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[54] **VERTICAL DRUM WATER TUBE WASTE HEAT RECOVERY BOILER**
17 Claims, 5 Drawing Figs.

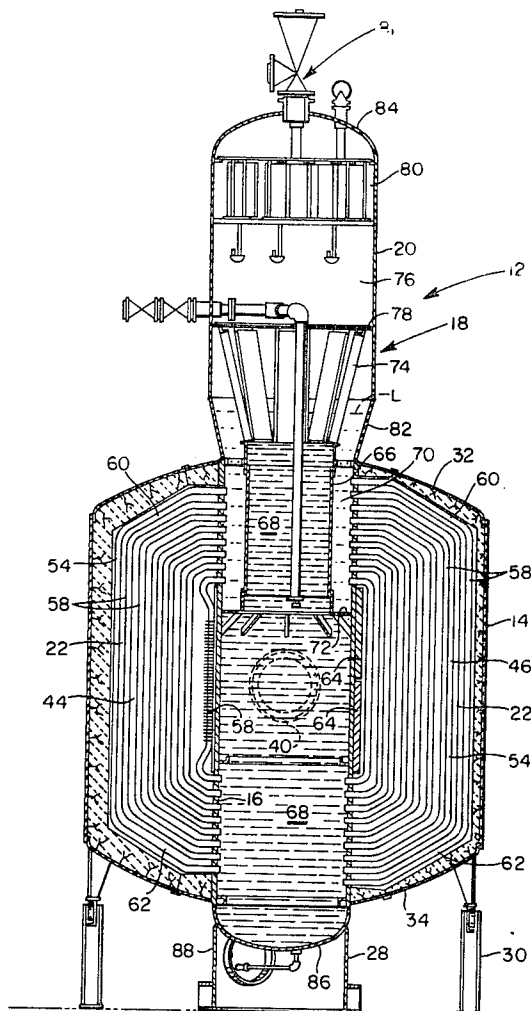
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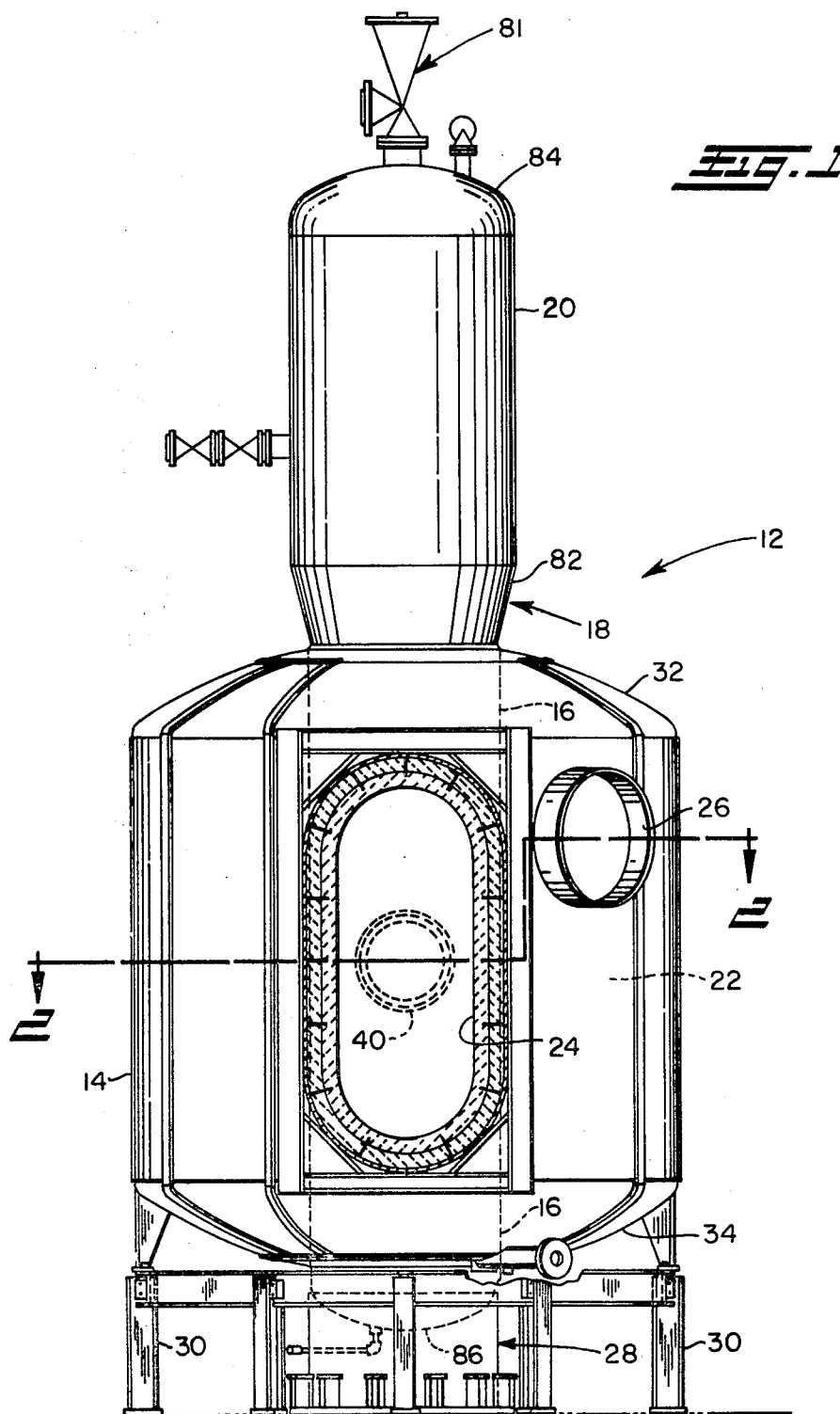
ABSTRACT: A shop assembled waste heat recovery boiler in which water tubes are subjected to a hot process gas flow. The tubes are vertically oriented and arranged in an annular gas passage encompassing a relatively large diameter vertically oriented cylindrical drum to which the tubes are connected. The drum is baffled to provide a riser space and a relatively large diameter downcomer for efficient natural circulation, and the type of tube surface in the gas passage is varied around the periphery of the drum to provide for optimum heat pickup. An enlarged diameter section of the drum extends above the elevation of the gas passage casing and constitutes the vapor space for the drum, and also a means for obtaining high quality steam. The boiler is characterized as being economical in construction, reliable, and adaptable in design to different applications.



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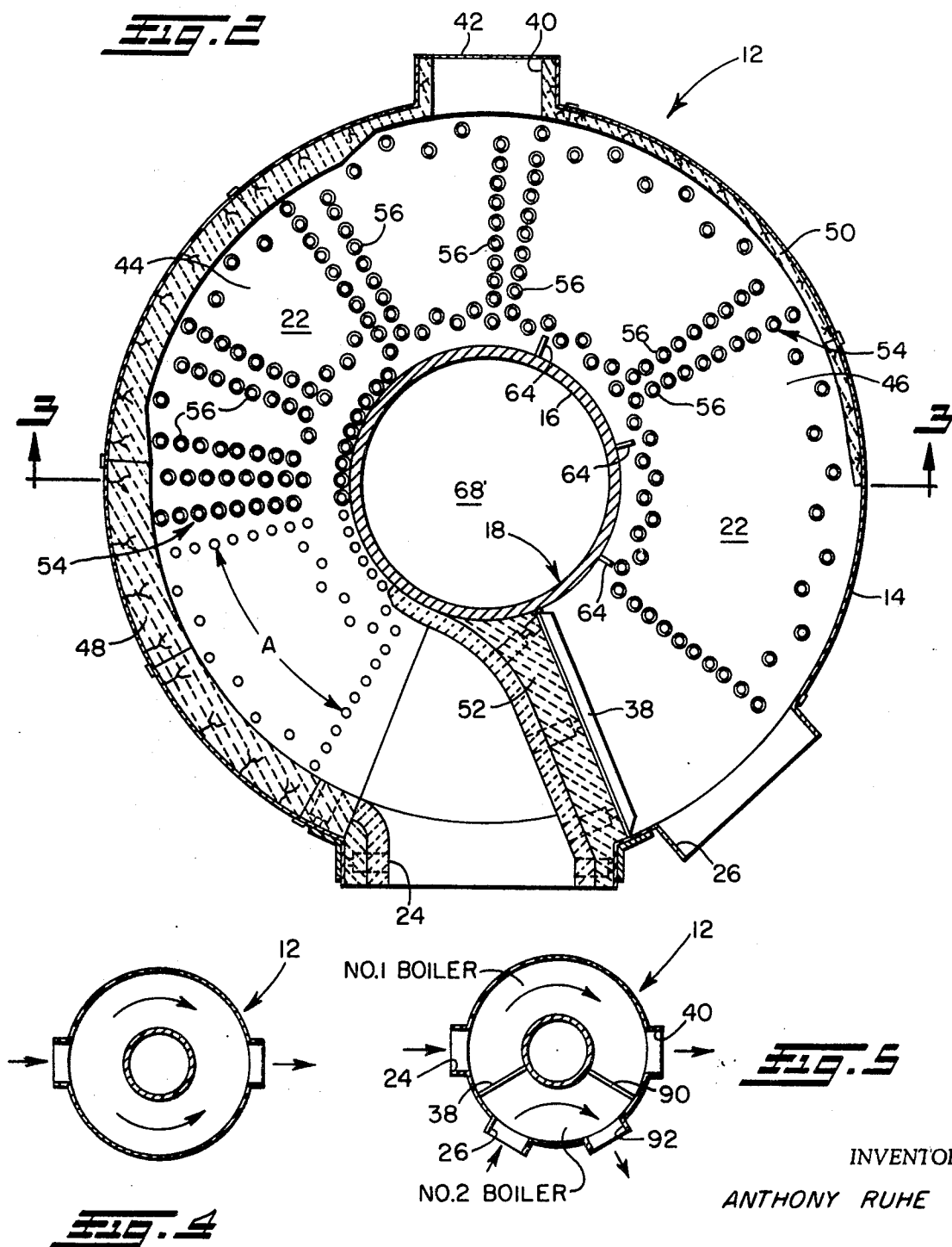
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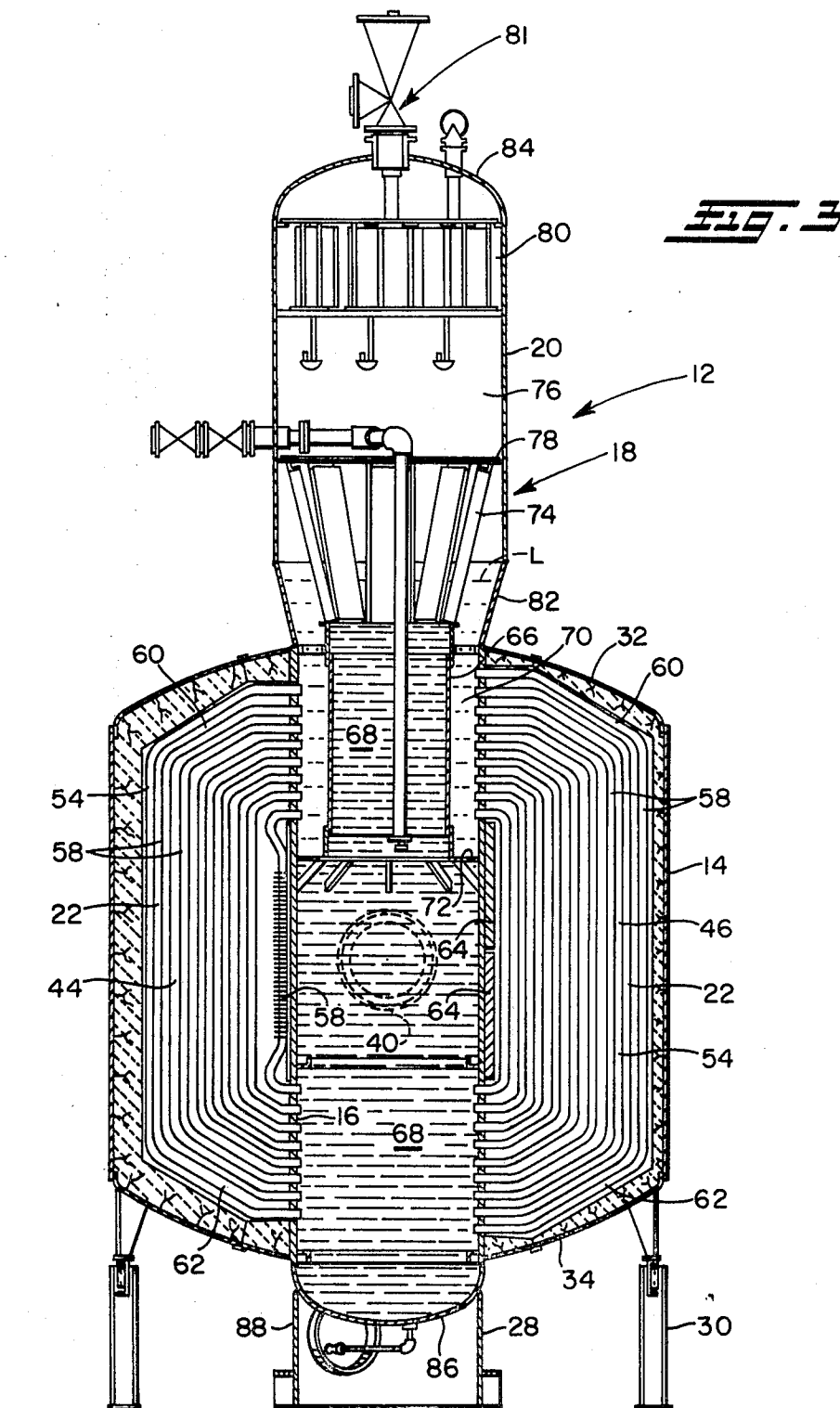


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VERTICAL DRUM WATER TUBE WASTE HEAT RECOVERY BOILER

The present invention relates to waste heat recovery boilers, and more particularly to such boilers of the water tube type. The invention is particularly applicable to the recovery of heat from high-temperature sulfur recovery gases produced by the combustion of hydrogen sulfide to produce elemental sulfur, and will be described with particular reference thereto, although it will be appreciated that the invention has other applications.

Large refineries produce great quantities of hydrogen sulfide, and its recovery as elemental sulfur is frequently justified. This is accomplished in the so-called "Claus" process by the combustion of a portion of the hydrogen sulfide and interaction with sulfur dioxide. The resulting product which includes water vapor and elemental sulfur is, as a result of the combustion, at a high temperature in the order of 2,200° to 2,500° F. It is desired to substantially cool the gas down to a temperature above that of sulfur condensation for the purpose of recovering the heat therein, and prior waste heat boilers for such service, usually of the fire tube type, have conventionally been plagued with such problems as tube burnout, stress cracking and/or sulfiding of joints, and other problems. Such boilers have also been relatively expensive in the past when high-steam pressures are required.

Accordingly, it is an object of the present invention to provide an improved waste heat recovery boiler which is relatively economical in construction, and in particular a boiler of the water tube type which is compact and which readily can be shop assembled and shipped as an integral unit.

It is also an object of the present invention to provide an improved waste heat recovery boiler of the natural circulation, water tube type in which the circulation rate on the steaming side of the boiler is high to avoid tube burnout and stress cracking of welds.

It is further an object of the present invention to provide such a boiler in which a gas flow under pressure and at a high temperature can be accommodated without the need of buckstays and other such support structure.

It is also an object of the present invention to provide a waste heat boiler in which relatively high-steam pressures can be developed, and in which high quality steam can be obtained.

To the accomplishment of the foregoing and related ends, the invention, then, comprises the features hereinafter fully described, the following description and the annexed drawings setting forth in detail a certain illustrative embodiment of the invention, this being indicative, however, of but one of the various ways in which the principles of the invention may be employed.

In such annexed drawings:

FIG. 1 is an elevation view of a waste heat boiler in accordance with the concepts of the present invention;

FIG. 2 is a plan section view taken along line 2—2 of FIG. 1;

FIG. 3 is an elevation section view taken along line 3—3 of FIG. 2; and

FIGS. 4 and 5 illustrate variations in accordance with the invention.

Referring to FIG. 1, the waste heat boiler 12 comprises an annular generally cylindrical shell 14. The shell 14 encompasses a generally cylindrical section 16 (shown in dashed lines) of a vertically oriented drum 18, the section 16 being generally concentric with the shell 14. The drum 18 has an upwardly protruding cylindrical section 20 extending a substantial distance above the elevation of the shell 14, and which is larger in diameter than the section 16. An annular gas passage 22 is provided by and intermediate the section 16 of the drum and the shell 14, the passage having a relatively large gas inlet 24 on one side of the shell, and a smaller gas outlet 26 which is situated next to the inlet but separated from the inlet in a manner to be described.

The boiler is designed for shop fabrication, and is provided at the bottom with an inner center support 28 primarily for the drum 18 and steaming components of the boiler, and a plurali-

ty of outer annular support members 30 primarily for the shell 14. Typical dimensions for the boiler are about a height of 30 feet from the ground level to the top of the boiler, and a width of about 13 feet plus or minus for the shell 14, although it is a feature of the invention that a shop assembled boiler of much larger dimensions can be constructed and shipped as an integral unit.

The boiler is adapted to receive hot gases from a source, which gases, in the case of a sulfur recovery or similar unit, are in the nature of about 2,200° to about 2,500° F. The gases may be under some pressure, for instance a pressure of about 10 p.s.i.g. In the case of gases from a sulfur recovery unit, it is desired to cool them to a temperature of about 550° F., plus or minus, which is above the condensation point of sulfur, but sufficiently low to remove a substantial amount of the heat from the gas flow.

To accomplish the above, the gas passage 22, shown in FIGS. 2 and 3, is annular extending from the inlet 24 of the casing to the outlet 26 around the periphery of the drum 18. In cross section, referring to FIG. 3, the passage is greater in height than in width. In addition to the surface of the drum 18 and the shell 14, the passage is defined on its upper and lower sides by upper and lower semispherical dished ends 32 and 34 welded between the shell 14 and the outer surface of the drum 18. It is a feature of the invention that the cylindrical surface of the shell 14 and semispherical surface of the dished ends are capable of withstanding the pressures of gases within the passageway without the need of buckstays and similar supporting structure.

The gas inlet 24 has substantially the same dimensions as the passageway 22 (notice FIGS. 1 and 2), thus being substantially greater in height than in width. The purpose of the large inlet opening is to accommodate the expanded high-temperature gas flow. The outlet 26 is circular in shape, and is much smaller in cross-sectional area than the inlet, being of that area necessary to accommodate the smaller volume of the lower temperature gas flow at this point. Between the inlet and outlet there is provided a baffle 38 which separates the two openings and establishes the flow path for the gases in the boiler.

On the side of the boiler opposite the gas inlet 24, the boiler has a small circular gas bypass opening 40, FIG. 2. By means of a butterfly valve 42 positioned in the bypass opening, or other similar mechanism, a portion of the gas flow in the passageway can be allowed to divert through the bypass opening, or all or a greater portion of the gas flow can be caused to traverse the full length of the passageway to the gas outlet 26. The purpose of the bypass opening is to provide an intermediate temperature gas flow for certain process applications. In addition, the bypass opening provides a means for carefully adjusting performance of the boiler as is required on some processes.

It is an important feature of the invention, that depending upon the process gas involved, and particular installation, the bypass opening can be positioned elsewhere around the periphery of the shell 14 rather than diametrically opposite the gas inlet 24. If it is desired to tap a higher temperature gas from the gas flow, the bypass opening would be located closer to the gas inlet, the design of the present invention offering substantial flexibility in this respect.

The gas passage 22 can be considered as having a relatively high-temperature zone 44 extending almost up to the bypass opening, and intermediate and lower temperature zones 46 thereafter. The shell 14 in the area of the gas inlet and high-temperature zone is lined with a substantial thickness of refractory 48, diminishing in thickness in the area 50 extending into the intermediate and lower temperature zones 46. The baffle 38 between the gas inlet 24 and gas outlet 26, and section 16 of the drum 18 in the area of the gas inlet are also lined with a substantial thickness of refractory 52.

The steaming side of the boiler comprises, in addition to the drum 18, a tube bank 54 positioned in the gas passage 22. The bank consists of a number of side-by-side radial rows 56 of

tubes (FIG. 2), the rows emanating from close to the surface of the drum 18 and extending outwardly to close to the surface of the refractory 48, 50. The tubes in the rows are spaced apart, and with reference to FIG. 3, are comprised of a vertically oriented intermediate straight section 58 and bent ends 60 and 62 connected to the drum section 16 at spaced elevations on the side of the drum. Each tube in each row 56, except for the outermost tube which is against or adjacent the refractory 48, 50, is nested inside of an adjacent outer tube, so that, approaching from the outside in, the tubes are of progressively shorter lengths, with the innermost tubes being of the shortest length.

In the high-temperature zone 44 of the gas passage, the innermost tubes of each row are provided with very sharp upper and lower bends so that the straight sections 58 of the tubes rest against or are adjacent to the outer surface of the drum section 16 (FIG. 3). This provides effective cooling of the surface of the drum in the hot gas zone, and avoids the need for extending the refractory 52 substantially beyond the inlet 24 of the gas passage.

In the area of the gas bypass opening 40 and towards the gas outlet, it is no longer necessary to protect the drum, since the gases have been substantially cooled in this area, and accordingly, the straight center sections of the innermost tubes are removed or spaced from the surface of the drum to more uniformly fill the flow area in the gas passageway. A plurality of radially extending vertical baffles 64 may be provided on the outside surface of the drum extending a short distance into the gas passage designed to prevent flow along the surface of the drum and direct the total gas flow into the passage area occupied by the tubes.

With reference to FIG. 2, the tubes of adjacent rows are slightly offset circumferentially with respect to each other to define a triangular tube layout or pattern and a plurality of tortuous flow paths within the gas passage. In the very hot area adjacent the gas inlet 24, and indicated by the letter "A," comprising the first eight rows of tubes, the tubes are bare whereas for the remainder of the gas passage, the tubes are finned or provided with extended surface. For purpose of clarity in FIG. 3, only one tube is shown as finned, although all of the tubes illustrated would be finned. Generally, the use of the extended surface or fins would be limited to the center sections of the tubes. The extended surface or fins increase the heat transfer into the tubes in the areas where the gas temperatures are lowered, and accordingly reduce the amount of tube surface needed. This in turn increases the compactness of the boiler, to the extent that the boiler can be shop assembled and shipped as an integral unit.

The drum lower section 16 which is encompassed by the shell 14 is divided by means of baffle 66 into downcomer liquid space 68 and an annular vapor-liquid riser area 70. The baffle is cylindrical and spaced from the inner wall of the drum, and by means of platform 72, is positioned at the elevation of the outlet ends of the tube bank 54. The platform 72 essentially seals the riser area from the downcomer liquid space, although it may be provided with a plurality of openings to drain the riser area. The center of the platform 72 is open to permit the downward flow of liquid in the downcomer liquid space. Above the drum baffle 66, a plurality of primary separators 74 are provided, of conventional design, communicating the riser area 70 with the vapor space 76 of the drum section 20. These separators extend between the drum baffle 66 and an inner flange 78 on the inside of the drum section 20 sealing the separators with the inside surface of the drum section 20. The lower ends of the separators are sealed by maintaining the water liquid level "L" in the boiler above the upper edge of the drum baffle 66.

Above the primary separators 74, the drum section 20 contains a plurality of separators 80 of conventional design for steam purification. Vapor outlet 81 is above separators 80.

The cylindrical section 20 of the drum is larger in diameter than the section 16 encompassed by shell 14. The purpose of this is to accommodate the expanded vapor flow, in the drum

section 20, and obtain optimum dryness in the vapor exiting from the drum. A definite relationship exists between velocity flow in the vapor space 76 and dryness in separators 80, and it is found that the greater diameter results in optimum dryness of the vapor. The particular design of the boiler permits use of the larger diameter section 20 defining the vapor space of the boiler with a narrower diameter downcomer area encompassed by the shell 14. The smaller downcomer liquid space is designed to accommodate very high pressures on the steaming side of the boiler with minimum metal thicknesses. As a general rule, the diameter of the downcomer liquid space is the minimum possible without loss of natural circulation efficiency in the boiler. In this latter respect, a downcomer liquid space of large diameter has a low-pressure drop and minimum pressure drop is required for optimum natural circulation flow.

To accommodate high pressures on the steaming side of the boiler, the small and large diameter sections (16 and 20 respectively) of the drum are connected by a frustoconical joint 82, and the upper and lower ends of the drum are capped by spherical or dished surfaces 84 and 86.

The design of the boiler is such that vapor pressures up to 1,000 and 2,000 pounds, or higher, can be accommodated on the steaming side thereof.

In operation, hot gas flow is admitted to the boiler gas inlet and is transmitted through the gas passage to the bypass opening or gas outlet. Heat is supplied to the riser tubes of the tube bank 54 within the gas passage establishing a natural circulation flow in the boiler. In addition to a large downcomer liquid space, and enlarged vapor space, the vertical orientation of the tube sections 58 substantially enhances the natural circulation rate in the boiler. This in turn prevents tube burnout, stress weld cracking and sulfiding, and other problems experienced with prior boilers.

The use of a central downcomer liquid space avoids the extra expense of external downcomer piping and connections therefor.

The supports for the boiler have already been mentioned. As shown in FIG. 3, the center support 28 can be in the form of a simple skirt 88 welded to the dished end 86 of the boiler drum. This skirt supports not only the drum, but also the tube bank for the boiler, and constitutes the primary support for the boiler. The plurality of annular support members 30 support only the shell components and refractory for the boiler.

Advantages of the invention should now be apparent. For one, the tube geometry results in a boiler which is flexible in design adaptable to different applications, and one which is relatively inexpensive. For instance, in the case of heat recovery from sulfur recovery gases, a heat of reaction takes place in the boiler. Employing a tube bank generally at right angles to the direction of gas flow permits adjusting the type of heating surface (that is bare tubes versus extended surface tubing) to temperature conditions in the passage. This in turn permits close prediction of performance, with the result that a more compact unit can be constructed. By avoiding the need of external piping and connections, the boiler can be shop assembled and shipped as an integral unit.

Employing a vertically oriented center drum permits the use of an inexpensive and simple center support for the boiler. Also, the drum need only be of minimum diameter to accommodate high-vapor pressures, although the design permits the use of an enlarged diameter upper section to obtain a high quality steam flow. Employing the drum as the downcomer, along with vertical orientation of the tube bank, results in optimum natural circulation in the boiler for trouble-free use. The smooth circular casing of the gas passage permits the use of gases under pressure, and the layout of the boiler also permits employing a gas bypass opening for further flexibility in design and use. The advantages of a cylindrical casing, employed with an annular gas passage, in addition to being able to withstand higher pressures, are that corners and weldments, subject to stress cracking, are avoided, and the casing is more easily lined with refractory.

Other advantages will be apparent to those skilled in the art.

Instead of directing the gas flow past the greater part of 360° around the drum, the gas outlet could be located diametrically opposite the inlet, as shown in FIG. 4, and the flow could be in two 180° streams around opposite sides of the drum. In this way, essentially the same boiler geometry could be adapted to handle much larger gas flows at reasonable pressure loss.

As still another variation, the boiler geometry can easily be adapted for dual boiler service. For instance, sulfuric acid plants may require No. 1 and No. 2 boilers. The single unit of the present invention can act as both simply by baffling the gas side of the unit to handle two separate gas streams (notice FIG. 5). This would require adding another baffle 90 similar to baffle 38 of FIG. 2 at a point near opening 40 and to the right of the opening. Openings 24 and 26 would constitute separate inlets for the two streams, and opening 40 an outlet for the stream entering opening 24. A second outlet 92 would be provided to the right of the proposed baffle 90 as an outlet for the stream entering opening 26. Again it is apparent that the basic geometry of the invention offers considerable flexibility.

As still a further variation and illustration of the flexibility of the boiler geometry, in accordance with the invention, the gas flow can be vertical, either upward or downward, on the gas side of the boiler. In this case the tubes would be finned with longitudinal fins rather than cross-fins.

The embodiments of the invention in which an exclusive property or privilege is claimed are defined as follows:

1. A waste heat boiler comprising an elongated upright cylindrical boiler drum of relatively large diameter and substantial length;

a cylindrical casing coaxial with the drum spaced from the surface of the drum to define an annular gas passage encompassing the drum;

dished ends for said casing connecting the casing to the drum, the cylindrical configuration for the drum being maintained for the full length thereof between said dished ends;

an array of tubes in said gas passage each including inlet and outlet connections connected to the drum at spaced elevations on the drum;

said tubes along a substantial portion of the lengths thereof being vertically oriented;

longitudinally extending baffle means within the drum at the elevation of the tube outlet connections dividing the drum into an annular riser in communication with the tube outlet connections and a central downcomer; and primary center support means for said boiler directly supporting said drum.

2. A waste heat boiler according to claim 1 further including vapor space means defining an enlarged diameter vapor space above and directly supported by said drum, first separator means between said riser and vapor space, liquid separated from the vapor in said separator means flowing to said central downcomer, said vapor space means being of enlarged diameter to accommodate vapor release therein.

3. A waste heat boiler according to claim 2 wherein the gas passage extends substantially around the periphery of the drum including inlet and outlet openings for the passage, the tubes in the area of the passage adjacent the inlet opening being bare and those in the direction of the outlet opening having extended surfaces.

4. The boiler of claim 3 wherein said tubes substantially fill said gas passage, said tubes being arranged in a plurality of parallel rows which emanate radially from the surface of the drum, shorter length tubes being nested inside of longer length tubes, the connections for the latter being at elevations along the drum further spaced apart than the connections for the shorter length tubes.

5. The boiler of claim 4 wherein said tubes have a generally C-configuration comprising said vertically orientated lengths and bent ends.

6. The boiler of claim 3 wherein said openings are substantially adjacent each other including a baffle extending across the gas passage separating the openings and establishing the annular gas flow.

7. The boiler of claim 6 including a gas bypass opening intermediate the gas inlet and gas outlet openings.

8. The boiler of claim 7 in which the inlet opening has a cross-sectional area similar to the cross-sectional area of the gas passage, the outlet opening being substantially smaller in cross-sectional area.

9. The boiler of claim 2 wherein said vapor space means comprises an upper cylindrical drum connected with and extending axially above said cylindrical boiler drum, said upper cylindrical drum having a diameter larger than the boiler drum.

10. The boiler of claim 2 wherein the innermost tubes in the area of the passage adjacent the gas inlet opening have the vertical lengths thereof contiguous with or adjacent to the outer surface of the drum to effectively cool said surface.

11. The boiler of claim 10 in which said drum and vapor means defining an enlarged diameter vapor space have dished ends to accommodate high steaming pressures.

12. The boiler of claim 1 wherein the primary support means comprises a cylindrical skirt welded to the bottom of the drum.

13. A waste heat boiler comprising an elongated upright generally cylindrical boiler drum of relatively large diameter and substantial length, said drum comprising upper and lower coaxially aligned sections, the upper section being slightly larger in diameter than the lower section;

a generally cylindrical casing coaxial with the drum lower section but spaced therefrom to define an annular gas passage encompassing said lower section;

dished ends for said casing connecting the casing to the drum lower section, the cylindrical configuration for the drum lower section being maintained for the full length thereof between said dished ends;

an array of tubes in said gas passage each being generally C-shaped but having a substantially vertically oriented straight section and including inlet and outlet connections at spaced elevations on the drum lower section, said tubes being arranged in a plurality of approximately parallel rows emanating radially from the drum lower section, shorter length tubes being nested inside of longer length tubes;

spaced-apart inlet and outlet openings for said gas passage arranged for the annular flow of gas in the passage;

a bypass opening intermediate said inlet and outlet openings;

said tubes in the area of passage inlet opening being bare tubes, and in the direction of the outlet opening having extended surfaces;

longitudinally extending baffle means within the drum lower section of the elevation of the two outlet connections dividing the drum lower section into an annular riser in communication with the tube outlet connections and a central downcomer; and

primary center support means for said boiler directly supporting said drum.

14. The boiler of claim 13 wherein the tube pattern defined by the tubes of adjacent rows is triangular.

15. The boiler of claim 14 wherein said upper section defines an enlarged diameter vapor space above and directly supported by said drum lower section, first separator means between said riser and vapor space, liquid separated from the vapor in said separator means flowing to said central downcomer, said upper section being of enlarged diameter to accommodate vapor release therein.

16. The boiler of claim 1 including a gas inlet, a gas outlet spaced from said inlet, the flow in said passage being in two streams from said inlet to the outlet.

17. A waste boiler comprising an upright cylindrical boiler drum of relatively large diameter and substantial length;

a cylindrical casing coaxial with the drum but spaced from the surface of the drum to define annular gas passage means encompassing the drum;

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dished ends for said casing connecting the casing to the drum, the cylindrical configuration for the drum being maintained for the full length thereof between said dished ends;

an array of tubes in said gas passage means each including inlet and outlet connections connected to the drum at spaced elevations on the drum;

said tubes along a substantial portion of the length thereof being vertically oriented;

further including baffle means dividing said gas passage

means into at least two separate gas passes; gas stream inlet and outlet openings for each of said gas passes;

longitudinally extending baffle means within the drum at the elevation of the two outlet connections dividing the drum into an annular riser in communication with the tube outlet connections and a central downcomer; and

primary center support means for said boiler directly supporting said drum.

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