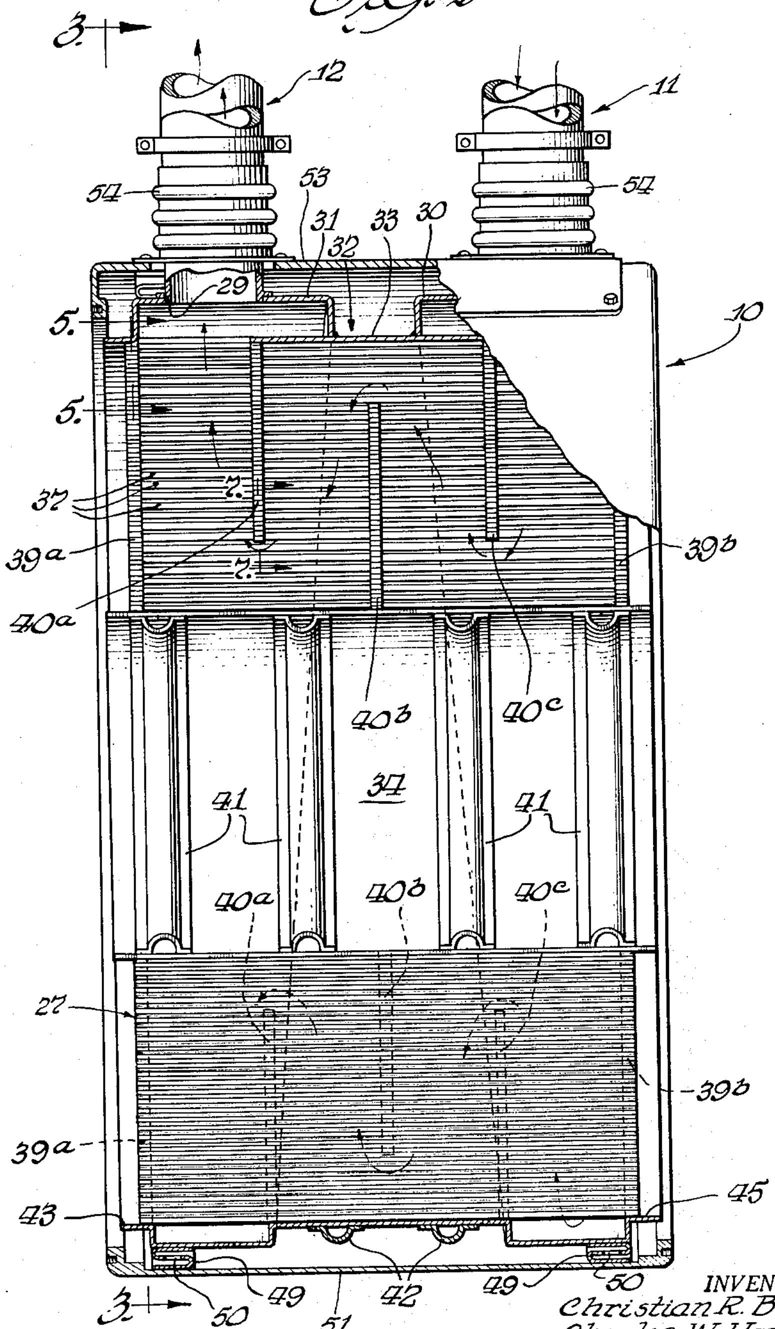

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Fig. 5

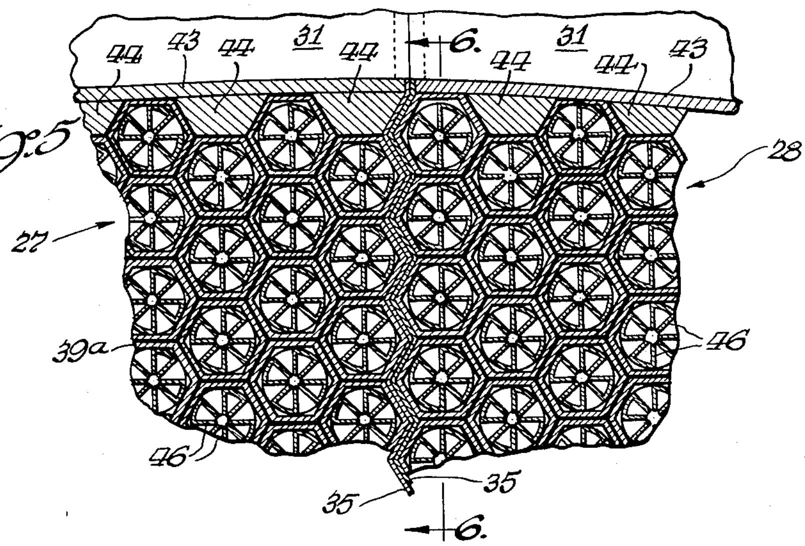

Fig. 6

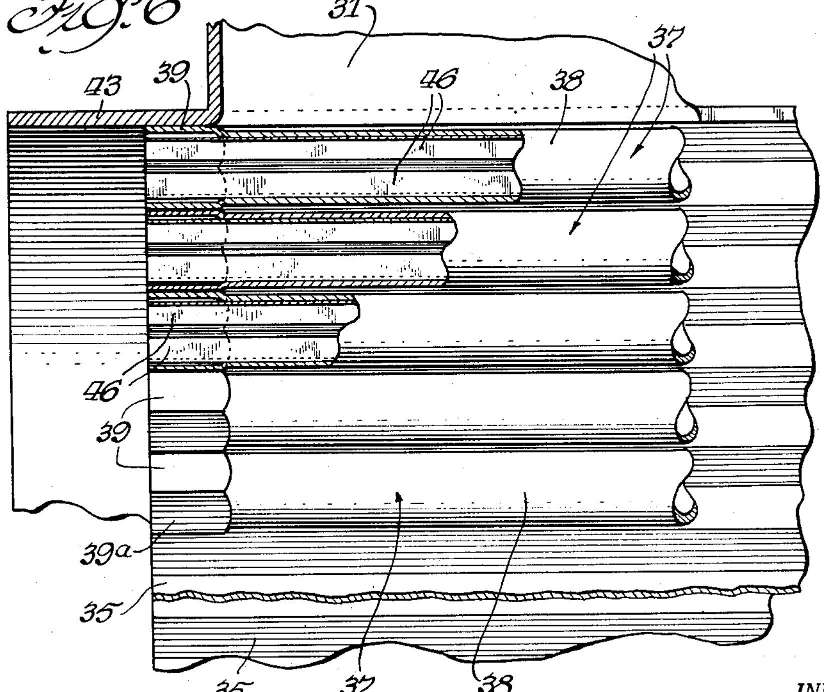

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Fig. 7

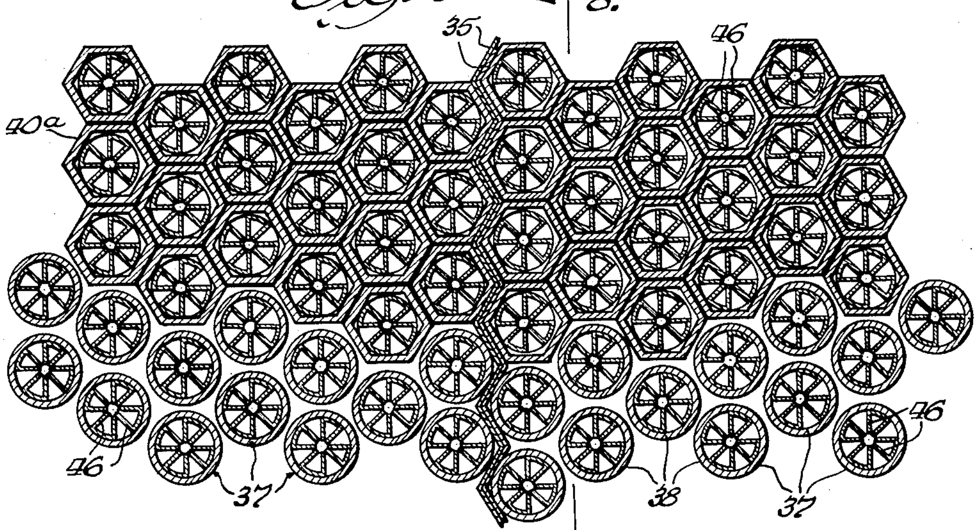


Fig. 8

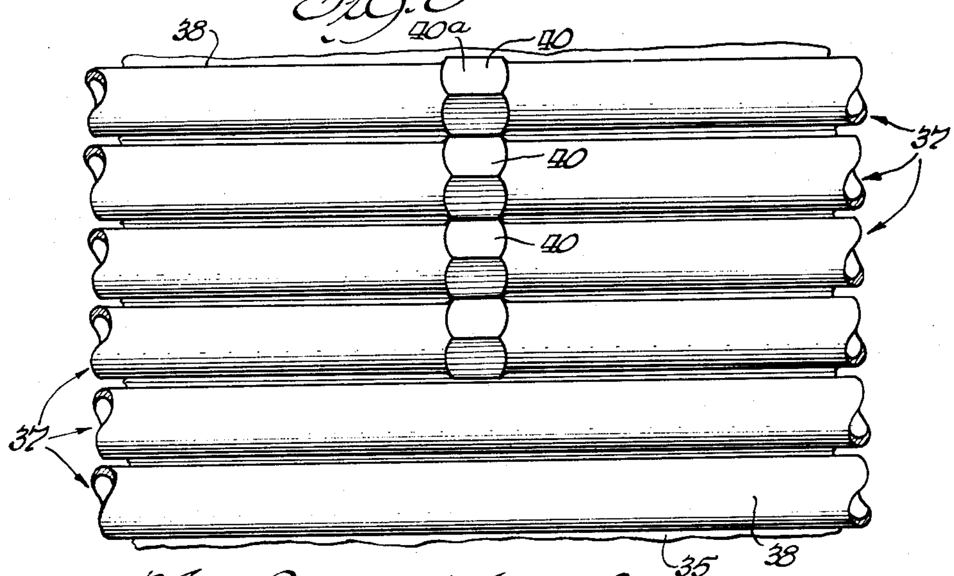


Fig. 9

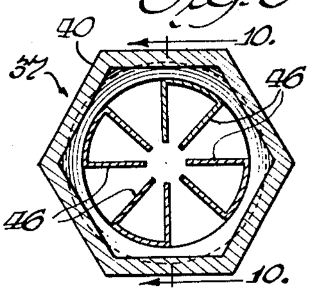
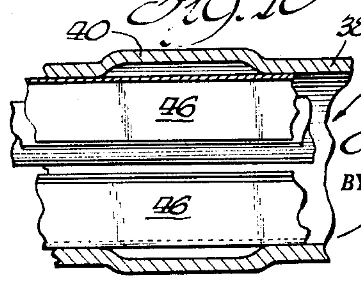


Fig. 10



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United States Patent Office

3,139,927
Patented July 7, 1964

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3,139,927
HEAT EXCHANGER

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Filed Nov. 10, 1954, Ser. No. 468,172
1 Claim. (Cl. 165—159)

This invention relates to the general field of heat exchange and more particularly to a new and improved heat exchange apparatus suitable for employment in power plant assemblies wherein the combined demands of a high rate of heat transference, a light weight of apparatus and ready removal and reassembly of the heat exchanger are present.

As an illustration of one embodiment of the invention, it is shown as employed in conjunction with the heating of air, serving to drive a jet engine and with the heat derived, for example, from a nuclear reactor or other suitable source. As the description proceeds, however, it will be apparent that the invention is in to way limited solely to this one arrangement, but on the contrary may be employed in other combinations and for other purposes.

A heat exchanger suitable for the illustrated usage is required to contain a corrosive heat-exchange medium such as sodium, potassium, lithium, a low-melting eutectic composition, or a material such as sodium hydroxide and thus should be constructed of a corrosion-resistant metal of adequate heat conductivity such as nickel, In conel, or stainless steel. The heat-exchange medium, when heated by a nuclear reactor, is likely to become a source of gamma-ray activity due to neutron bombardment and thus must be drained from the system while maintenance or other work is conducted upon the power-plant assembly. Accordingly, provision for ready attachment and detachment of the heat exchanger from its cooperative apparatus is required. Moreover, since the heat exchanger is intended to contain a medium having a temperature in the order of 1200–1500° F. and under a pressure of about 100 p.s.i. at normal operation, it is apparent that provision for expansion of the metal structure must also be provided. Also, since the medium contained by the heat exchanger may be subject to fire in the case of leaks, it is important that a compact, structurally strong apparatus be provided in order to minimize this danger.

An object of the present invention is to provide a new and improved heat exchanger that is formed in cooperating parts enabling the heat exchanger to be assembled about another structure. The parts are compactly formed and are capable of withstanding operation at high temperatures.

Other objects will become apparent from the accompanying drawings and the description that follows:

In the drawings:

FIG. 1 is a diagrammatic sectional view illustrating the arrangement of the heat exchanger of the present invention in combination with a jet-engine power plant;

FIG. 2 is an elevation of a tube employed in the heat exchanger;

FIG. 3 is a transverse sectional view of the heat exchanger, taken on the line 3—3 of FIG. 4;

FIG. 4 is a longitudinal sectional view of the heat exchanger, taken on the line 4—4 of FIG. 3;

FIG. 5 is a fragmentary sectional view taken on the line 5—5 of FIG. 4;

FIG. 6 is a fragmentary sectional view taken on the line 6—6 of FIG. 5;

FIG. 7 is a fragmentary sectional view taken on the line 7—7 of FIG. 4;

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FIG. 8 is a fragmentary sectional view taken on the line 8—8 of FIG. 7;

FIG. 9 is a transverse sectional view through an intermediate enlarged portion of a heat-exchanger tube, taken on the line 9—9 of FIG. 2;

FIG. 10 is a longitudinal sectional view taken on the line 10—10 of FIG. 9; and

FIG. 11 is a transverse sectional view corresponding to FIG. 9 but showing a modified form of heat-exchanger tube.

Referring now first to FIG. 1, a heat exchanger or radiator 10, of the present invention, is shown as embodied in a jet-engine power plant, suitable for propelling an airplane, not shown. A suitable heat-exchange medium, such as sodium, is circulated through a source of heat, as for example, a nuclear-reactor assembly, not shown, and enters the heat exchanger 10 through an inlet conduit 11. This radiator is provided with an outlet conduit 12 through which the slightly cooled medium is recirculated to the source of heat, being maintained meanwhile under a suitable pressure head by means of pumps, not shown.

As will be noted, the radiator 10 is centrally located within the jet-engine assembly and surrounds a centrally located drive shaft 13 which connects a turbine 14 with a compressor 15. A suitable auxiliary drive shaft 16 may be employed to take power from shaft 13 and through conventional gearing 17 to drive auxiliary equipment 18, as needed.

Air enters the power plant adjacent an inlet diffuser 19, is compressed within the compressor 15, passes through radiator 10 in which it is raised to a temperature in the range of 1100–1400° F., then expands through the turbine 14, and later issues from a conventional jet outlet such as a variable area propulsion nozzle, not shown. In certain situations it may be desirable to supplement the power derived from this heated air, and accordingly a series of combustion chambers 20, located between the radiator 10 and turbine 14, is provided. These chambers receive a portion of the compressed air and burn therein any suitable chemical fuel, introduced through feed lines 21. The products of combustion mix with the remainder of the compressed air and are directed jointly into turbine 14. The outer surface of the power plant is formed by a metallic envelope 22 serving to confine air passing therethrough, while the inner portions of the power plant are defined by a second metallic envelope 23 serving to confine the air as it passes from the compressor to the turbine. A third metallic envelope 24 encases the drive shaft 13 and its bearings, which latter may be mounted in any conventional manner upon the engine structure. In this way annular sheets of cooling air are provided between the outside of the radiator and the inside of the engine casing and also between the inside of the radiator and the main shaft housing. These sheets of air move aft along the engine axis and also provide cooling for the annular space between the outside of the combustion chamber section and the engine casing and between the inside of the combustion chamber section and the main shaft housing.

As shown in FIGS. 3 and 4, the end of each of the conduits 11 and 12 connected with the heat exchanger 10 is split into two branches 25 and 26, which are respectively connected to separable halves 27 and 28 of the heat exchanger 10. More specifically, flanged ends 29 on the branches 25 and 26 are attached to openings formed in inlet and outlet headers 30 and 31 forming part of outer walls 32 of the heat exchanger 10, the flanged ends 29 on the inlet conduit 11 being attached to the inlet headers 30, and the flanged ends on the outlet conduit 12, to outlet headers 31. Each of heat-exchanger halves 27 and 28 has an outer wall 32, which comprises, in addition to inlet and outlet headers 30 and 31 as specified previously, an intermediate section 33 which connects them. The inlet and outlet headers 30 and 31 and the intermediate section 33 of each heat-exchanger section are generally cylindrical and semicircular and are secured, respectively, to the inlet and outlet headers and the intermediate section of the other heat-exchanger half, so that a combined outer wall 32—32 is formed, which is generally circular and cylindrical. Each of the heat-exchanger halves 27 and 28 has an inner wall 34 which is generally semicircular and cylindrical and is joined with the inner wall 34 of the other heat-exchanger half to form a combined inner wall 34—34. On each heat-exchanger half the outer wall 32 and the inner wall 34 are spaced from one another and are interconnected by an upper side wall 35 and alower side wall 36 which extend generally radially. The upper side wall 35 and the lower side wall 36 of one heat-exchanger half lie, respectively, on the upper side wall and the lower side wall of the other heat-exchanger half.

In each heat-exchanger half the space inclosed by the outer wall 32, the inner wall 34, the upper side wall 35, and the lower side wall 36 is filled with a plurality of tubes 37, which may be made of Inconel and have a wall thickness of about .015 inch. As shown in FIG. 2, each tube 37 comprises a plurality of circular portions 38 of considerable length, two short expanded hexagonal end portions 39 which are located at the ends of the tube, and one or more intermeidate expanded hexagonal portions 40 which lie at intermediate regions of the tube so as to space the circular portions 38 from one another. The expanded portions 39 and 40 may be formed by a fluid applied internally of the tubes at a high pressure and external dies into which the tube portions are expanded. The expanded tube portions may have other polygonal shapes than hexagonal. At each end of each heat-exchanger half 27 or 28 the expanded portions 39 fit together and are bonded to one another as shown in FIG. 7 so as to form on an end of the heat-exchanger half a closure to the spaces between the tubes, the closures on the ends of the heat-exchanger halves 27 and 28 adjacent the outlet 12 being designated as 39*a*, and the closures on the other ends, as 39*b* in FIG. 4. In each heat-exchanger half the expanded intermediate portions 40 fit together and are bonded to one another, as shown in FIG. 8, so that baffles 40*a*, 40*b*, and 40*c* are formed, as shown in FIG. 4, to extend radially outwardly part of the distance between the inner walls 34 and the outer walls 32 of the heat-exchanger halves 27 and 28. These baffles impede flow through the heat exchanger 10 lengthwise of and in the spaces around the tubes 37, so that fluid flowing across the tubes from the inlet 11 to the outlet 12 is forced to follow a zig-zag path. For each heat-exchanger half 27 or 28 the baffles 40*a* and 40*c* extend from the ends of the intermediate section 33 radially inwardly to a region spaced radially outward from the inner wall 34, and the baffle 40*b* lies between the baffles 40*a* and 40*c* and extends radially outward from the inner wall 34, to a region spaced radially inward from the intermediate section 33 of the outer wall 32. Thus some tubes 37 each have three intermediate expanded portions 40, some have two intermediate expanded portions, and others have only one intermediate expanded portion.

On each heat-exchanger half the inner wall 34 is reinforced by four channels 41 secured to its inner surface and extending the arcuate length of the inner wall, the channels 41 on the one inner wall 34 abutting the channels on the other inner wall. On each heat-exchanger half the outer wall 32 is reinforced by two channels 42 secured to the outer side of the intermediate section 33.

On each heat-exchanger half the width of each of the headers 30 and 31 varies from a maximum at the top adjacent the inlet 11 and outlet 12 to a minimum at the bottom of the heat-exchanger half. Thus the intermediate section 33 of the outer wall 32 extends into or overlaps the headers in different amounts varying from a maximum at the top of the heat exchanger to a minimum at the bottom where the overlap is zero. The radial depth of the headers 30 and 31 also varies, being a maximum at the top of the heat exchanger and minimum at the bottom.

As shown in FIGS. 5 and 6, the outlet headers 31 have circular flanges 43 in which the expanded end portions 39 on the tubes 37 constituting the end closure 39*a* are positioned. Since these end portions 39 are polygonal in shape, filler pieces 44 are provided in the spaces between the end portions 39 and are bonded to the header flanges 43 and the adjacent expanded end portions, so that end closures 39*a* do in fact close off the spaces between the circular portions 38 of the tubes 37. Similar filler pieces are provided at a circular flange 45 (FIG. 4) on the inlet header 30 to make the end closure 39*b* effective. The upper and lower side walls 35 and 36 are corrugated at least at the regions opposite the tube enlargements 39 and 40, as shown in FIG. 5, so that the enlargements fit these regions closely and are bonded thereto.

As shown in FIGS. 9 and 10, each of the tubes 37 is provided with four channels 46 which extend the length of the tube and are spaced circumferentially about the interior of the tube. The base of each channel 46 is bonded to the tube, and the sides of each channel converge. The purpose of the channels is to increase the heat transfer between gas flowing through the tubes and a liquid flowing across the exterior of the tubes. It will be noted that the channels 46 engage the tubes 37 at the circular portions 38.

FIG. 11 shows an alternate form of the invention in which a tube 47 is of uniform diameter throughout its length and has hexagonal flanges or rings 48 bonded to its exterior at its ends and one or more intermediate portions. These rings 48 constitute a substitute for the expanded end portions 39 and expanded intermediate portions 40 on the tubes 37, in that the various tubes 47 can be assembled so that the rings 48 thereon fit together to form the end closures 39*a* and 39*b* and baffles 40*a*, 40*b*, and 40*c*. The tubes 47 carry heat-conducting channels 46 which are associated with tubes 47 in the same manner as with the tubes 37.

As shown in FIGS. 3 and 4, the heat-exchanger halves are mounted in the outer envelope 22 by means of S-members 49 which are placed between the headers 30 and 31 and the end portions of the envelope 22 and are S-shaped so as to provide room for expansion and contraction of the headers with respect to the envelope 22. The S-members 49 have perforations 50 which permit the flow of gas along the heat exchanger between outer envelope 22 and the outer wall 32. There are four S-members 49 in all, two at the inlet header 30, and two at the outlet header 31. The S-members 49 are arcuately coextensive with the heat-exchanger halves 27 and 28, abutting at the bottom at the juncture of the heat-exchanger halves 27 and 28 and extending upward around the heat-exchanger halves about to the branches 25 and 26 of the inlet and outlet conduits 11 and 12.

The outer envelope 22 is formed of a plurality of arcuate parts including a lower generally semicircular cylindrical part 51, two side parts 52, and an upper part 53. The lower part 51 is secured to the side parts 52, which are in turn secured to the upper part 53. The part 53 has four openings that freely receive the branches 25 and 26 of the inlet and outlet conduits 11 and 12. Corrugated expandible sleeves 54 surround the lower portions of the branches 25 and 26 and have their ends sealingly secured to the upper envelope part 53 and the branches 25 and 26.

The heat-exchange medium, such as sodium, comes from a source of heat, such as a nuclear reactor, and enters the heat exchanger 10 through the branches 25 and 26 of the inlet conduit 11. One part of the heat-exchange medium goes through the heat-exchanger half **27**, and the other, through heat-exchanger half **28**. From the inlet branch **25** or **26** the medium goes through the inlet header **30** into the space occupied by the tubes **37** and follows a zig-zag path across the exterior of the tubes as determined by the baffles **40***a*, **40***b*, and **40***c* to the outlet header **31**. The heat-exchange medium follows this zig-zag path, not only at the upper portion of the heat-exchanger halves, but also at the side and lower portions thereof, because of the way in which the intermediate sections **33** of the outer walls **32** project into the headers **30** and **31**. Thus some of the heat-exchange medium is forced around the heat-exchanger halves **27** and **28** from the top toward the bottom before it can start its zig-zag path between the headers **30** and **31**.

The construction of the heat exchanger **10** is such that it can be removed without disturbing the drive shaft **13** which it surrounds or the compressor **15** and the combustion chambers **20**. It is contemplated that such removal may be necessary because of the possibility of contamination of the heat exchanger due to the circulation of sodium therethrough heated by a neutronic reactor. The parts **51**, **52**, and **53** of the outer envelope, which surround the heat exchanger **10**, are disconnected from one another and the other parts of the envelope **22** and are removed. The inlet and outlet conduits **11** and **12** are removed. Now the heat-exchanger halves **27** and **28** are separated from one another and removed from around the drive shaft **13**.

The intention is to limit the invention only within the scope of the appended claim.

What is claimed is:

A heat exchanger comprising a segmented outer circular shell; a pair of semicylindrical mating sections eccentrically disposed therein, each section comprising an inner semicircular wall, an outer semicircular wall spaced therefrom and concentric therewith, side walls extending in general alignment with one another and secured to the circular walls so as to hold the circular walls in spaced relationship with one another, the mating sections being assembled so as to cause the side walls of one section to lie upon the side walls of the other section and the inner

walls to enclose a space, a plurality of parallel tubes extending through the space enclosed by said walls, and a plurality of baffles associated with the tubes and protruding alternately inward from the outer circular wall and outward from the inner circular wall of said sections, providing a circuitous path in each mating section of the heat exchanger between the branches of the inlet and outlet conduits; and means for circulating a fluid around the tubes, said means including an inlet distribution header having tapered semicircular outer walls generally concentric with the outer shell and eccentric with respect to the inner and outer walls of the semicylindrical sections and being connected to said sections adjacent one end, whereby the greatest radial depth of the header is at the region of greatest width and the greatest radial depth and least radial depth of the header are at the top and bottom, respectively, an outlet distribution header similar to the inlet header described above and being connected to said sections adjacent the other end, an inlet conduit having two branches connected to the inlet header on opposite sides of and directly adjacent to one set of side walls of the mating sections lying upon one another and at a region of the inlet header of greatest depth; and an outlet conduit having two branches similarly connected to the outlet header.

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