United States Patent

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[54] **SHELL-SIDE LIQUID METAL BOILER**
1 Claim, 5 Drawing Figs.

[52] **U.S. Cl.** **165/158,** 122/32, 165/161, 165/174, 165/133, 165/155, 176/92
[51] **Int. Cl.** **F28f 9/22,** F22
[50] **Field of Search** 122/32; 176/92; 165/159, 160, 161, 158, 174, 133, 155

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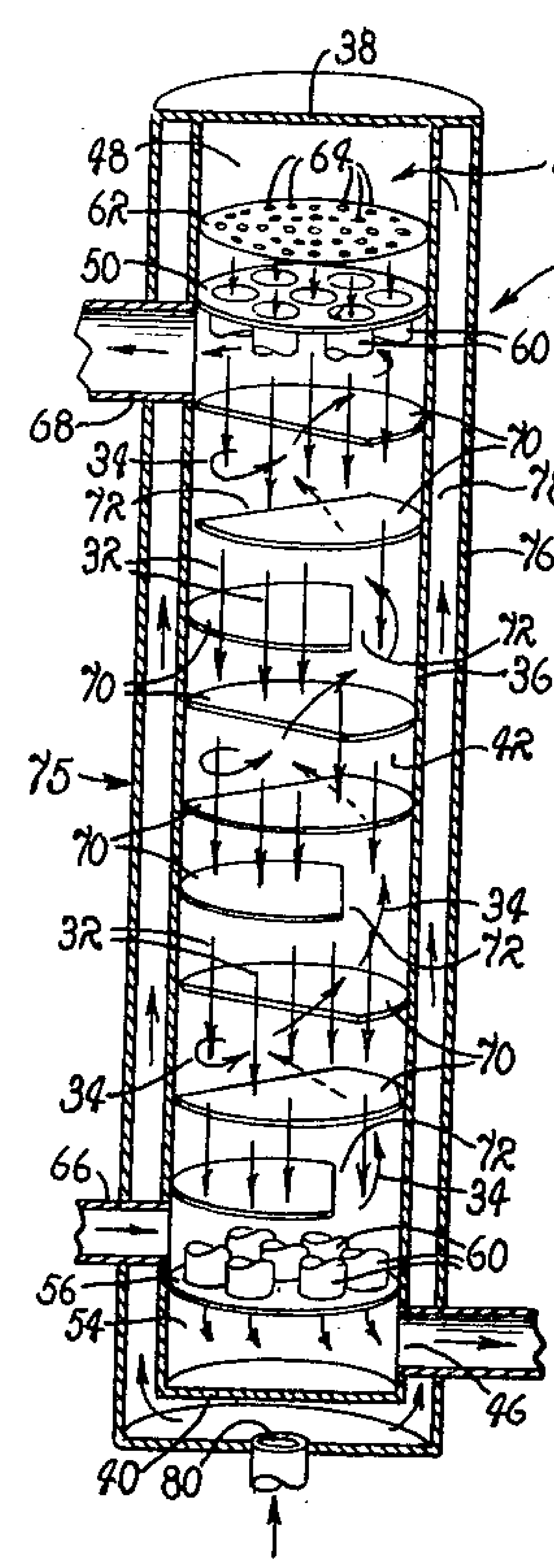
ABSTRACT: A shell-side liquid metal boiler including a tube and shell heat exchanger particularly suited for use in effecting a heat exchange between continuously flowing primary and secondary fluids within a two-loop Rankine cycle power system, characterized by a plurality of tubular conduits through which there is delivered a heated primary fluid, and a boiler shell circumscribing the conduits defining a boiler chamber within which shell-side boiling of the secondary fluid is achieved, a feature of the invention being the provision of a plurality of mutually spaced, angularly related baffle plates mounted within the boiler and defining a tortuous path having both crossflow and spiral-flow path components, whereby the secondary fluid is permitted to circulate about the surfaces of the tubular conduits for achieving a heat exchange through shell-side boiling of the liquid metal within the boiler chamber.



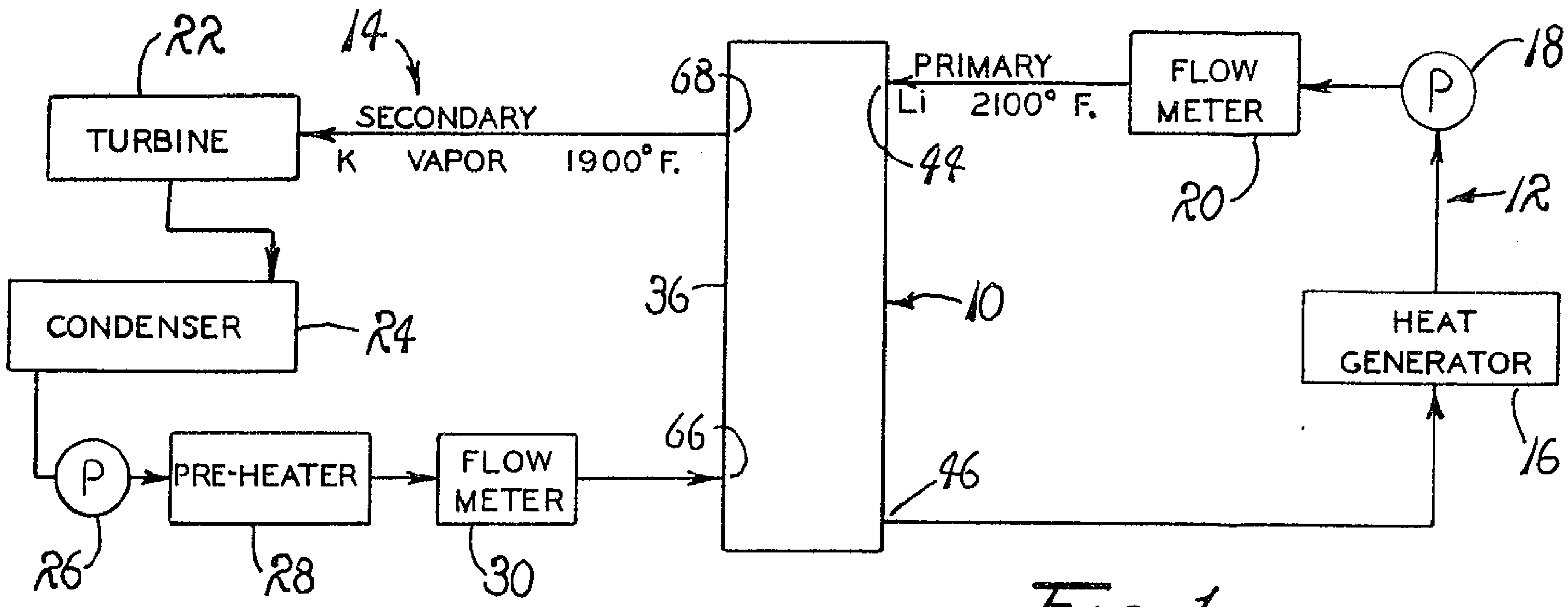


FIG. 1.

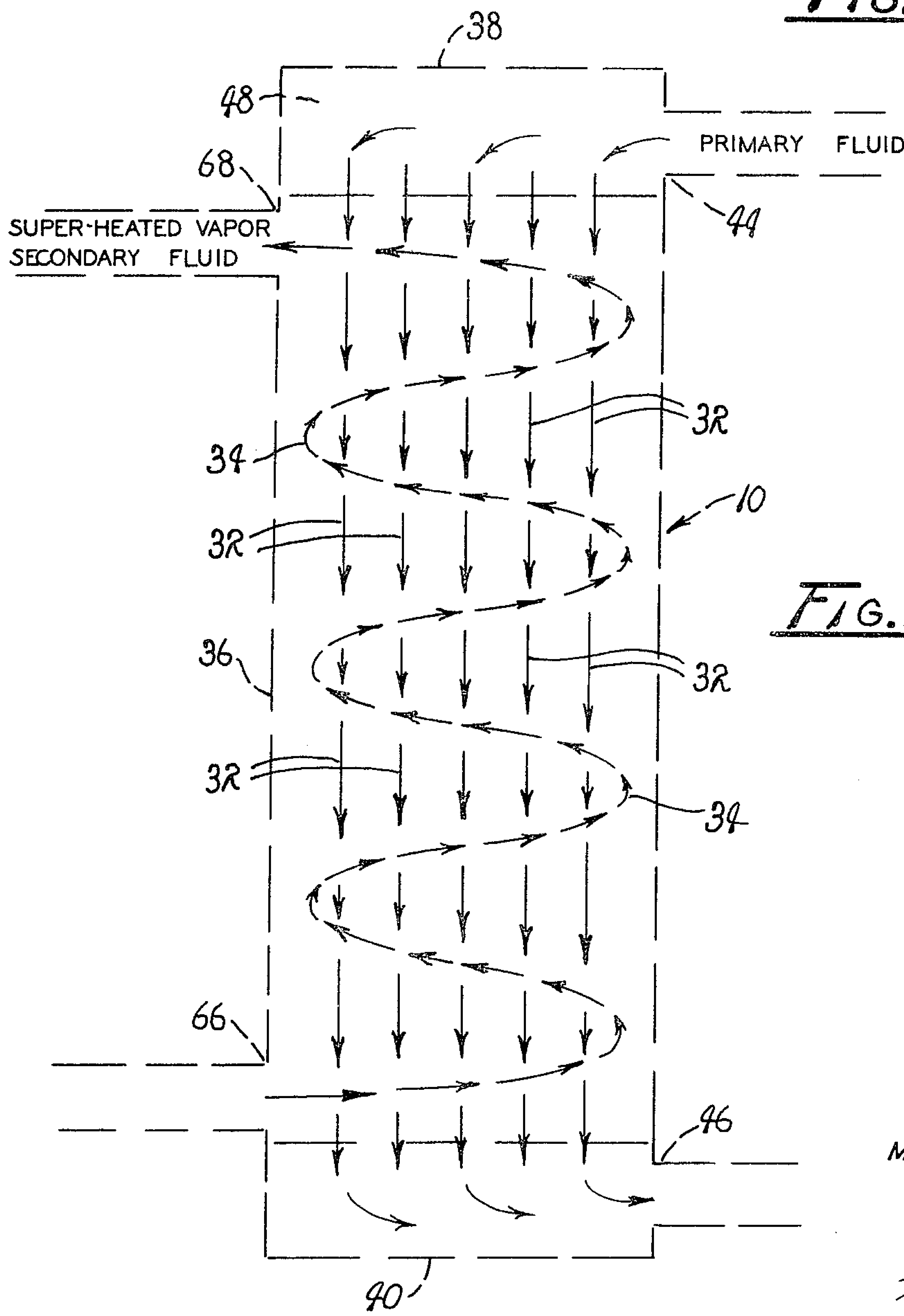


FIG. 2.

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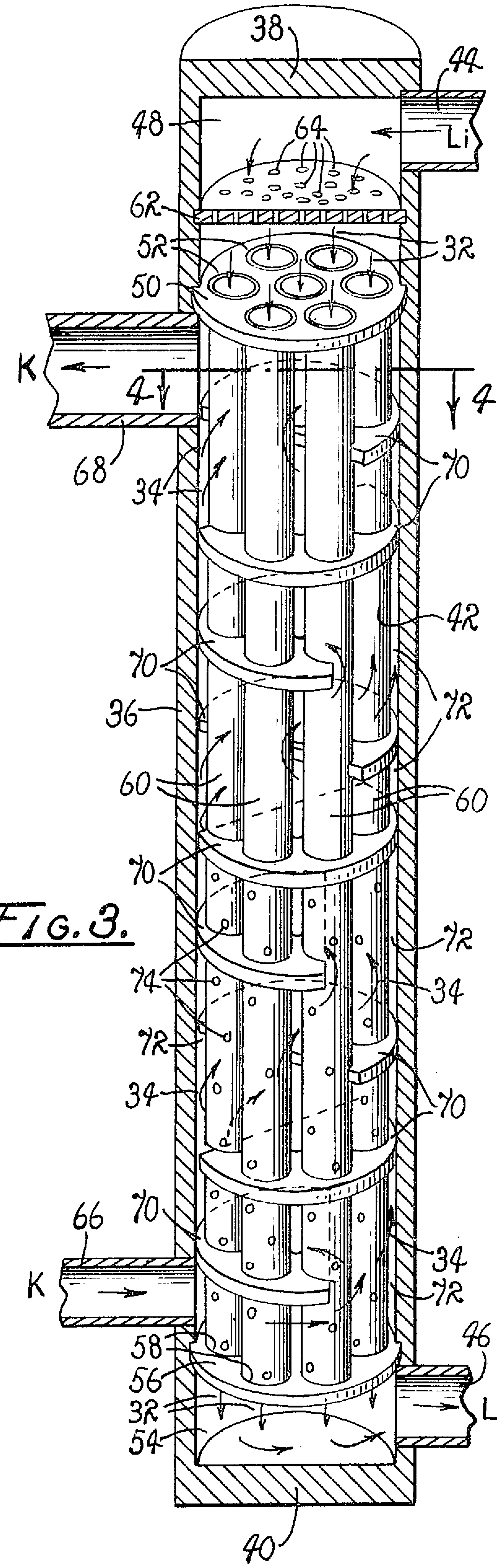

FIG. 3.

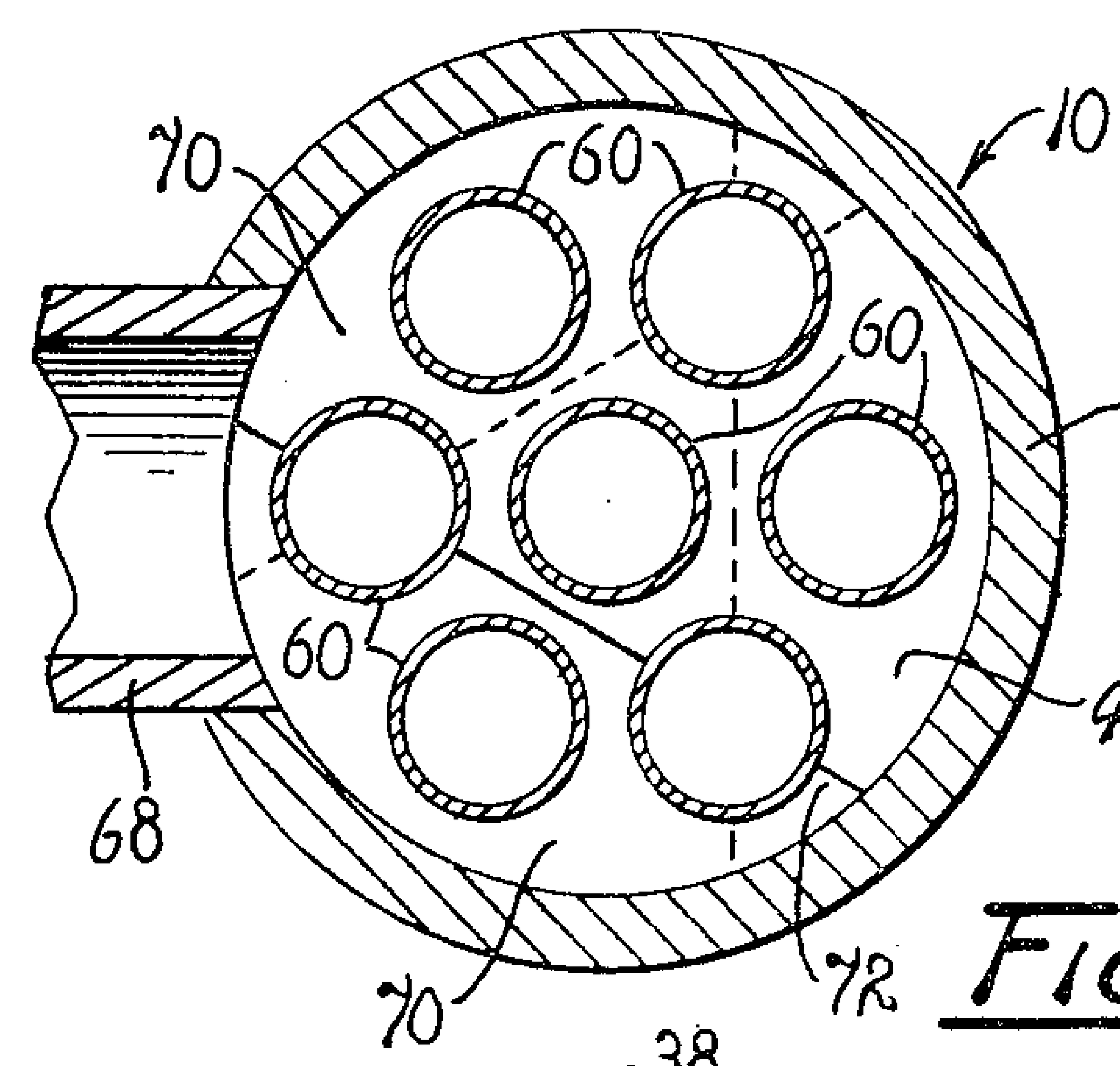

FIG. 4.

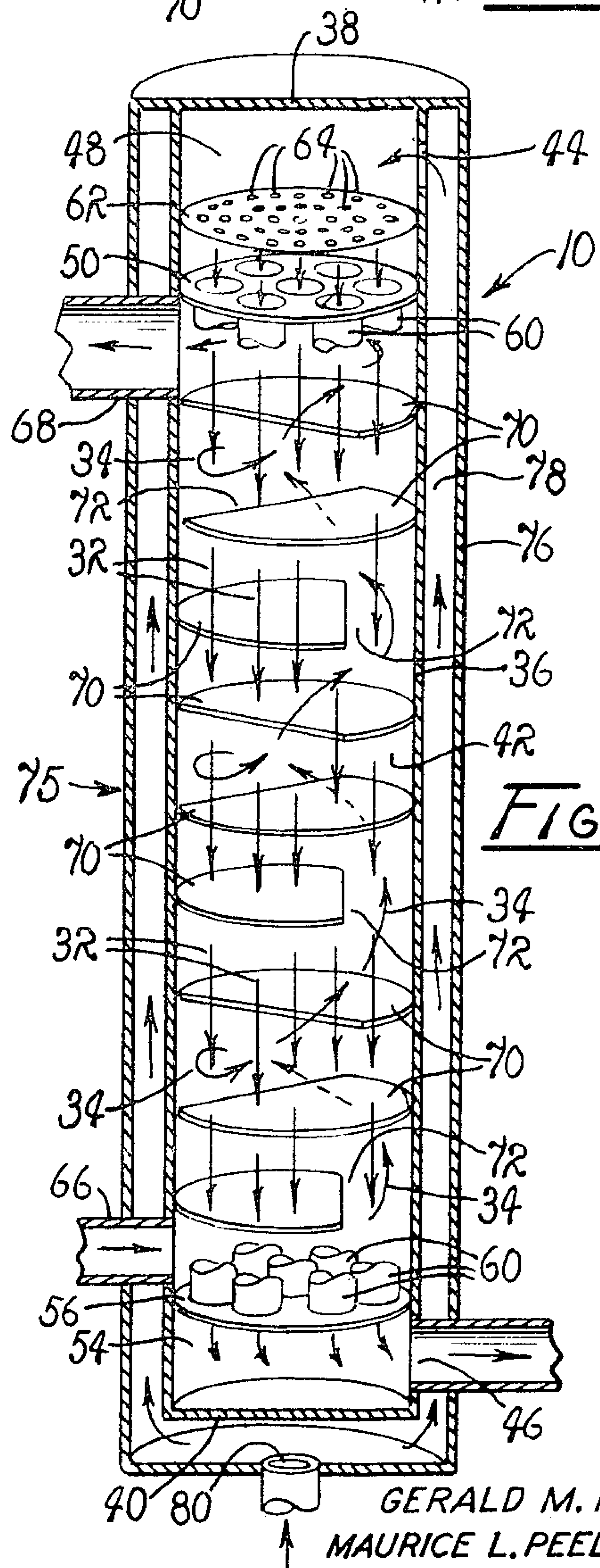

FIG. 5.

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SHELL-SIDE LIQUID METAL BOILER

ORIGIN OF INVENTION

The invention described herein was made in the performance of work under a NASA contract and is subject to the provisions of Section 305 of the National Aeronautics and Space Act of 1958, Public Law 85-568 (72 stat. 435; 42 USC 2457).

BACKGROUND OF THE INVENTION

1. Field of the Invention

The field of the invention relates to liquid metal boilers and more particularly to boilers employed in heating liquid metals for use in generating electrical power within Rankine cycle systems.

2. Description of the Prior Art

Energy conversion systems are notoriously old. However, where electrical energy is obtained through a thermal energy conversion system it has been found that about 50 percent to 80 percent of the available heat must be radiated or rejected. Liquid metal radiators provide radiation and rejection of energy at high temperatures of operation. Liquid metal boilers are deemed to be particularly useful in Rankine cycle systems and are suited for use with nuclear reactors. However, liquid metal boilers heretofore available have not totally satisfied existing needs.

The prior art includes liquid metal boilers wherein a plurality of parallel tubes serve as conduits for conducting liquid metals along parallel paths through a heat transfer zone of a heat exchanger so that heat is transferred to the liquid metal as the metal flows through the tubes for thereby converting the liquid metal to its vapor state. Such boilers inherently lack the capability of providing a 100 percent pure vapor, free from surged and splashed liquid and liquid spray.

In employing metal boilers of the prior art variety, wherein the metal is heated as it is delivered through parallel tubes for conduits, total vaporization of metals is quite difficult to achieve, as such requires that the liquid remain in contact with the walls of the heated conduits. This, of course, requires the liquid to be delivered in streams of a tubular configuration having a vapor core. As a practical matter such delivery cannot be achieved. Furthermore, where the metal is confined as a mixture of vapor and liquid "slugging" invariably occurs, since the vapor tends to force "slugs" of liquid through the conduits.

Another difficulty often encountered in employing parallel conduits for delivering liquid metals through a heat transfer zone of a heat exchanger is system instability which arises as a result of the fact that different rates of vaporization simultaneously occurs within the several conduits.

Therefore, even though nuclear reactors constitute ideal sources of energy for Rankine cycle systems there exists a need for a practical boiler to boil liquid metals with a high degree of efficiency and predictability. This is particularly true where such systems are employed aboard space craft for use in space flight operations of an extended duration.

OBJECTS AND SUMMARY OF THE INVENTION

It is therefore an object of the instant invention to provide an improved liquid metal boiler which employs a tube and shell heat exchanger having a high degree of operational stability.

Another object is to provide an improved metal boiler particularly suited for use in imposing a change of phase on liquid alkali metals for achieving metal vapors through shell-side boiling.

Another object is to provide an improved liquid metal boiler which is adapted to impose a change of phase on alkali metals with a high degree of predictability.

Another object is to provide an improved liquid metal boiler which is adapted to achieve shell-side boiling of potassium.

Another object is to provide an improved liquid metal boiler for converting cooled liquid potassium to a heated vapor by achieving a heat exchange between liquid lithium and the potassium as the potassium is caused to circulate about tubular conduits employed in delivering heated lithium through the boiler.

Another object is to provide an improved shell-side liquid metal boiler adapted to conduct a heated primary fluid through a plurality of spaced, tubular conduits, and to deliver a secondary fluid along a tortuous path having both crossflow and spiral-flow path components extending about the conduits so that a change of phase is imposed on the secondary fluid as it progresses through the boiler.

Another object is to provide an improved liquid metal boiler for converting liquid alkali metal to heated vapor by achieving a heat exchange between liquid metals through conduction, as the alkali metal is caused to circulate about tubular conduits employed in delivering a heated fluid therethrough, whereby a heat exchange through conduction is achieved.

Another object is to provide within a liquid metal shell-side boiler a plurality of substantially parallel baffle plates for directing liquid potassium along a tortuous path having both crossflow and spiral-flow path components circumscribing a heat delivery system including a bundle of substantially parallel, spaced tubular conduits through which heated liquid lithium is delivered in order that the lithium be permitted to give up relatively large quantities of heat to the potassium for achieving a heat exchange therebetween, whereby the potassium is caused to undergo a change of phase from a liquid to a vapor having a high exit quality extending into vapor superheat.

These and other objects and advantages of the instant invention are achieved by providing a liquid metal boiler having a shell of a tubular configuration circumscribing a plurality of axially extended, lithium conducting conduits and baffle plates arranged within the shell in a manner such that circulation of liquid potassium about the conduits is achieved to effect shell-side boiling of the potassium as it is caused to progress along a tortuous path, having both spiral and crossflow path components extending between the adjacent surfaces of the conduits and the boiler shell.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a diagrammatic view of the system embodying the shell-side liquid metal boiler of the instant invention.

FIG. 2 is a flow diagram depicting the path of flow for primary and secondary fluids as the fluids are caused to flow along adjacent paths through the boiler illustrated in FIG. 1.

FIG. 3 is a cross-sectional elevation of the boiler shown in FIG. 1, illustrating the relationship established between the conduits utilized in conducting a primary fluid through the boiler and the baffle plates employed in delivering a secondary fluid along a tortuous path having both crossflow and spiral-flow path components and extending about the conduits.

FIG. 4 is a cross-sectional view taken generally along line 4—4 of FIG. 3.

FIG. 5 is a cross-sectional elevation of a modified form of the boiler shown in FIG. 1.

DESCRIPTION OF THE PREFERRED EMBODIMENT

Turning to FIG. 1, therein is illustrated a shell-side liquid metal boiler **10** operatively disposed within Rankine cycle power system. As shown, the system includes a primary loop **12** and a secondary loop **14**. The primary loop is adapted to deliver heated liquid lithium to the boiler **10** for purposes of achieving a transfer of heat while the secondary loop **14** is adapted to deliver liquified potassium, which absorbs heat from the lithium of the primary loop, and to conduct heat from the boiler **10** as a discharge of vaporized potassium occurs.

Since Rankine cycle power systems are known, and lithium-potassium boiler systems have heretofore been employed in such systems, a detailed description thereof is omitted in the interest of brevity. However, it is to be understood that the primary loop 12 is a substantially closed-loop which includes a heat generator 16 of a suitable configuration, such as a nuclear reactor, adapted to elevate the temperature of a primary fluid, such as liquid lithium, to a working temperature of approximately 2,100° F., while the secondary loop 14 is a substantially closed-loop which is utilized to deliver a cooled secondary fluid, such as potassium, to the boiler 10 for purposes of achieving a heat exchange between the metals, whereupon the secondary fluid is converted to a vapor and delivered from the boiler 10 at an exit temperature of approximately 1,900° F.

At the output side of the heat generator 16 there is provided a pump 18 which serves to impel the primary fluid through the loop. The pump 18 is of a suitable design which, as a practical matter, may be a centrifugal unit driven by a variable speed DC motor, not shown. At the output side of the pump 18, between the pump and the boiler 10, there is a flowmeter 20 which, where desired, is employed in detecting and controlling the rates of flow for liquid lithium flowing through the loop 12.

As depicted, the secondary loop 14 includes therein a turbine 22 directly connected with the output of the boiler 10 so that it is driven by the secondary fluid as the fluid is circulated within the loop. In practice, the turbine 22 is employed in driving an electrical energy generating device, such as, for example, a three-phase, 200 cycle induction generator.

At the hydraulic output side of the turbine 22, there is connected a condenser 24 which is employed in extracting heat from the secondary fluid, as it egresses from the turbine 22, to impose a phase change for reverting the secondary fluid to its liquid phase in order that flow control be enhanced. From the condenser the cooled secondary fluid is delivered to a suitable pump 26 which serves to impart to the secondary fluid a given flow rate. At the output side of the pump 26, between the pump and the boiler 10, there is a preheater 28 which serves to elevate the temperature of the secondary fluid to preselected values prior to its being delivered to the boiler 10. As a practical matter, the loop 14 also includes a flow meter 30 adapted to be employed in controlling the flow of a secondary fluid through the secondary loop as it is delivered from the pump to the boiler 10.

As best illustrated in FIG. 2, the primary fluid is delivered through the boiler 10 along substantially parallel paths, designated by parallel arrows 32, while the secondary fluid is delivered along a tortuous path including both crossflow and spiral-flow path components, as indicated by the arrows 34. By employing both spiral-flow and crossflow path components, an efficient heat transfer is achieved within the boiler as the primary fluid is caused to give up its heat to the secondary fluid so that a high exit vapor heat is achieved as the secondary fluid is discharged from the boiler 10.

In order to achieve the flows indicated by the arrows 32 and 34, the boiler 10 also includes a tubular shell 36 sealed at opposite ends by a pair of spaced end plates 38 and 40. Consequently, within the shell there is established a substantially sealed boiler chamber 42, FIG. 3. The boiler chamber thus established is provided with a primary fluid delivery port 44, which serves to introduce to the chamber heated, liquid lithium, and a primary fluid discharge port 46, which serves to discharge the lithium from the boiler chamber 42, once a heat exchange has been achieved between the primary and secondary fluids.

Adjacent to the delivery port 44 there is an entry plenum chamber 48 defined by a transverse plate 50 spaced inwardly from the plate 38. The plate 50 is provided with a plurality of openings 52 disposed at equidistances throughout the plate and extends therethrough for accommodating passage of the primary fluid so that the chamber 48 functions as an input manifold.

Adjacent to the discharge port 46 there is provided an exit plenum chamber 54 defined by a transverse plate 56 spaced from the end plate 40. This includes a plurality of openings 58 arranged in coaxial alignment with the openings 52 of the plate 50 so that the chamber 54 is caused to serve as a discharge manifold.

Between the plates 50 and 56 there is extended a plurality of tubular conduits 60 disposed in substantial parallelism with the opposite ends of each being inserted in the coaxial openings 52 and 58 of the plates 50 and 56, respectively, so that the entry plenum chamber 48 is caused to communicate with the exit plenum chamber 54 through the conduits 60. It will therefore be appreciated that a flow of primary fluid is, in operation, established between the entry and exit plenum chambers as it is introduced through the port 44. Within the plenum chamber 48 there is arranged a plate 62 including therein a myriad of relatively small openings 64 defining parallel fluid passages which tend to reduce turbulence within the flow of the primary fluid, prior to its delivery to the tubular conduits 60 in order that turbulence within the flow be reduced prior to the delivery of the primary fluid through the tubular conduits 60.

In communication with the chamber 42, between the plates 50 and 56, there is a secondary fluid delivery port 66 and a secondary fluid discharge port 68 by which the secondary fluid is delivered to and extracted from the boiler chamber 42 of the boiler 10. It is important here to note that the secondary fluid is confined by the shell 36 as it progresses through the boiler chamber 42, and that the primary fluid is confined by the tubular conduits 60 axially extended through the chamber 42. By employing this arrangement, shell-side boiling for the secondary fluid is achieved whereby system stability is greatly enhanced.

As it is desirable to achieve efficient heat transfer, in order that a high exit vapor quality predictably be achieved, there is provided a plurality of baffle plates 70 which impose direction control on the flow of the secondary fluid as the secondary fluid flows through the boiler chamber 42. Each of the baffle plates 70 is of a generally disk-shaped configuration having a portion severed along a predetermined chord so that the periphery of each of the plates defines a truncated circle. As a practical matter, the manner in which the peripheral portion of the baffle plate is removed is a manner of convenience and the extent thereof is dictated by the flow rate to be imposed on the system. In any event, it is to be understood that the truncated portions of the plates 70 and the internal surface of the shell 36 establish a plurality of passageways 72 accommodating a desired flow rate for the secondary fluid as it flows through the chamber 42.

The plates 70 are so arranged within the shell 36 that the passageways 72 are angularly displaced by 120° for thereby defining a tortuous path helically extended through the boiler chamber 42, including both crossflow and spiral-flow path components. Hence, as the secondary fluid is introduced through the delivery port 66 it is conducted about the conduits 60 along a helical path of progression extending from the secondary fluid delivery port 66 to the secondary fluid discharge port 68. Consequently, the fluid is caused to be delivered into engagement with the external surfaces of the tubular conduits 60 for thereby achieving a heat exchange between the primary and the secondary fluids as they progress in substantially opposite directions through the boiler chamber 42.

In practice, each of the tubes 60 further is provided with a plurality of minute nucleation cavities 74 formed along the surface of the tubes in order to initiate nucleate boiling of the secondary fluid as it progresses through the boiler chamber 42 and experiences shell-side boiling.

Of course the material employed in fabricating the boiler 10 is dictated by the types of primary and secondary fluids utilized and the operative temperatures encountered during the operation of the system. In practice, where the boiler 10 is to be employed in a lithium-potassium system, the components and piping are of a material such as niobium wrapped with layers of zirconium and tantalum. Therefore, the technique employed in joining the various components is a matter of convenience dictated by the particular metals being employed.

The boiler 10 has been employed with a 30-kw. Rankine cycle system such as that shown in FIG. 1. In such a system, the heat generator **16** serves to elevate the temperature of the primary fluid, or lithium, sufficiently for heating the secondary fluid, or potassium, to a superheated vapor state for driving a turbogenerator. As a practical matter, the temperatures to which the lithium operatively is heated by the generator **16** approximates 2,100° F., while the working temperature of the secondary fluid, as it exits the boiler **10**, is approximately 1,900° F. When employing the boiler **10** with a Rankine cycle system it has been found possible to achieve approximately 100 percent boiler exit vapor quality and heat transfer rates of greater than 3,000 B.t.u/hr.-ft.^{2}-° F. at flow rates of 4–8 lb./sec.-ft^2.

In instances where it is found desirable to accelerate the heating of the secondary fluid by applying heat to the external walls of the shell **36**, a modified boiler **75** may be employed. As illustrated in FIG. **5**, the shell **36**, of the boiler **75** is circumscribed by a secondary jacket **76** which serves to define a cylindrical chamber **78** surrounding the external surfaces of the shell **36** while an additional primary fluid injection port **80** is provided at a location such that the primary fluid is caused to progress along the external surfaces of the shell **36**, prior to being delivered through the delivery port **44** into the plenum chamber **48**.

OPERATION

The operation of the described embodiment of the subject invention is believed to be clearly apparent and is briefly summarized at this point. With the boiler **10** coupled within a Rankine cycle system, of the type illustrated in FIG. **1**, the heat generator **16** is activated for elevating the temperature of the primary fluid as it exits the boiler **10**. The heater **16**, in effect, serves as a means for replenishing the heat given up or lost to the secondary fluid as the fluids are circulated through the boiler **10**. Upon exiting the heat generator **16**, the heated primary fluid is impelled by the pump **18** on a return flow to the conduits **60** within boiler chamber **42**. As a practical matter, the pump **18** delivers the lithium through the flow meter **20** and is adjustable for imposing selected flow rates upon the system. As the lithium is delivered through the flow meter **20** it is caused to be delivered to the entry plenum chamber **48**, and thence to the tubular conduits **60**, via the plate **62**, which serves to inhibit turbulence as the direction of flow for the fluid is altered. As the lithium progresses through the conduits **60**, heat is extracted therefrom and conducted by the walls of the conduits thus tending to cool or reduce the temperature of the lithium. In order that the lithium be returned for reheating within the generator **16**, it is delivered from the conduits **60** into the exit plenum chamber **54** and thence through the port **46** for recycling.

Simultaneously, with the circulation of the primary fluid, the secondary fluid, or liquid potassium, is delivered as a liquid at approximately 600° F. from the preheater **28**, through the secondary fluid delivery port **66** and into the boiler chamber **42** in a manner such that it is caused to contact the external surfaces of the tubular conduits **60**. As the secondary fluid is brought into contact with the external surfaces of the conduits, it is heated, by extracting heat from the walls of the conduits **60**. As sufficient quantities of heat are extracted from the conduits a phase change is imposed upon the secondary fluid for thus causing the liquid to be converted to a vapor as it progresses along the tortuous path defined by the passageways **72**. As the passageways **72** are angularly related, the path followed by the secondary fluid includes both cross-flow and spiral-flow path components which cause the fluid to pass across the surfaces of the tubular conduits **60** at right angles thereto, as well as to experience helical progression. As the secondary fluid progresses through the chamber **42**, the nucleate cavities **74** initiate nucleate boiling of the fluid, so that at exit the temperature of the thus vaporized potassium is approximately 1,900° F. From the boiler **10** the fluid is delivered as a vapor to the turbine and ultimately returned to the preheater through the condenser **24** and pump **28**.

Where a secondary jacket **76** is employed in delivering heat externally through the wall of the shell **36**, the primary fluid also is delivered through the conduit **80** and caused to circulate about the shell **36** as it progresses towards the delivery port **44**. Consequently, the temperature of the secondary fluid is elevated by heat delivered through the walls of the conduits **60**, as well as by heat delivered through the wall of the shell **36**.

Although the invention has been herein shown and described in what is conceived to be the most practical and preferred embodiment, it is recognized that departures may be made therefrom within the scope of the invention, which is not to be be limited to the illustrative details disclosed.

What is claimed is:

1. A shell-side metal boiler comprising:

A. a sealed shell defining therewithin a first chamber of a substantially cylindrical configuration;

B. a plurality of tubular conduits mounted in said first chamber in parallelism with the longitudinal axis thereof for delivering a heated primary fluid therethrough;

C. means defining a secondary fluid delivery port within one end portion of said shell for introducing a secondary fluid into said first chamber;

D. means defining a secondary fluid discharge port within the opposite end portion of said shell for discharging the secondary fluid from the first chamber;

E. means including a plurality of angularly related and longitudinally spaced baffle plates transversely seated in said first chamber defining a helical path extending between said end portions of said shell for conducting the secondary fluid through said first chamber from said secondary fluid delivery port to said secondary fluid discharge port;

F. means defining within said opposite end portion of said shell an entry plenum chamber communicating with the conduits for delivering said primary fluid to said conduits;

G. means defining an exit plenum chamber within said one end portion of said shell communicating with the conduits for receiving said primary fluid from said conduits;

H. a substantially sealed jacket of a cylindrical configuration spaced from the external surface of said shell and concentrically related thereto defining therebetween a second chamber concentrically related to said first chamber;

I. means defining within said sealed jacket, adjacent said one end portion of said shell, a primary fluid delivery port for delivering primary fluid to said second chamber; and

J. means defining within said opposite end portion of the shell a primary fluid discharge port extending between said second chamber and said entry plenum chamber, whereby the primary fluid delivered to said second chamber is discharged into said entry plenum chamber.

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