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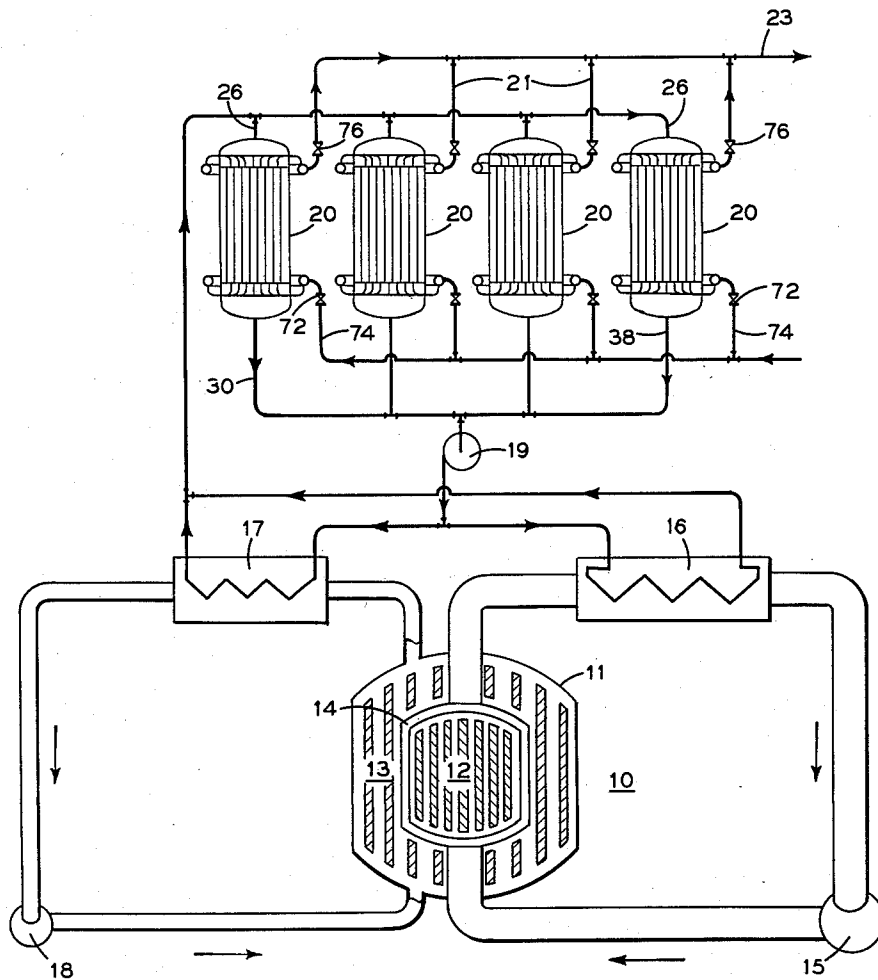
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FLUID HEATERS

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FIG. 1



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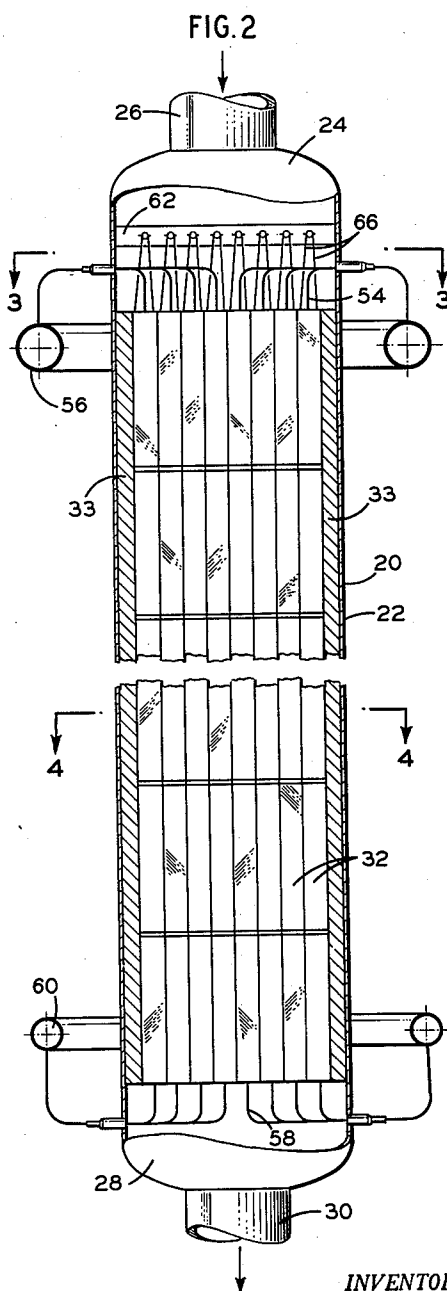
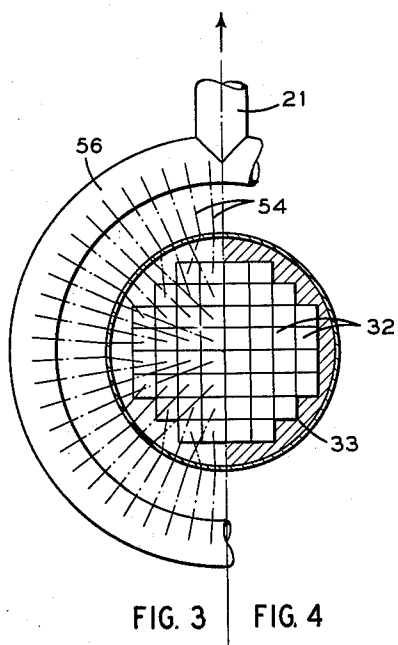
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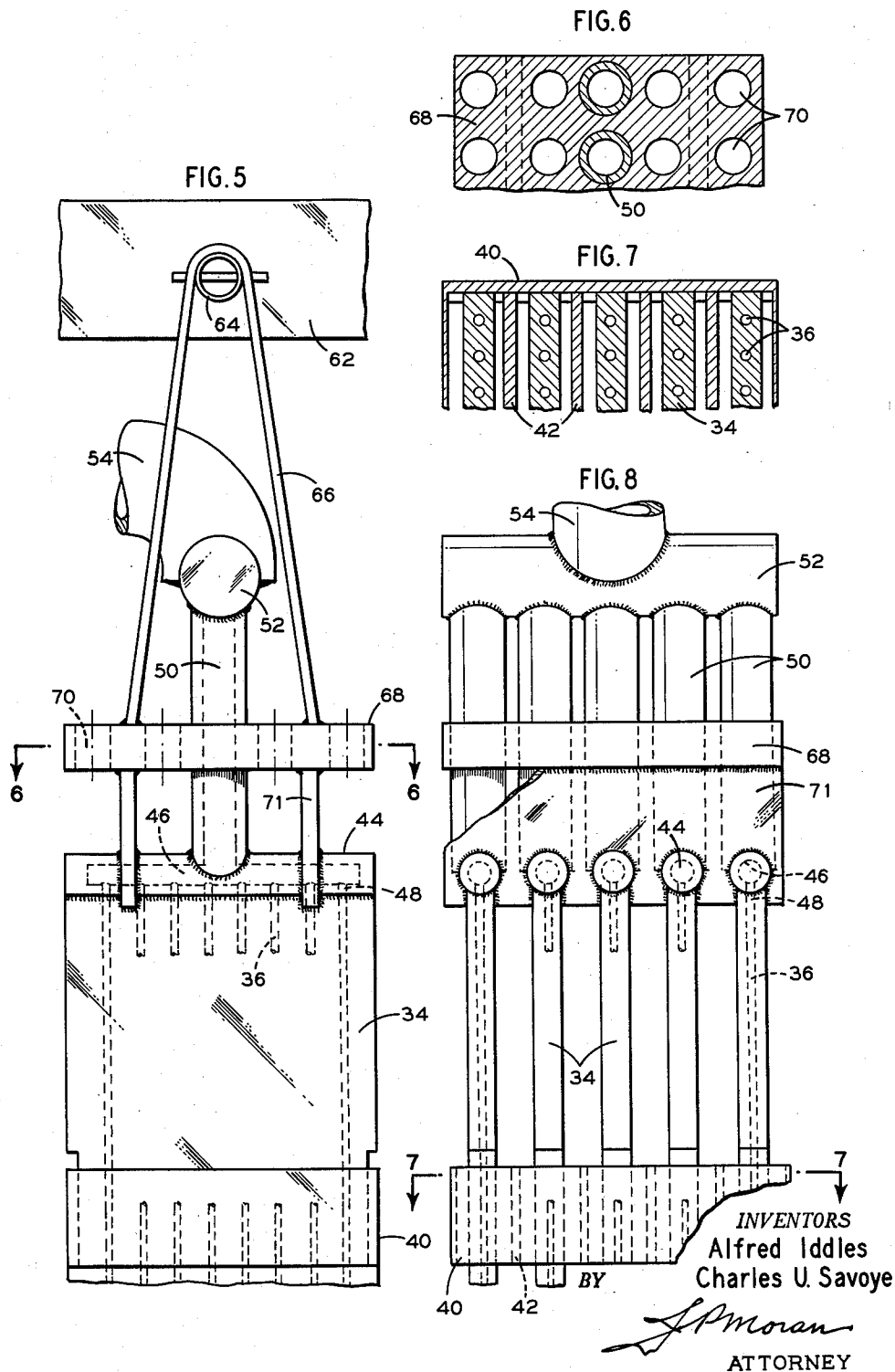
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FLUID HEATERS

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FLUID HEATERS

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6 Claims. (Cl. 257-306)

The present invention relates in general to the construction and operation of fluid heaters, and more particularly, to the construction and operation of vapor generating and superheating units in which the source of heat is a circulating stream of hot liquified metal, such as sodium, potassium, or a eutectic combination thereof.

Fluid heaters of the character described require the use of metal resistant to corrosion for any heat transfer parts contacted by the liquid metal. To minimize the requirements of corrosion resistant metal, such as the expensive stainless alloy steels, in such apparatus, the heat transfer parts should be constructed and arranged to provide a minimum size and weight of these parts for a given fluid heating capacity. This in turn requires a high rate of heat transfer per unit of surface contact area.

Corrosion resistant alloy steel tubing of the sizes normally used in high pressure steam generating units is highly expensive. The high heat conductance value of liquid metal requires a relatively high velocity in the steam generating and superheating tubes to avoid overheating of the tubes. This in turn would require a long length of water and steam travel in the tubes and necessitate tube lengths in forced flow once through type steam generating units which would involve design as well as economic limitations. The longer the tube length required in a forced flow once through boiler, for example, to produce steam at the desired superheat temperature, the greater will be the overall fluid pressure drop through the tubes and the higher the cost of tubing. If however the tube diameter should be reduced, the fluid pressure drop there-through and the fluid pumping requirements will be correspondingly increased.

In accordance with the present invention, a high efficiency and high capacity liquid metal heated vapor generating and superheating unit is provided by the use of a multiplicity of very small diameter parallel fluid heating passages formed in groups of spaced heat transfer elements which are connected and arranged to form a forced flow once through type vapor generating unit operable at pressures in excess of the critical pressure (3207 p.s.i.) and superheating the vapor generated to a temperature in excess of 1000° F. With this construction and arrangement, the essential high fluid velocities through the fluid passages can be maintained and the resulting high fluid pressure drop kept within permissible limits, while lending itself to a fluid heater design characterized by its compactness and relatively low amount of expensive corrosion resistant material in the heat transfer parts.

A further feature of the invention is the provision of an improved high pressure heat transfer element construction and method of manufacture in which a relatively thin rigid plate or slab of corrosion resistant alloy metal is drilled at predetermined intervals along one end to form a series of parallel very small diameter passages extending the full length of the plate. Such heat transfer elements can be made of any desired length by longitudinally aligning the corresponding fluid passages of a plurality of plates and welding the plates in end to end contact. A plurality of such welded plates are then assembled in space parallel relation in one or more holding frames to form a rigid heat transfer element, the interplate spaces serving as high velocity liquid metal flow passages.

The various features of novelty which characterize

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the invention are pointed out with particularity in the claims annexed to and forming a part of this specification. For a better understanding of the invention, its operating advantages and specific objects attained by its use, reference should be had to the accompanying drawings and descriptive matter in which a preferred embodiment of the invention is disclosed.

Of the drawings:

FIG. 1 is a diagrammatic illustration of a liquid metal fuel reactor power plant having steam generating units constructed in accordance with the invention;

FIG. 2 is an enlarged sectional elevation of one of the steam generating units indicated in FIG. 1;

FIGS. 3 and 4 are combined plan views taken on the lines 3-3 and 4-4 of FIG. 2 respectively;

FIG. 5 is a fragmentary elevation showing the heat transfer element supporting structure;

FIG. 6 is a partial horizontal section taken on line 6-6 of FIG. 5;

FIG. 7 is a partial horizontal section taken on the line 7-7 of FIG. 8; and

FIG. 8 is an end view of a group of the elements shown in FIG. 5.

The invention is particularly adapted for use in the construction and operation of vapor generating units in atomic power plants utilizing liquid metal as a heat transfer medium, as illustrated in the liquid metal fuel reactor power plant in FIG. 1. Such plants comprise a reactor 10 having a shielded pressure vessel 11 enclosing a core section 12 and breeder blanket section 13 separated by a graphite vessel 14. The core fuel is a uranium-bismuth solution circulated upwardly through the core section and in a closed loop containing a pump 15 and primary heat exchanger 16. The breeder blanket fluid is a slurry of thorium-bismuth which is circulated upward through the blanket section 13 and in a closed loop containing a primary heat exchanger 17 and pump 18. The heat absorbed in operation in the reactor core and blanket fluids is transferred in the primary heat exchangers 16 and 17 respectively to a stream of liquid sodium circulated by a pump 19, as indicated by the arrows, through the primary heat exchangers and then downwardly through a plurality of steam generating units 20 arranged in parallel and delivering steam through steam outlet pipes 21 to a steam main 23 leading to a point of use. The liquid sodium enters the generating units 20 at a temperature of approximately 1150° F., for example, and is discharged to the pump 19 at a temperature of approximately 750° F. at the designed full load.

In accordance with the invention the steam generating units 20 are of the forced flow once through type and so constructed and operated as to permit the use of a high efficiency steam cycle, as, for example, supplying the feed water at 3500 p.s.i. and 600° F., and generating and superheating the steam to a temperature of 1050° F. with an outlet pressure of 3000 p.s.i.

As shown in FIGS. 2-8, each steam generating unit 20 comprises a cylindrical upright pressure vessel 22 having a top head 24 to which a liquid metal inlet 26 is connected and a bottom head 28 to which a liquid metal discharge pipe 30 is connected. The heat transfer surface consists of a large number of vertically elongated heat exchange elements 32 of rectangular horizontal cross-section arranged in standardized units in the symmetrical formation shown in FIG. 3-FIG. 4. The irregular space between the formation of elements 32 and the circumferential wall of the pressure vessel 22 is occupied by a filler material 33, such as graphite, which is chemically inert to the liquid metal employed. Each heat transfer element is formed by five vertically elongated relatively thin flat-sided rigid alloy steel plates 34 arranged in parallel spaced relation.

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Each plate is advantageously formed with vertical fluid passages 36 of very small diameter extending throughout the entire length thereof, preferably by drilling the passages in a multiple drilling machine. Drilling the passages insures a more accurate and uniform passage cross-section in such small passages than is possible with any other known method of forming fluid flow passages. In accordance with the invention each of the passages 36 preferably has its circumference spaced from both of the adjoining parallel flat faces of the plate by a distance not greater than the passage diameter. For example, each of the plates shown is provided with eight passages .125 inch diameter having a center-to-center spacing of .375 inch and positioned .10 inch from each adjoining face of the plate. The plates are arranged with a distance of .75 inch between the plate center lines leaving a passage of .425 inch between adjacent plates throughout their length for the smooth high velocity flow of liquid metal downwardly therethrough.

The plates are arranged in the desired spaced relation in a series of vertically spaced rectangular tie frames 40 fitting tightly against the opposite side edges of the plates 34. Spacer bars 42 extend parallel to the plates in the interplate passages to reinforce the sides of each tie frame. The tie frame is substantially square (e.g. approx. 3.75 x 3.43 inches). To the upper end of each top plate is welded a collecting header 44 having a horizontally extending passage 46 and a series of short branch passages 48 registering with the passages 36 of the corresponding plate. The header 44 is fusion welded to the top edge of the corresponding plate. If during the welding operation the passages 36 or 48 should be partly or wholly closed by weld metal, such passages can be redrilled to clear the same. The length of the individual plates is dependent upon the limit of accuracy of the drilling operations in making the passages 36 and the plate length is advantageously made as long as is feasible with the available commercial drilling equipment. However it is unlikely that a single plate so drilled will be sufficient to provide the desired length of heat transfer element and the plates are advantageously butt-welded in end-to-end relation in a manner similar to the connection of the headers 44 to the plates 34 to form a welded sectional heat transfer element.

Each of the headers 44 of a heat transfer element is connected by a riser pipe 50 to a cross-header 52, and the cross-headers in turn connected by pipes 54 through the pressure vessel wall to an external annular header 56. The lower ends of the heat transfer plates are similarly connected to plate headers, pipes, and a cross-header to feed water inlet pipes 58 and an annular inlet header 60. The described heat transfer elements are preferably top-supported from beams 62 mounted in the top head of the vessel by means of cross tubes 64 and straps 66 carried by the tubes 64 and connected at their lower ends to a horizontally arranged plate 68 coextensive with the cross-section of the heat transfer element. The plate 68 has rows of vertical holes 70 therein for the downflow therethrough of liquid metal. Each of the support plates 68 is connected by a pair of spaced webs 71 to the headers 44 of the corresponding element. Each plate 68 thus serves as a liquid metal distributor and support plate for the corresponding heat transfer element.

The heat exchanger described is particularly adapted for use as a forced flow once-through steam generating unit adapted to generate and superheat steam to high temperatures at pressures at or above the critical pressure. When so used feed water is supplied to the head 60, for example, at a pressure of 3500 p.s.i. and an inlet temperature of 600° F. The entering feed water is delivered to the lower end of all of the heat transfer elements by the pipes 58 and distributed to the individual plates of each element. Under such pressures the feed water flows upwardly at a high velocity through the multiplicity of small passages 36 in heat absorbing relation with the high

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temperature liquid metal supplied through the pipe 26 and distributed throughout the cross-sectional area of the pressure vessel occupied by the heat transfer elements. The liquid metal passes downward in counterflow relation to the heat transfer plates through the narrow smooth walled passages formed by the parallel flat plate faces. In view of the low liquid metal pressure drop along the plates, such as 1-2 p.s.i., a downflow of the liquid metal is desirable in order that any uneven lateral temperature distribution of the liquid metal would tend to be self-leveling instead of self-augmenting. The described form of heat transfer elements insures a flow of liquid metal confined to the areas of high heat transfer rates. Any differential expansion between the heat transfer elements and the pressure vessel is taken up by the curved feed water inlet tubes 58 at the bottom of the vessel. With a liquid metal film coefficient value such as 10,800 B.t.u. per sq. ft. per hr. per ° F. for liquid sodium and heat transfer elements of the character described, a high rate of heat transfer will take place to the steam and water in the passages 36, causing the steam to be generated and superheated to a high temperature, such as 1050° F., during a single passage through a heat transfer plate passage. The liquid metal thus flows downwardly in counterflow relation to the steam and water and discharges through the pipe 30 to the pump 19. In the designed operation the temperature of liquid sodium will be reduced from an inlet temperature of 1150° F. to an outlet temperature of 750° F. The described construction provides a compact relatively low cost fluid heater capable of generating steam at high capacities and operable over a substantial load range to superheat steam to a high temperature. The heat transfer plates and other parts contacted by the liquid metal may be safely made of a low chromium ferritic alloy steel, such as A.I.S.I. type 347.

Liquid metal, such as sodium or potassium, when contacted by water, as when a leak should occur in a heat transfer plate, will oxidize at a rapid rate, releasing hydrogen gas. The pressure vessel is designed to withstand a pressure considerably above the liquid metal operating pressure and safety valves (not shown) may be employed to prevent the vessel pressure from rising to dangerous values. In addition, cut-off valves 72 are provided in the feed water supply connections 74 to the individual steam generating units and valves 76 in the steam discharge lines 21 to close automatically if the pressure in the liquid metal space of the vessel should rise above a lesser predetermined value, and thus cut out the damaged steam generating unit while permitting the remaining units to continue operation.

While in accordance with the provisions of the statutes we have illustrated and described herein the best form of the invention now known to us, those skilled in the art will understand that changes may be made in the form of the apparatus disclosed without departing from the spirit of the invention covered by the claims, and that certain features of our invention may sometimes be used to advantage without a corresponding use of other features.

What is claimed is:

1. A fluid heating unit comprising a vertically elongated pressure vessel having a liquid metal inlet and outlet at opposite ends thereof and containing a multiplicity of heat transfer elements arranged in contacting relation within said vessel in a cross-sectional configuration different from the internal cross-sectional configuration of said vessel, a filler material chemically inert to said liquid metal filling the space between said elements and the wall of said vessel, each of said heat transfer elements having a series of spaced parallel relatively thin flat-sided corrosion-resistant metal plates each integrally formed with transversely spaced parallel fluid heating passages extending the full length thereof with the interplate spaces longitudinally coextensive with said fluid heating passages and communicating at their ends with said liquid metal inlet

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and outlet for a flow of liquid metal therethrough in heat transfer contact with said plates, and means for supplying a fluid to be heated to said fluid heating passages for parallel flow therethrough in indirect longitudinal heat transfer relation with said heating fluid.

2. A fluid heating unit comprising a vertically elongated pressure vessel having a liquid metal inlet and outlet at opposite ends thereof and containing a multiplicity of heat transfer elements arranged in contacting relation and a symmetrical formation within said vessel, a filler material chemically inert to said liquid metal filling the space between said elements and the wall of said vessel, each of said heat transfer elements having a series of spaced parallel relatively thin plates each integrally formed with transversely spaced parallel fluid heating passages less than 0.5 inches diameter extending the full length thereof with the inter plate spaces longitudinally coextensive with said fluid heating passages and communicating at their ends with said liquid metal inlet and outlet for a flow of liquid metal therethrough in heat transfer contact with said plates, means for supplying a fluid to be heated to said fluid heating passages for parallel flow therethrough in indirect longitudinal heat transfer relation with said heating fluid, and means for top supporting said heat transfer elements.

3. A forced flow once through vapor generating unit comprising a vertically elongated pressure vessel having a liquid metal inlet and outlet at opposite ends thereof and containing a multiplicity of heat transfer elements arranged in contacting relation within said vessel, a filler material chemically inert to said liquid metal filling the space between said elements and the wall of said vessel, each of said heat transfer elements having a series of spaced parallel relatively thin plates each integrally formed with transversely spaced parallel vertically arranged fluid heating passages less than 0.5 inch diameter extending the full length thereof with the interplate spaces longitudinally coextensive with said fluid heating passages and communicating at their ends with said liquid metal inlet and outlet for a flow of liquid metal therethrough in heat transfer contact with said plates, and means for supplying a vaporizable liquid to said fluid heating passages for parallel flow therethrough in indirect longitudinal heat transfer relation with said heating fluid.

4. A forced flow once through vapor generating unit comprising a vertically elongated pressure vessel having a liquid metal inlet and outlet at opposite ends thereof and containing a multiplicity of heat transfer elements arranged in contacting relation and a symmetrical formation within said vessel, a filler material chemically inert to said liquid metal filling the space between said elements and the wall of said vessel, each of said heat transfer elements having a series of spaced parallel relatively thin flat plates each integrally formed with transversely spaced parallel vertically arranged fluid heating passages having a diameter at least one-third of the plate thickness but not greater than 0.5 inch diameter extending the full length thereof with the interplate spaces longitudinally coextensive with said fluid heating passages and communicating at their ends with said liquid metal inlet and outlet for a flow of liquid metal therethrough in heat transfer contact with said plates, means for supplying a

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vaporizable liquid to said fluid heating passages for parallel flow therethrough in indirect longitudinal heat transfer relation with said heating fluid, and means for top supporting said heat transfer elements.

5. A forced flow once through steam generating unit comprising a vertically elongated pressure vessel having an oxidizable liquid metal inlet and outlet at opposite ends thereof and containing a multiplicity of heat transfer elements arranged in contacting relation within said vessel, a filler material chemically inert to said liquid metal filling the space between said elements and the wall of said vessel, each of said heat transfer elements having a series of spaced parallel relatively thin plates each integrally formed with transversely spaced parallel vertically arranged fluid heating passages extending the full length thereof with the interplate spaces longitudinally coextensive with said fluid heating passages and communicating at their ends with said liquid metal inlet and outlet for a flow of liquid metal therethrough in heat transfer contact with said plates, means for supplying feed water to said fluid heating passages for parallel flow therethrough in indirect longitudinal heat transfer relation with said heating fluid, and means for cutting off the supply of feed water on a predetermined increase in pressure in the liquid metal space in said pressure vessel.

6. A fluid heating unit comprising a vertically elongated pressure vessel having a heating fluid inlet and outlet at opposite ends thereof and containing a multiplicity of heat transfer elements arranged in contacting relation within said vessel, each of said heat transfer elements having a series of spaced parallel relatively thin flat sided metal plates extending longitudinally of said vessel between said inlet and outlet, each plate being of substantially uniform cross-sectional area throughout its length and integrally formed with transversely spaced parallel fluid heating passages extending the full length thereof with the interplate spaces longitudinally coextensive with said fluid passages and communicating at their ends with said heating fluid inlet and outlet for a flow of heating fluid therethrough in heat transfer contact with said plates, and means for supplying a fluid to be heated to said fluid heating passages for parallel flow therethrough in indirect longitudinal heat transfer relation with said heating fluid.

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