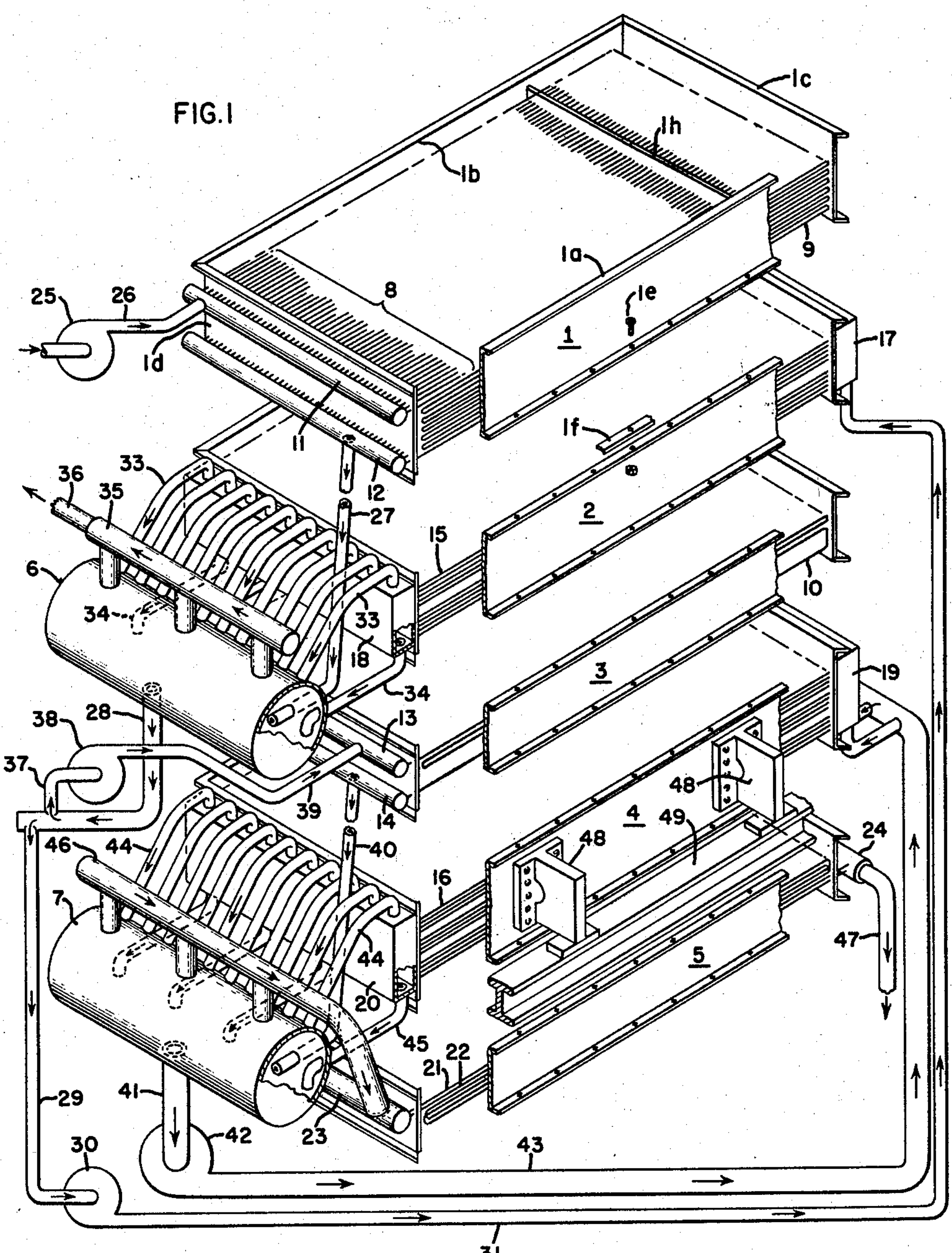
Sept. 8, 1964 H. F. MAY 3,147,742

MULTI-PRESSURE WASTE HEAT BOILER

Filed Dec. 3, 1962 2 Sheets-Sheet 1

FIG. I



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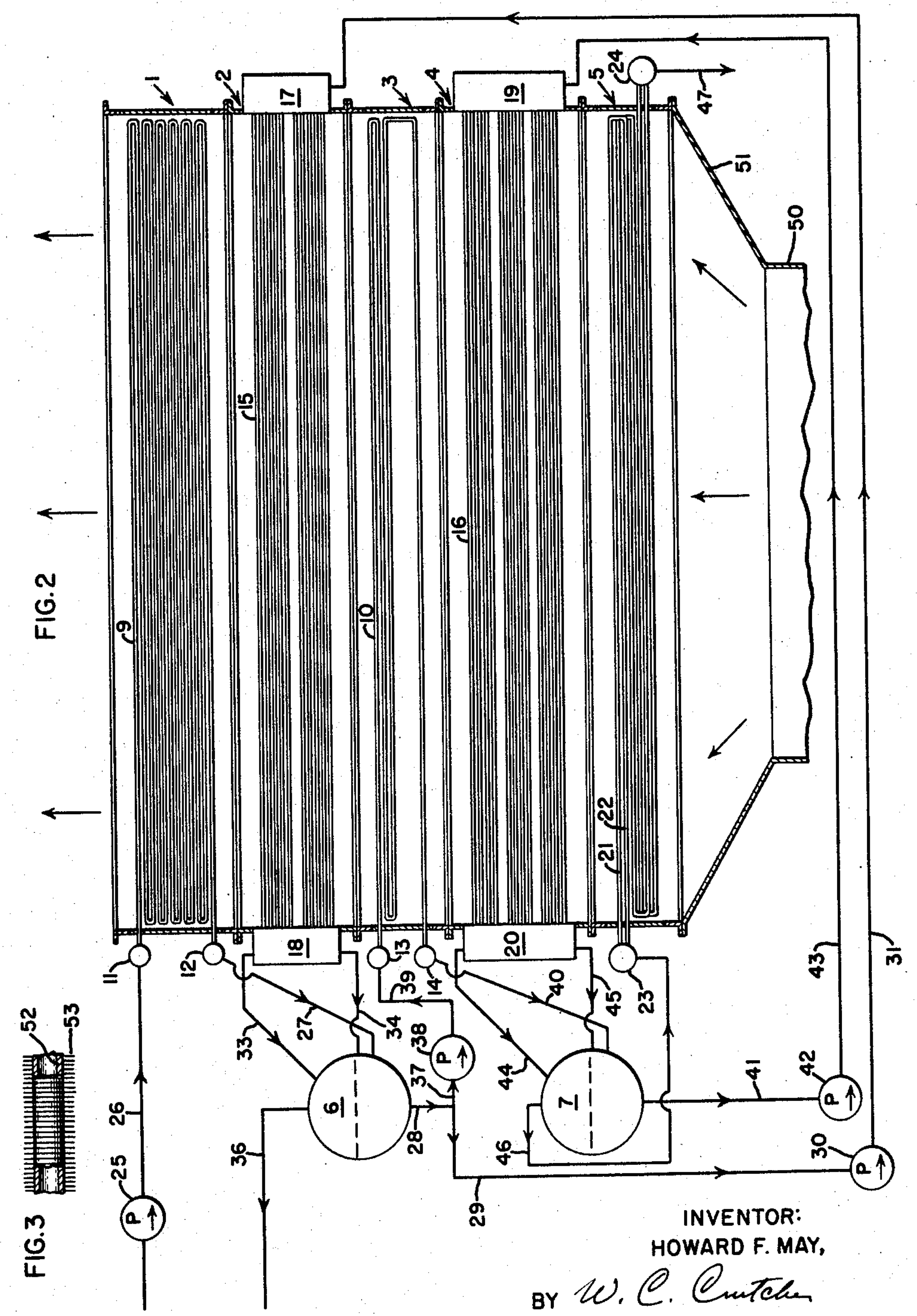

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MULTI-PRESSURE WASTE HEAT BOILER

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6 Claims. (Cl. 122—7)

This invention relates to an improved arrangement for a boiler generating steam at more than one pressure level, preferably from waste heat, such as a gas turbine exhaust or blast furnace operation. More particularly, the invention applies to a waste heat recovery system employing upward flow of exhaust gas through a plurality of compact cooperating units, arranged for minimum interconnecting piping and improved heat transfer.

It is well known that improved thermodynamic cycle efficiency can be achieved by utilizing heat which would otherwise be lost, such as gas turbine exhaust, to generate steam for process use or power generation. It has also been suggested that further improvements can be effected by generating steam at more than one pressure level at progressively lower temperatures. Such an arrangement is disclosed in abandoned application Serial No. 114,718, filed on June 5, 1961, in the name of Robert P. Giblon and assigned to the assignee of the present application, in which improved heat recovery is achieved by disposing a low pressure boiling water heat exchanger in a gas turbine exhaust stack, which generates heat to preheat the feed water passing to a conventional economizer, also located in the stack.

Although most boilers are of the generally vertical "bent tube" type with a high temperature steam drum disposed uppermost in order to utilize the temperature difference to assure circulation, proposals for forced circulation boilers with straight horizontal tubes and recirculating pumps have been advanced for special applications. These have been for steam generation at a single pressure, where the arrangement of drums and connecting piping is not so critical, as it is with multi-pressure units. The problem of working out a practical arrangement for the banks of tubing to provide accessibility, ease of maintenance, and most efficient heat transfer for a multi-pressure waste heat boiler is critical to the economic feasibility of the boiler. Additional factors such as standardization of tubing size, self-contained separate units, and similarity of parts should also be considered.

In order to provide the simplest construction with a minimum of exhaust gas ducting, it is desirable that a waste heat boiler be disposed directly above the waste gas outlet for upward flow. If this is done, minimum height of the waste heat boiler is essential and the temperature drop of the waste gas over this minimum height must therefore be quite sharp. Proper support of the tubing banks with allowance for expansion is necessary. It is also desirable that the waste heat boiler be composed of units which are replaceable, those units most susceptible to corrosion damage from combustion gases being more readily accessible than units which are less subject to damage.

Accordingly, one object of the present invention is to provide an improved compact and economical arrangement for a multi-pressure waste heat boiler suitable for mounting directly above a waste gas producer outlet.

Another object of the invention is to provide a waste heat boiler having a minimum vertical dimension in the direction of waste heat gas flow with steep temperature gradient in the waste heat gas over this distance.

Another object of the invention is to provide an improved arrangement for forced circulation steam generation at more than one pressure level in a waste heat boiler.

Still another object of the invention is to provide an

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improved waste heat boiler for multi-pressure steam generation with separate stackable horizontal tube banks arranged for balanced flow using the same size tubing throughout.

Another object of the invention is to provide an improved waste heat boiler, wherein the units most susceptible to corrosion are accessible for ease of maintenance and cleaning in direct order to their susceptibility to such corrosion.

Yet another object of the invention is to provide an improved waste heat boiler using a minimum of associated connecting piping arranged for ease of inspection and maintenance.

Other objects and advantages of the invention will become apparent from the following description taken in connection with the accompanying drawing in which:

FIG. 1 is an exploded perspective view in simplified form, showing the separate units of the waste heat boiler in its preferred embodiment for a steam generating system of two pressure stages,

FIG. 2 is a cross section through the waste heat boiler as disposed above a gas turbine exhaust outlet, showing the associated external piping in diagrammatic form and,

FIG. 3 is an enlarged view of the finned tubing used in the various heat exchange sections.

Briefly stated, the invention is practiced by employing a number of separate rectangular open-ended duct sections having integrally-contained horizontal finned tubing and stacked upon one another, with the lowest temperature section on top. Heating of the liquid to vaporization temperature is accomplished in series-connected serpentine finned tubing within suitably placed economizer sections, while vaporization at more than one pressure level is accomplished in parallel-connected finned tubing of at least two evaporator sections with forced recirculation of the liquid in a closed loop at a rate greatly in excess of the evaporation rate.

Referring now to the exploded perspective view of FIG. 1, the waste heat boiler comprises a vertical stack of rectangular box-like heat exchange sections. Commencing with the lowest temperature section on top, these are consecutively, a low pressure (LP) economizer **1**, an LP evaporator **2**, a high pressure (HP) economizer **3**, an HP evaporator **4**, and an HP superheater **5**. Closely associated with heat exchange sections **1–5** is an LP steam drum **6**, and an HP steam drum **7**.

Sections **2–5** are all similar in construction to section **1**, which includes flanged side walls **1***a*, **1***b*, and end walls **1***c*, **1***d*. The sections are open at top and bottom and the interior is filled with horizontal, vertically spaced rows **8** of horizontally extending heat exchange tubes. The tubes are indicated as single lines in FIG. 1 due to the small scale of the drawing, but are preferably finned tubes to be described later in detail. The tubes are supported in spaced plate hanger supports **1***h* (only one shown) which are secured between side walls **1***a*, **1***b*. The flanges of sections **1–5** are adapted for stacking on top of one another and are secured with spaced bolts **1***e*. Gasket strips **1***f* seal between flanges and the bolt holes are provided with generous clearance for thermal expansion. The side walls and end walls of sections **1–5**, therefore, support the tube bundles and, in addition, cooperate to form a rectangular vertical duct, which is fed from the bottom with hot gas.

The tubes in each row of the LP and HP economizer sections **1**, **3** are connected at opposite ends with the tubes of the row immediately above and immediately below in series-flow relation as indicated at **9**, **10** respectively. An inlet header **11**, and an outlet header **12**, attached to end wall **1***d* or LP economizer section **1**, are connected to the top row of tubes and to the bottom row of tubes respectively. Similarly, an inlet header **13** and an outlet header 14 service the top and bottom rows of series-connected tubes 10 in HP economizer 3.

The construction of the LP evaporator 2 and HP evaporator 4 is slightly different from that of the economizer sections 1, 3 mentioned above, in that the heat exchanger tubes 15, 16 in each of the two sections are connected in parallel flow relationship with all the other heat exchanger tubes in the same section. A rectangular box 17, supported on the far end wall of section 2, serves as an inlet header, while a similar box 18, on the near end wall of section 2, serves as an outlet header. Similarly, HP evaporator 4 includes an inlet header 19 and outlet header 20. All of the rows of tubes 15 in section 2, therefore, are connected directly between headers 17, 18 and all the rows of tubes 16 in section 4 are connected between headers 19, 20. Thus, evaporators 2, 4 may be characterized as "once through" heat exchangers as opposed to the serpentine flow of liquid taking place in tubes 9, 10 of the economizers 1, 3.

The HP superheater section 5 is arranged slightly differently from above, in that every other row of tubes 21 is paired or paralleled with a row of tubes 22, and each double row 21, 22 is connected in series flow with other double tube rows, as will be apparent from the drawing. An inlet header 23 furnishes saturated steam to each pair of tubes, such as 21, 22, and an outlet header 24 on the far end wall collects superheated steam.

It will be understood that each of the sections 1–5 contains a large number of tubes per row as indicated by the short line segments of row 8 in FIG. 1. However, the basic characteristics of the various heat exchangers can be determined by examining only one such tube in each row (in FIG. 1, the nearest tube in each row), since additional tubes in each row merely increase capacity of the boiler proportionately.

The LP steam drum 6 is located closely adjacent the end of LP evaporator 2 near header 18, and collects both steam and liquid from the low pressure evaporator. Similarly, the high pressure drum 7 is located adjacent outlet header 20 of high pressure evaporator 4.

The remaining components of the system, including pumps and connecting conduits, will now be described according to the flow path taken by the fluid from inlet to outlet of the boiler.

Cold feed water is pumped by an LP feed pump 25 through a feed water supply pipe 26 to LP economizer header 11. After flowing through the series-connected rows of pipes 9, heated feed water from header 12 enters LP drum 6 by way of a pipe 27 at approximately the proper temperature for vaporization at the pressure existing in LP drum 6. Feed water leaves drum 6 through an outlet pipe 28, branch pipe 29, and is pumped by an LP circulating pump 30 through pipe 31 to the LP evaporator header 17 on the far end of section 2. The liquid boils as it passes through parallel-connected rows of pipes 15 entering outlet header 18. Several LP steam pipes 33 supply saturated steam from the top of header 18 to the top portion of drum 6, while additional pipes 34 connected to the bottom of header 18 supply unevaporated liquid to the lower part of drum 6.

According to one aspect of the invention, the rate of liquid pumped through the LP steam generation loop, consisting of pipes 28, 29, circulating pump 30, pipe 31, header 17, pipes 15, header 18, pipes 33, 34 and drum 6, is substantially in excess of the rate at which steam is generated in pipes 15. Preferably this recirculation rate is on the order of 5 times or more the rate at which the water is converted to LP steam. Thus, it will be apparent that tubes 15 contain a relatively large amount of liquid, which has better heat transfer characteristics than does steam, and the interiors of tubes 15 are completely wetted. By this means, the efficiency of LP evaporator 2 is improved and substantial heat is extracted from the exhaust gas, which undergoes a large temperature drop in a relatively short distance.

LP saturated steam in the upper part of steam drum 6 is collected by a header 35 and supplied through a pipe 36 to a utilization point for low-pressure steam, such as a process steam header or a low-pressure stage of a steam turbine.

As to the high-pressure portion of the cycle, a part of the water leaving drum 6 through pipe 28 passes through a branch line 37 and has its pressure substantially raised by an HP booster pump 38. Pump 38 supplies HP economizer header 13 by means of a pipe 39, whereupon the entering feed water, now with an increased pressure, is raised in temperature to its higher vaporization temperature in series-connected rows of pipes 10 and is supplied to HP economizer outlet header 14. From header 14, the HP feed water flows throuugh pipe 40 to HP drum 7. The feed water leaves drum 7 through a pipe 41 and is pumped by an HP recirculating pump 42 through a pipe 43 to the inlet header 19 on the far end of HP evaporator 4. The liquid flows through the parallel-connected rows of pipes 16 to outlet header 20. As before, saturated HP steam flows from the top of header 20 through pipes 44 and unevaporated liquid flows from the bottom header 20 through pipes 45 to steam drum 7.

By analogy to the LP evaporator, again the components of the recirculated fluid in the HP steam generation loop, consisting of pipe 41, pump 42, pipe 43, header 19, pipes 16, header 20, pipes 44, 45, and drum 7, are selected to provide a recirculation rate substantially in excess of the actual rate at which liquid is evaporated in pipes 16. A suitable recirculation rate again is five times the rate at which liquid is evaporated, although some variation in recirculation rate is to be expected with various designs.

An HP drum header 46 collects saturated steam from the top of drum 7, and supplies it to inlet header 23 of the HP superheater section 5. Superheated steam is collected from pipes 21, 22 by header 24, and a pipe 47 supplies HP superheated steam to a utilization point such as the first stage of a steam turbine (not shown). The use of steam at two pressures, such as HP superheated steam from pipe 47 and LP saturated steam from pipe 36, may be integrated, for instance, by supplying the same turbine with steam at two different points or pressure stages of a turbine.

It remains to note that structural support for the waste heat boiler consists of brackets 48 attached to the opposite side walls of HP evaporator 4. These brackets 48 rest on a structural supporting framework indicated by I-beam section 49. Thus the top three sections 1–3 are supported by resting on section 4, while superheater section 5 hangs from section 4.

Referring now to FIG. 2 of the drawing, the waste heat boiler of FIG. 1 is shown in cross section, with sections 1–5 stacked on top of one another, with the associated external drums, pumps, and conduits shown in diagrammatic fashion. The waste heat boiler is shown disposed above the exhaust outlet duct 50 of a gas turbine (not shown) and connected thereto by a diverging transition duct 51. Gas flows upwardly through the boiler from gas turbine exhaust 50, exhausting directly to the atmosphere as indicated by the arrows. It will be apparent that the waste heat boiler, due to the use of horizontal tubes, is extremely compact in a vertical direction.

Although again, in FIG. 2, the tubes 9, 15, 10, 16, 21, 22 are shown without fins due to the scale of the drawings, these tubes preferably have extended external surfaces or fins. Also the tubes are all of the same size and capacity in order to achieve economy in manufacture, due to the many tubes required.

Reference to FIG. 3 of the drawing illustrates a typical finned tube employed in heat exchangers 1–5. There it is seen that the tube 52 has a large number of thin projecting fins 53 which project into the hot exhaust gas and increase the surface area of the outside of the tube. Thus, the area on the "gas side" is very large (where the heat transfer coefficient is correspondingly small), while the surface area inside tube **52** is smaller. A satisfactory finned tube for the waste heat boiler described would be a 1″ outside diameter carbon steel tube with .095″ wall thickness having steel fins spirally wound around the tube and attached thereto by resistance welding or copper brazing. The fins might be .040″ in thickness, projecting ½″ from the tube and wound at the rate of 7 fins per linear inch.

As mentioned previously, each row of tubes **9, 10** in the economizer section is connected in series. This may be done by bending the tubes in serpentine fashion or preferably by welding U-bends to the ends of alternate tubes. Conversely, the rows of tubes **15, 16** in the evaporator sections are all connected in parallel between the inlet and outlet headers to provide a large flow area. The superheater **5**, of course, constitutes a special case, wherein a combination of series-parallel connections is employed.

The operation and advantages of the improved boiler are as follows. FIG. 2 shows the arrangement of one tube in each row from top to bottom of the waste heat boiler. A number of such tubes in each row would be employed, and this would increase the capacity and flow area of the boiler proportionately. For example, fifty tubes per row in an arrangement similar to that of FIG. 2 might be employed in a typical waste heat boiler. As an example of the compactness achieved, a boiler having the layout shown in FIG. 2, using the tubes described in FIG. 3 and having 50 tubes per row, would be about 10 ft. wide and 22 ft. long, but only 16 ft. high. Within this volume would be over 2000 straight lengths of tubing, weighing on the order of 65 tons. Such a boiler will generate 17,000 pounds per hour of LP steam at 100 p.s.i., 325° F., and 65,000 pounds per hour of HP steam at 420 p.s.i., 820° F. The gas leaving duct **50** at a temperature of the order of 850° F. is reduced to a temperature of around 250° F. at the boiler outlet in only 16 ft. of travel. The mass of finned tubing, in addition, performs an important silencing function for turbine exhaust gases.

Steam is generated in the evaporator sections **2, 4** at two different temperatures, dependent upon the pressures in LP and HP drums **6, 7** respectively. The HP economizer section **3** disposed between sections **2, 4** contains liquid varying in temperature from that in drum **6** to that in drum **7**. Lower temperature liquid exists in LP economizer **1**, while the highest temperature exhaust gas passes over the tubes of superheater section **5**. By means of the alternating of series-connected and parallel-connected tubing rows in the sections, balanced heat removal is achieved in a very short vertical space. Also finned tubes of the same size can be used in all sections.

With the exception of the superheater section **5**, the heat exchange capabilities of the upper sections **1–4** are greatly enhanced by the fact that the tubes are either filled with liquid or thoroughly wetted with liquid. In other words, heat transfer takes place under the more efficient gas-to-liquid rather than under gas-to-gas conditions. To this end, the high forced recirculation rate through evaporator tubes **15, 16** by means of circulating pumps **30, 42** respectively insures that all of the relatively small diameter tubes are thoroughly wetted with liquid to prevent "burnouts" and to improve heat transfer.

The use of open-ended rectangular duct sections which support the tube bundles and headers, as well as forming a duct for the exhaust gas when stacked together, simplifies maintenance and construction costs. Expansion and contraction can take place in each section separately. It will further be noted that the lowest temperature sections on top may be removed in order of operating temperature, going from low temperature to high temperature. The lower temperature sections of waste heat boilers are more subject to corrosion caused by condensation of corrosive vapors from products of combustion. Hence, the top lower temperature sections are easily accessible for removal and repair or cleaning, if necessary.

Thus, it can be seen that the disclosed waste heat boiler provides an improved arrangement and very compact design for extracting the heat from exhaust gases in a minimum of vertical height. The improved arrangement using separate sections with self-contained tube banks of horizontally-disposed finned tubing of uniform characteristics provides an improved waste heat boiler for multi-pressure steam generation at relatively low cost.

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

1. A boiler for generating steam at a plurality of pressure levels comprising:

a plurality of substantially rectangular duct sections vertically stacked on top of one another, each of said duct sections having a plurality of horizontal, vertically spaced rows of extended external surface heat exchange tubes extending across the duct sections,

at least two of said duct sections comprising evaporating heat exchangers and having all of said tube rows connected in parallel flow relationship,

at least one steam drum disposed adjacent the end of each of said evaporating duct sections and connected to receive water and saturated steam from the parallel connected tube rows thereof, the upper one of said steam drums being at a lower pressure than the steam drum below it,

recirculating pump means for each said evaporator sections and steam drums connected to move waste through said evaporating tubes at a rate substantially in excess of the evaporation rate thereof in a closed loop forced circulation,

at least one other of said duct sections comprising an economizer heat exchanger and stacked between said two evaporating heat exchanger duct sections, and having its tube rows connected in serpentine or series flow relationship, said economizer being connected to receive water from the steam drum of the evaporator disposed above it and also connected to furnish heated feed water to the steam drum of the evaporator section below it, and

a source of heating gas connected to the bottom of the stacked duct sections, said gas flowing upwardly across said tube rows.

2. A boiler for generating steam at a plurality of pressure levels comprising:

first, second and third substantially rectangular duct sections vertically stacked on top of one another consecutively from top to bottom, each of said duct sections having a plurality of horizontal, vertically spaced rows of extended external surface heat exchange tubes extending across the duct section,

said first and third of said duct sections comprising low pressure and high pressure evaporating heat exchangers respectively and each having all of its tube row connected in parallel flow relationship,

low pressure and high pressure steam drums disposed adjacent the end of the first and third duct sections respectively and connected to receive water and saturated steam from the parallel connected tube rows thereof,

low pressure and high pressure recirculating pump means, each connected to recirculate water in a closed loop from low pressure and high pressure steam drums respectively through low pressure and high pressure evaporators respectively, at a rate substantially in excess of the evaporation rate of said evaporators,

said second duct section comprising a high pressure economizer heat exchanger and stacked between said low pressure and high pressure evaporating duct sections and having its tube rows connected in serpentine series-flow relationship,

booster pump means connected to receive water from the low pressure steam drum and to furnish it at a higher pressure to said economizer heat exchanger inlet,

conduit means connected between the economizer outlet and the high pressure steam drum and,

a source of heating gas connected to the bottom of the stacked duct sections, said gas flowing upward therethrough across said tube rows.

3. A boiler for generating steam at a plurality of pressure levels comprising:

a plurality of substantially rectangular duct sections, vertically stacked on top of one another, each of said duct sections having a plurality of horizontal, vertically spaced rows of extended external surface heat exchange tubes supported by the walls thereof, and extending across the duct section,

at least two of said duct sections comprising low pressure and high pressure evaporating heat exchangers, and each having all of said tube rows connected in parallel flow relationship, said low pressure evaporator being disposed higher in the stack than said high pressure evaporator,

low pressure and high pressure steam drums disposed adjacent the ends of the low pressure and high pressure evaporating heat exchangers respectively, and connected to receive water and saturated steam from the parallel connected tube rows thereof,

low pressure and high pressure recirculating pump means, each respectively connected to recirculate water in a closed loop through an associated evaporating heat exchanger from its associated steam drum at a rate substantially in excess of that at which water is evaporated in the heat exchanger,

at least two additional duct sections comprising low pressure and high pressure economizer heat exchangers and stacked immediately above and below the low pressure evaporating duct section, each of said economizer heat exchangers having its tube rows connected in serpentine series-flow relationship and having an inlet header and outlet header disposed on the wall of the duct section connected to the top row and bottom row of tubes respectively,

first and second conduit means connecting the outlet headers of the low pressure and high pressure economizer sections respectively to the steam drums of the low pressure and high pressure evaporator sections respectively,

low pressure booster pump means connected to furnish feed water to the inlet header of the low pressure economizer,

high pressure booster pump means connected to receive liquid from the low pressure steam drum and to furnish it at a higher pressure to the inlet header of the high pressure economizer, and

a source of hot gas connected to the bottom of the stacked duct sections, said gas flowing upwardly therethrough across the tube rows.

4. The combination according to claim 3, wherein an additional one of said duct sections comprises a superheater disposed immediately below the high pressure evaporating duct section and having an inlet header connected to receive saturated steam from the high pressure steam drum and wherein at least two of the superheater tube rows are connected in parallel, said parallel connected rows in addition being connected in series with other parallel rows within the superheater in serpentine fashion, the tubes of all the economizer, evaporator and superheater duct sections being finned tubing of substantially the same size and characteristics.

5. A boiler for generating steam at a plurality of pressure levels comprising:

first, second, third, fourth, and fifth substantially rectangular duct sections vertically stacked on top of one another consecutively with the first duct section on top, each of said duct sections having spaced parallel end walls and spaced parallel side walls and being open at either end, and each having a plurality of horizontal, vertically-spaced rows of finned tubes of substantially the same size and characteristics extending parallel to the side walls and supported thereby, said duct sections each also having inlet and outlet headers disposed along the end walls and connected to the tubes of at least one row,

said first and third of said duct sections comprising low pressure and high pressure economizer heat exchangers respectively, each having consecutive tube rows connected in series flow relationship with the top and bottom rows connected to the inlet and outlet headers respectively,

said second and fourth duct sections comprising evaporating heat exchangers and having all of the tube rows therein connected in parallel flow relationship between inlet and outlet headers disposed on opposite end walls,

low pressure and high pressure steam drums disposed adjacent the outlet headers of said second and fourth duct sections respectively,

first and second conduit means connecting the top and bottom respectively of the low pressure evaporator outlet header with the low pressure steam drum,

third and fourth conduit means connecting the top and bottom respectively of the high pressure evaporator outlet header with the high pressure steam drum,

fifth and sixth conduit means connecting the first duct section outlet header with the low pressure steam drum and the third duct section outlet header with the high pressure steam drum respectively,

first booster pump means connected to supply the inlet header of the first duct section with feed water,

second booster pump means connected to receive water from the low pressure steam drum and to supply it at a higher pressure to the inlet header of the third duct section,

first and second recirculating pump means connected to receive water from the low pressure and high pressure steam drums respectively and to supply it to the inlet headers of the second and fourth heat evaporating exchange sections respectively, said recirculating pump means being selected to pass water through the parallel connected tube rows of the second and fourth duct sections at a rate substantially in excess of the evaporation rate within said tubes,

said fifth duct section having its inlet header connected to receive saturated steam from the high pressure steam drum and having at least a pair of tube rows connected in parallel to the inlet header and also connected in series flow relationship with other pairs of tube rows to supply superheated steam to the outlet header of the fifth duct section, and

a source of hot gas connected to the bottom of the stacked duct sections, said gas flowing upwardly therethrough across said finned tubing.

6. A boiler for generating steam at a plurality of pressure levels comprising:

a plurality of substantially rectangular duct sections vertically stacked on top of one another, each of said duct sections having spaced parallel end walls and spaced parallel side walls and having a plurality of horizontal, vertically spaced rows of finned tubes, all of substantially the same size and characteristics supported by and extending parallel to said side walls, each of said duct sections having inlet and outlet headers disposed on the end walls and connected to all of the finned tubes in at least one of said rows within the duct section,

at least two of said duct sections comprising evaporating heat exchangers with the tube rows connected in parallel between inlet and outlet headers disposed on opposite end walls, other of said duct sections comprising economizer heat exchangers with the tube rows connected in series flow relation,

at least one steam drum disposed adjacent the outlet header of each of the evaporating heat exchangers, and

at least one recirculating pump for each evaporator and associated steam drum arranged to recirculate liquid therethrough in a closed steam generation loop at a rate substantially in excess of the evaporation rate within the evaporator tubes,

each of said evaporating heat exchanger sections operating at a different pressure level.

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CERTIFICATE OF CORRECTION

Patent No. 3,147,742 September 8, 1964

Howard F. May

It is hereby certified that error appears in the above numbered patent requiring correction and that the said Letters Patent should read as corrected below.

Column 6, line 30, for "waste" read -- water --; line 57, for "row" read -- rows --.

Signed and sealed this 5th day of January 1965.

(SEAL)
Attest:

ERNEST W. SWIDER
Attesting Officer

EDWARD J. BRENNER
Commissioner of Patents