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BOILER

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Fig. 1

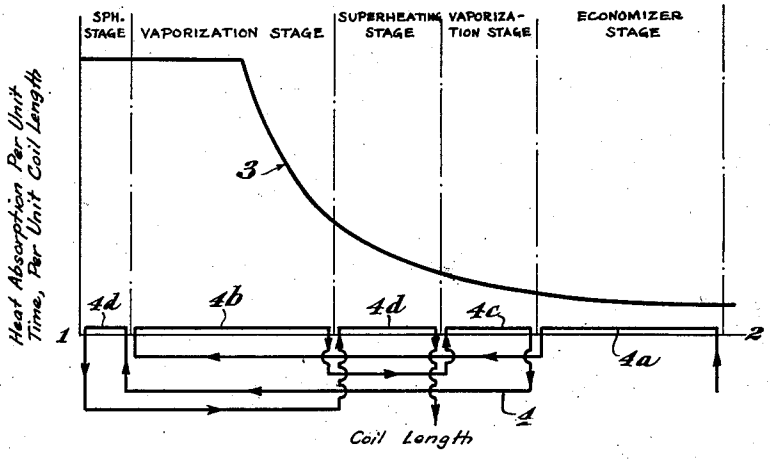
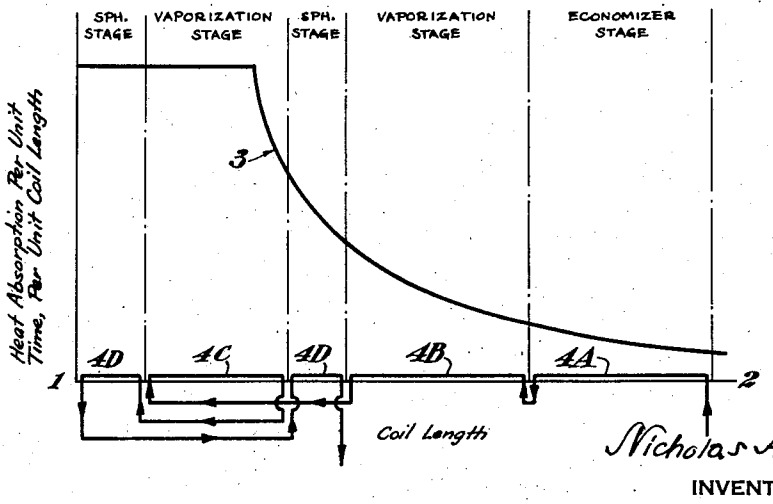


Fig. 2



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Fig. 3

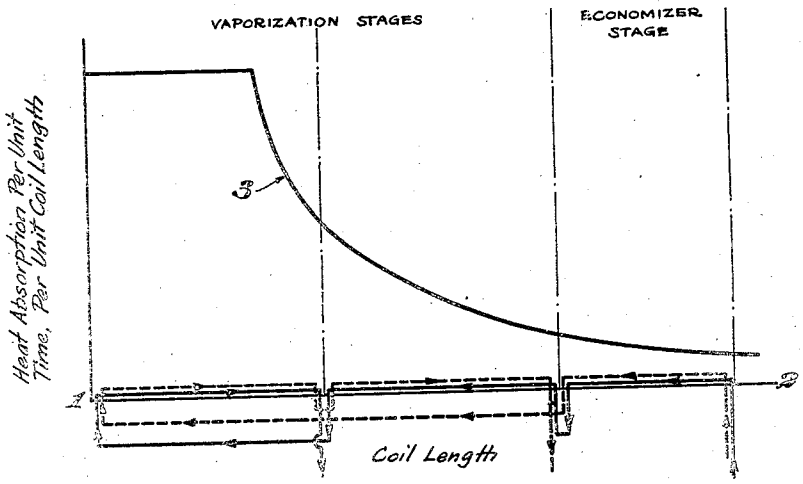
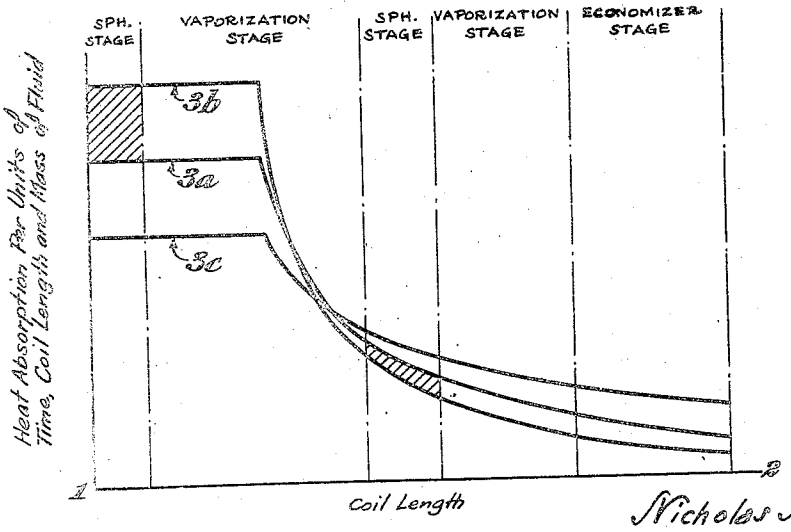


Fig. 4



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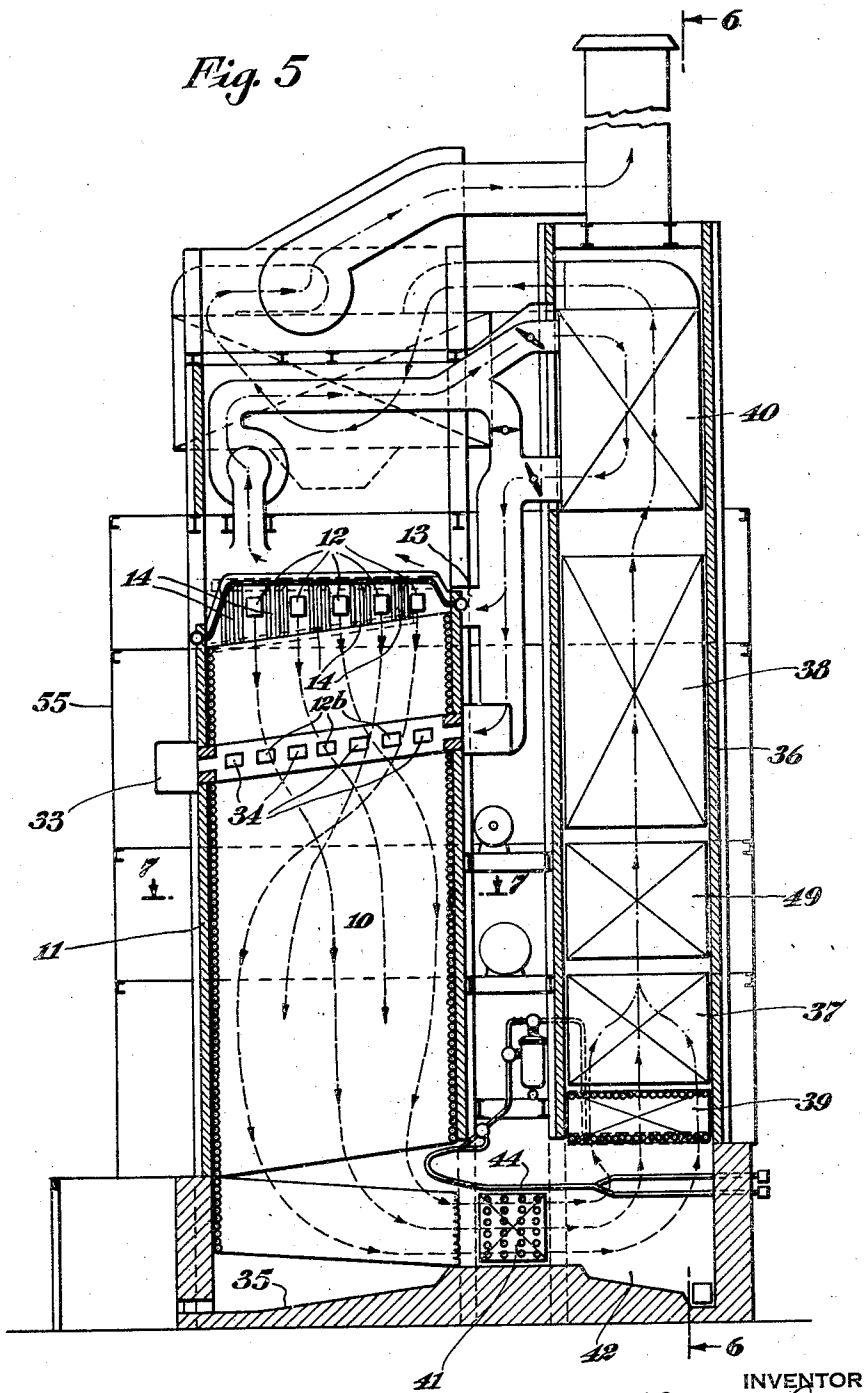
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Fig. 5



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Fig. 6

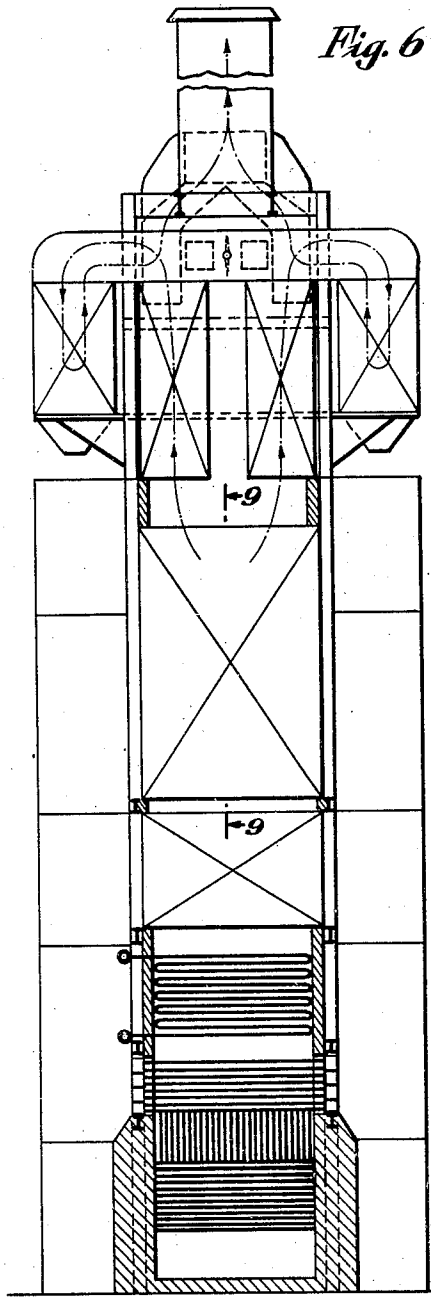


Fig. 7

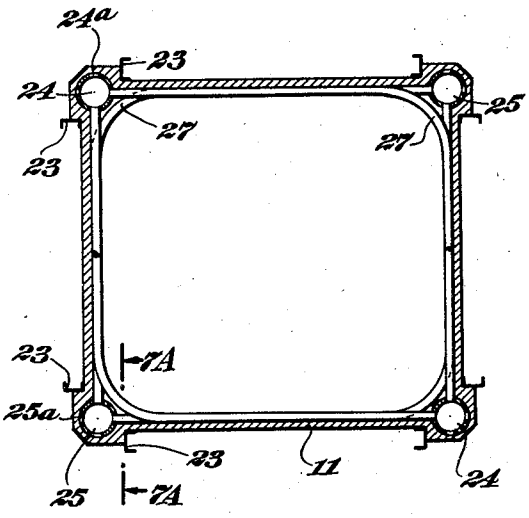
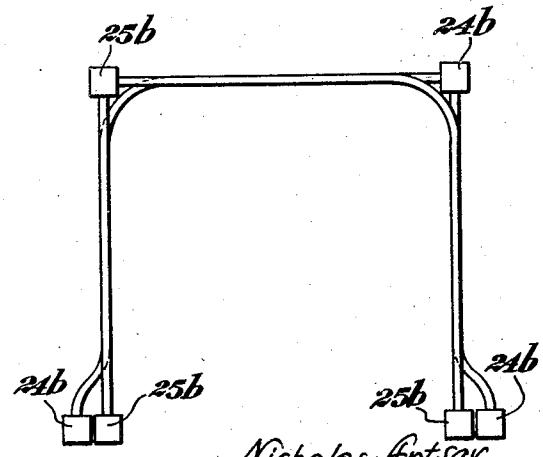


Fig. 8



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Fig. 9

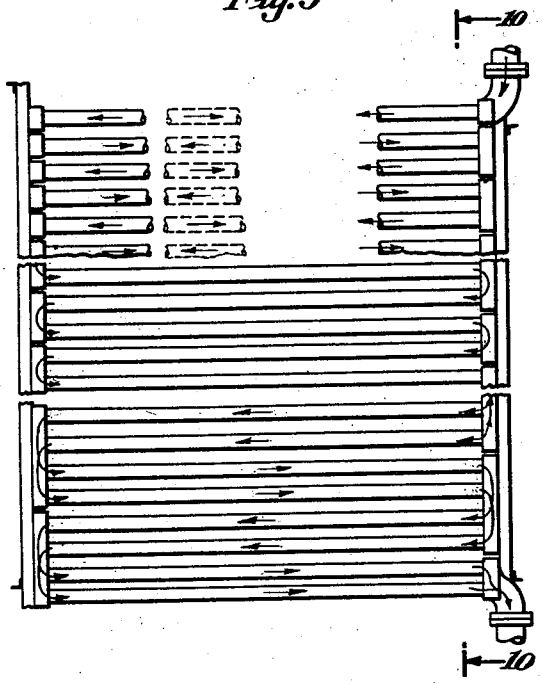


Fig. 10

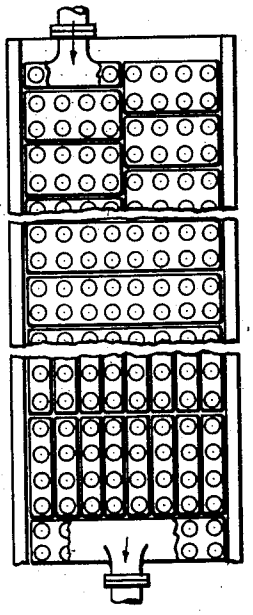


Fig. 11

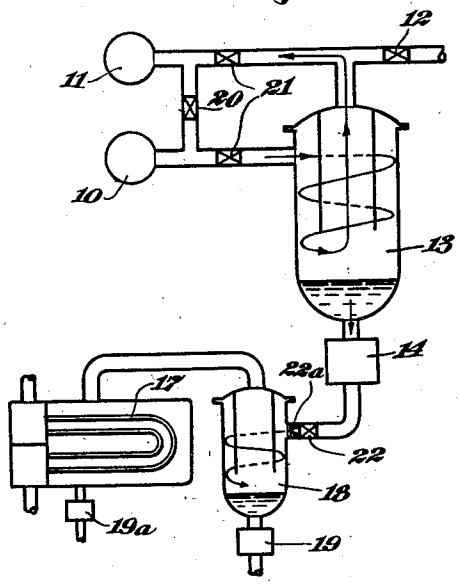
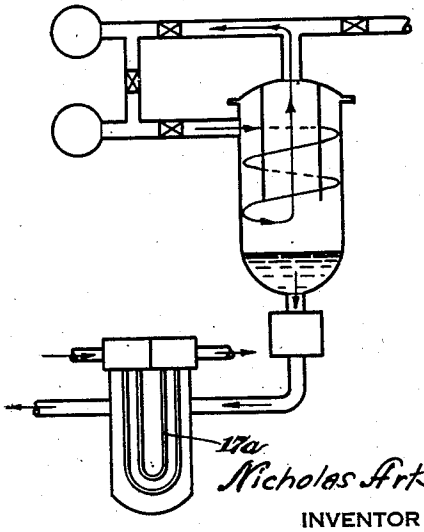


Fig. 12



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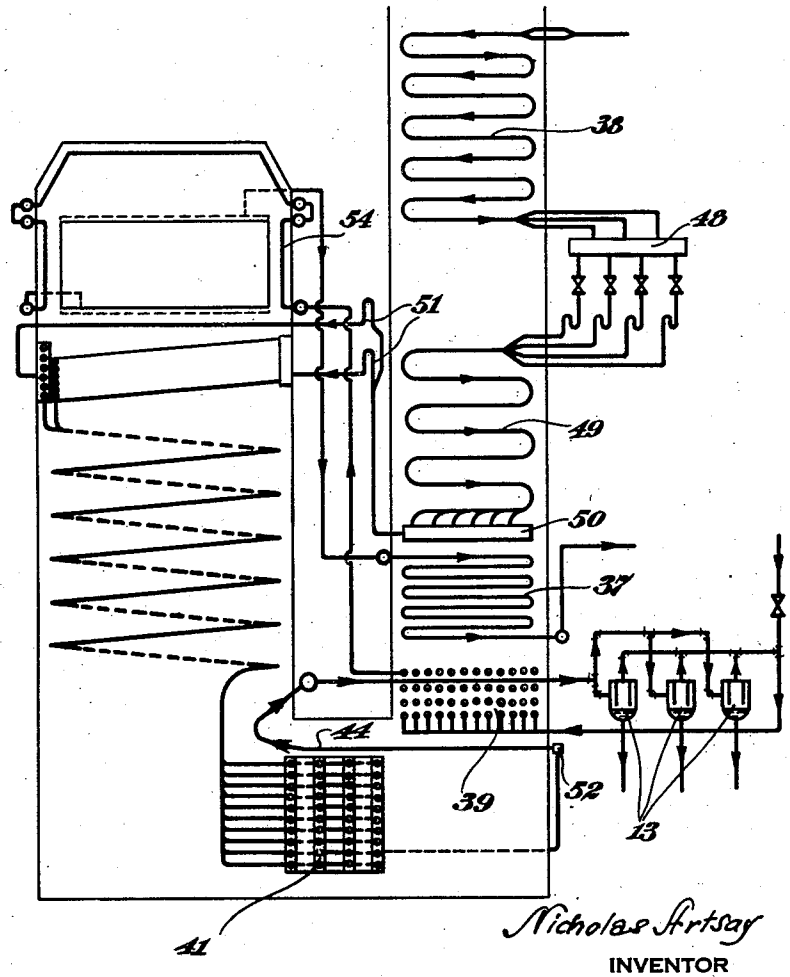
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Fig. 13



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Fig. 14

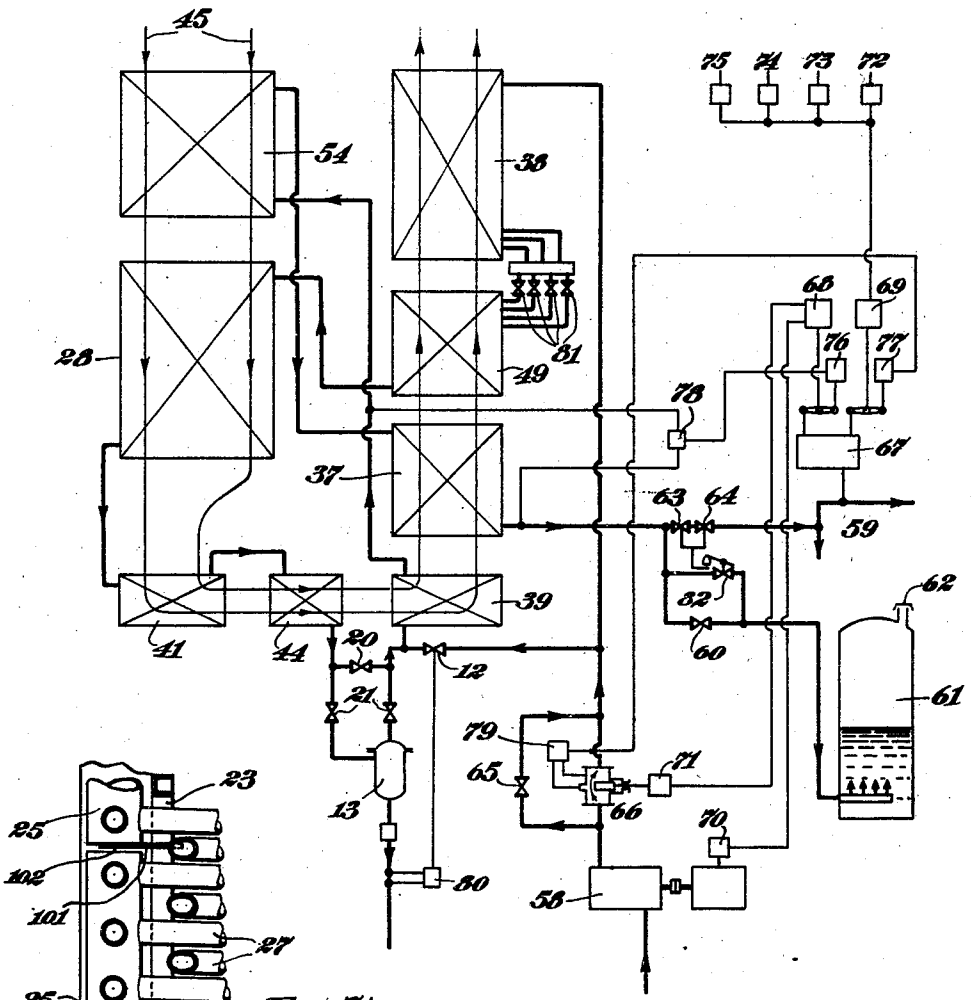


Fig. 7A

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UNITED STATES PATENT OFFICE

2,003,419

BOILER

Nicholas Artsay, New York, N. Y.

Application December 16, 1931, Serial No. 581,347

8 Claims. (Cl. 122—235)

The invention relates to steam boilers or steam generators of the so-called flash type and has for its purpose the provision of an improved form and operation of such boilers. The detailed points of improvement over prior boilers of this type will be clear from a reading of the following specification.

The invention is illustrated in the drawings filed herewith. In these drawings Figs. 1, 2, 3 and 4 are diagrams used in the discussion of the theory of the invention; Fig. 5 illustrates a vertical longitudinal section more or less diagrammatic of a boiler in accordance with my invention; Fig. 6 is a section on line 6—6 of Fig. 5; Fig. 7 is a section on an enlarged scale on line 7—7 of Fig. 5; Fig. 7*a* is an enlarged sectional view on line 7*a*—7*a* of Fig. 7; Fig. 8 is a section similar to that of Fig. 7 showing a modification; Fig. 9 is a vertical section on line 9—9 of Fig. 6; Fig. 10 is a section on line 10—10 of Fig. 9; Fig. 11 is a diagrammatic view on an enlarged scale of a detail of the boiler; Fig. 12 is a view similar to Fig. 11 of a variation; Fig. 13 is a diagrammatic showing of my boiler arrangement illustrating particularly the connections between the several tubular parts or elements; and Fig. 14 is a diagrammatic view of the boiler with its controls.

In water tube boilers of the coil or flash type as hitherto built, there is no natural thermal or gravity circulation of the water, all of the water which is to be converted into steam entering the boiler at one end of the coil, or at one end of the coils when there are a number of them in parallel, and emerging at the other end as steam. The rate at which the water or steam and water mixture or steam moves at any point in the coil is always equal to the rate at which the boiler is being fed. The coil itself comprises several more or less distinct stages. The first of these in the path of the water motion is the feed water heating stage sometimes called the economizer stage, this being followed by the evaporating stage where the water is gradually converted into saturated steam, and in most cases the steam generating stage is followed by a superheating stage where the steam generated is heated up to the desired temperature.

On the gas side of the boiler, all of the gas produced by combustion first gives up some of its heat by radiation in a radiant heat zone which is followed by a first hot convection zone, next by a convection zone of medium gas temperature, and finally by a colder convection zone where the residual heat is partially recovered by so-called economizers or by air preheaters.

It has hitherto been believed by the majority of those working in this art that the solid water even moving slowly in tubes is the most effective cooling medium for the metal of the tubes. The usual arrangement of boilers of this type has therefore been to preheat the water, usually to a point approaching the boiling point, and then to lead it into the zone of most intense heating effect, that is, the hot radiant heat zone and then letting it flow successively through coils in cooler zones. Vaporization with such an arrangement begins in the intensely hot radiant zone and ends in the main convection zone. Where the steam after generation is to be superheated, this is arranged for in a number of different ways as far as the temperature zone is concerned in which the superheating is done. Quite commonly the steam generating coil is split or divided and superheating surface inserted at one or more points.

One of the important phases of my invention relates to the vaporization stage. To explain it, use will be made of Figs. 1 to 3. Referring to Fig. 1, this figure represents the usual arrangement of heating stages as related to the several heating zones. The base 1—2 of the diagram represents the full length of the coil, or of one of the parallel coils where there are several in parallel, and the ordinates from this line to the curve 3 represent the rate of heat absorption per unit length of the coil. The area under the curve 3 therefore corresponds to the total heat absorbed by the coil per unit of time. The hot gases move from left to right. The high flat part of the curve 3 corresponds to the radiant zone where the heating by radiation is most intense. The vertical dotted lines indicate the divisions between the several stages. The broken line 4 represents the water or steam containing surface. The portions of this line lying above the line 1—2 represent tubes exposed to the heating effect in the respective zones while the portions under the base line 1—2 represent outside connections between the stages. Water enters the economizer stage 4*a* and after being heated is led to the evaporating stage 4*b* in the radiant zone. The conversion of water into steam is finished in the main convection zone in the stage 4*c*. Stage 4*d* is the superheating stage. In the example illustrated in Fig. 1 this is split up into two parts one of which is located in the convection zone and the other in the radiant zone.

Fig. 2 represents in a similar manner an arrangement according to my invention. Water enters the economizer stage 4A and after it has been heated in this stage flows into the first part

of the evaporating stage 4B which lies in the main convection zone. Here a substantial amount of water is converted into steam thereby accelerating the motion of the mixture of water and steam. This mixture then flows through the second part of the evaporating stage 4C arranged in the radiant zone where vaporization is completed under conditions of most intense heat. Thus a particular feature of my invention is to accelerate the water flow by evaporating a substantial part of it (and thereby producing by the high velocity an intimate emulsion-like mixture of steam and water) before admitting it to the zone of most intense heat absorption, taking into account the rise of boiling point due to pressure increase caused by frictional resistance to the flow. The evaporation is completed in 4C and the steam then superheated in the superheater 4D. In boilers of the coil type as built in the past, the tubes have been of relatively small diameter so that the segregation of steam bubbles and their collection at the sides of the tubes was not likely to occur. If coil boilers are to be built with tubes of diameter sufficient to allow an effective cleaning, this bubble segregation becomes an important factor and is likely to result in localized overheating and damage to the tube and in their bursting. In a coil boiler with stages of vaporization arranged as I have described in connection with Fig. 2, the dangerous moment of the first formation of the steam bubbles and their natural segregation due to their buoyancy is relegated to the colder convection zone where the temperature of the gas is too low to endanger the tube even if part of the surface is blanketed by a layer of steam and therefore not adequately cooled by the moving water.

Fig. 3 is inserted to bring out more clearly the novelty of my invention. In this figure the superheating zones are omitted and it will be understood that they can be inserted in any zone, for example, as illustrated in Fig. 2. In this Fig. 3 the curve of heat absorption rate 3 is similar to that of Figs. 1 and 2. The arrangement used in the past and my arrangement are both drawn in in this figure for comparison. The heavy dotted line indicates the usual arrangement while the full heavy line indicates my arrangement. An inspection of the figure will make it clear that with the old arrangement of vaporization stages in the convection zone the flow of the fluid to be heated and evaporated is parallel to the gas flow while with my arrangement these two are for the larger part in countercurrent. As far as I am aware, such a substantial degree of vaporization preliminary to entering the radiant zone has never been used heretofore and my theoretical investigations show that very beneficial results follow from the change introduced by me.

A second important phase of my invention relates to the troublesome effects of high concentration of dissolved and suspended matter in the boiler water.

In the usual boilers with thermal circulation the small amount of salts and dirt introduced with the feed water stays in the boiler and the concentration gradually increases, its bad effects being somewhat lessened by a periodical or continuous blow-down and the substitution of fresh feed water. Besides troubles in the boiler proper due to scale formation steam separated in the drum and delivered to the superheater carries with it a small amount of entrained moisture with the dissolved concentrated salts in it. Even these small amounts of salts have been found very harmful to superheaters, steam reheaters and turbines. In the case of coil boilers as usually constructed, all the salts and dirt introduced with the feed water will pass to the superheater and the turbine or other engine as there is no such blow-down possible as in boilers of the type first referred to. My invention is designed to remove or at least to mitigate this evil. For this purpose I propose to withdraw near the end of the vaporization all of the steam-water mixture from the coil, to pass it through a steam separator, such for example as a centrifugal separator, to return the steam to the coil, and to dispose separately of the concentrated solution separated out. The withdrawal should be made at a point near the end of vaporization where only approximately 5 to 10% of the water is left unconverted into steam. Preferably, in the interest of uniform regulation, I substitute an amount of fresh feed water of low initial concentration for the concentrate withdrawn.

In order to carry out this proposal it is necessary to keep the point of total vaporization at approximately the same spot in the coil so that the percentage of water withdrawn will not vary greatly when the rate of steaming and firing is varied. That this is entirely feasible will be clear from the following considerations.

Referring to Fig. 4, the curve 3*a* shows the heat absorption rate per unit length of coil and per unit weight of steam output at normal operation. Curve 3*b* shows it at a lower boiler output. 3*c* shows it for an overload operation. When the steaming rate increases, the proportion of heating effect by radiation decreases, while the proportion of heating by convection increases. These opposing characteristics of the two zones make it possible to select superheating surfaces in such a way that the loss of heating effect in the convection part of the superheater is balanced by the increased heating effect in its radiant part as shown by the shaded areas. A result, important for the present invention, follows from this characteristic of superheating surface so arranged. The usual aspect of this is that with varying loads on the boiler and superheater the final superheat remains constant. In connection with my invention it is interesting to put this in the converse form, i. e., that if the final superheat is kept constant, the amount of superheating surface will also remain constant, or in other words the point where evaporation is complete is fixed. It will further be obvious that if the distribution of superheating surface between that part which is heated by radiation and that part which is heated by convection is judiciously made, not only will the point of total evaporation remain fixed, but the point at which any given percentage, for example 95%, of the water has been evaporated also remains substantially fixed. It therefore becomes possible to withdraw unevaporated water in a constant desired proportion or in other words at a desired concentration of salts in it.

In case it is not desired to use superheat but to use the steam in saturated condition, the rate of firing is regulated to deliver steam at some low superheat which always is of some advantage and then the point of total vaporization will also be in a definite spot of the coil making the withdrawal of the concentrate in proper quantities possible.

A complete boiler in accordance with my invention is illustrated in Fig. 5. This figure shows a steam generator of large capacity and of a form

such as would be used for an outdoor installation. The furnace chamber 10 is enclosed by tubular coils, the details of which are shown in Fig. 7 and will be described below. This tubular envelope is suitably insulated on the outside as at 11. The roof of the furnace is also lined with tubes connected to headers and included in the tubular system.

Burners 12 are placed in both sides of the sloping roof and they are connected with the primary air supply 13. The spaces between the burners are cooled by tubular elements 14 connected in series with the tubular elements of the roof or, if desired, with elements of the upper part of the furnace envelope. If preferred, these spaces may also be closed by suspended refractory panels. Secondary air for completing the combustion is admitted by the duct 33 and the nozzles 34. These nozzles 34 are placed on the four walls of the furnace, the tubular envelope of the furnace being interrupted for this purpose. Preferably the axes of the nozzles are so placed as to cause a rotary motion to the flame. It is within the scope of the invention to arrange auxiliary cross burners to accelerate the ignition of the main coal jets in case coals are used which are slow to ignite. Such auxiliary burners can take the place of some of the secondary air nozzles, without affecting in substance the features of the preferred form described. They are indicated at 12*b*. When fuels are used that are easily ignited, it is not necessary to provide the secondary air nozzles 34, all the air necessary for combustion being in that case supplied at the burners.

The bottom 35 of the furnace is arranged to have the slag accumulate on it in a molten state. Such slag is then removed by tapping. If preferred, this can be modified by having a tubular slag screen at the bottom.

Referring now to the more detailed construction of the tubular envelope of the furnace chamber 10, attention is directed to Fig. 7 showing a section on line 7—7 of Fig. 5. The tubular structure shown covers the entire perimeter of the furnace. Pairs of columns 23, 23 are installed at the corners of the furnace. In the form shown there are four pairs of such columns, the horizontal projection of the furnace being rectangular. The number may be varied and the shape of the furnace may be made other than rectangular. The paired columns are connected by several small horizontal plates 101—101, Fig. 7*a*, on which short headers 24, 25 rest. Each pair of columns 23 therefore supports several short headers in a vertical row. The total flow of the steam and water mixture is divided between the two sets of vertical headers 24 and 25, and further subdivided between the parallel tubes respectively connecting these two sets of headers, the steam and water mixture flowing through them in parallel. The respective levels of the headers and the inclination of the tubes is such that after a complete circuit around the furnace the parallel tubes connect into the header placed in the same vertical row immediately below the initial header. There are thus two parallel paths for the steam and water mixture each comprising short headers placed at diagonally opposite corners and parallel tubes connecting these headers. The clearance between the tubes of one set of headers is made substantially equal to the tube diameter or slightly larger, and the tubes of the second set occupy the spaces between the tubes of the first set. The sides of the furnace thus present a completely water cooled tubular envelope. With such a construction it will be unnecessary to have the usual solid brick setting, and inexpensive thermal insulation 11 will be sufficient. The headers 24, 25 may safely be anchored between the columns, the thermal expansion of the tubes being taken up by bending of the tubes at the corners as at 27. In the case of large or high pressure boilers, it is advisable to anchor only one half of the headers, the other half being allowed to slide on the supporting plates joining the columns 23. The vertical thermal expansion of the furnace envelope is reduced in this construction to the vertical expansions of the separate vertical header and this is not cumulative, some clearance being provided for this purpose between the header tops and the supporting plates as at 102, Fig. 7*a*. The position of the columns gives the necessary accessibility to the header hand holes 24*a*, 25*a* provided for inspection, cleaning, and rolling in of the tubes. In practice, the headers will of course be suitably insulated and access doors provided to the hand holes.

As a variation, in the case of steam generators of small output, the short vertical headers can if desired be fitted with flanges and bolted together to make up the vertical columns. The variety in shape of the headers is not limited in my invention. For instance headers of triangular section with one hand hole for each pair of tubes may be used with benefit, also headers made of long pipes with inner partitions welded in or cast at required points of subdivision. Vertical assemblies of steel boxes connecting one or more pairs of tubes and welded to the vertical columns can be also used instead of the short headers just described. In these cases, all the outside piping and casing should provide for the total vertical thermal expansion.

In Fig. 8 is shown a variation for cases where it is thought necessary to arrange one wall of the furnace for a refractory lining or where it is desired to leave it, or a portion of it, open for a stoker. In this case there are two sets of headers each comprising three series of headers. The two sets are designated 24*b* and 25*b* respectively and together with the connecting tubes furnish continuous covering for the three furnace walls. The tubes of the two sets of headers are interspaced as in the case described in connection with Figs. 7 and 7*a*. To provide the necessary return flow at the ends of the water cooled furnace covering, successive pairs of headers at these points are made in one piece.

Referring further now to Fig. 5 the casing 36 encloses the convection heating surfaces. This includes the convection superheater 37, the economizer 38, the last vaporization stage 39, and the first vaporization stage 40. An air preheater 41 is also preferably arranged succeeding the steam generating stages in the path of the gases.

The connections of the various component parts of the tubular system of the boiler will be explained below, where reference will be made to Fig. 13.

The gases generated in the furnace usually entrain small particles of molten slag which settle on the first rows of boiler tubes, clogging them by gradual accumulation. This is a common and serious trouble with the majority of water tube boilers particularly where pulverized coal is used as fuel. In all water tube boilers the flow of gas in the first rows of tubes is such that the accumulating slag gets a support either

from the tube itself where the latter is nearly horizontal or from the underlying slag accumulations on nearly vertical tubes. In my arrangement I provide a plurality of widely spaced horizontal water cooled tubes 41 at the point where the gases leave the furnace, the flow of gas across these tubes also being horizontal. The advantage of this arrangement is that the slag which usually settles in formations extending along the line of gas flow, gets no support and the accumulation breaks of its own weight. The remaining entrained particles of slag solidify after passing the water cooled slag screen 41 and will not clog the first rows of tubes in the convection zone but will settle in large part in the ash pocket 42, being separated out of the gas by the sharp upward turn of the gas flow at this point.

As far as the convection surface is concerned, its construction does not present anything radically new over established practice except that the tubes are laid out mostly horizontally for the best utilization of space, there being no necessity to allow for natural gravity circulation. Figs. 9 and 10 show vertical sections at right angles to each other of the convection tube bank. Good heat transfer requires certain velocity of the water and steam mixture in the tube. The heat transfer increases with the velocity but the frictional resistance to the flow increases very rapidly with an increase in the velocity. It is therefore necessary to increase the number of tubes arranged in parallel as the evaporating water increases in volume. Instead of increasing the number of tubes arranged in parallel the size of the tubes could be increased but this is less desirable.

The convection bank of tubes may be arranged in many ways known to the art. As the increase in the specific volume proceeds, due to the formation of steam, the number of parallel coils should be increased. Figs. 9 and 10 show one of the possible ways in which square headers are stacked up. The bank consists of several rows of tubes, eight tubes in each row for instance. The flow starts in four parallel tubes, thus having cross-over headers and cross-down headers as shown in the upper part of Figs. 9 and 10. When the number of tubes connected in parallel should be increased, for instance doubled, the cross-over headers are eliminated and only cross-down headers are used, as shown in the middle part of Figs. 9 and 10. When the next doubling of the number of parallel tubes is required, the short vertical cross-down headers are used as shown in the lower part of Figs. 9 and 10. Instead of headers, so-called U bends, or connecting boxes may be used and the tubes supported on drilled plates according to the established economizer construction practice. This part of the description is intended to illustrate the preferred way of changing the number of parallel flows and in no way restricts the invention to the method shown on Figs. 9 and 10. The number of tubes which it will be necessary to use in any given case evidently depends upon the steaming capacity of the boiler and the size of the tubes.

In the preferred form of my invention as illustrated in Fig. 5, the slag screen 41 is supplemented by the water cooled arch 44 which comprises a header and tubes connected to it. The arch as well as the slag screen are connected in series with the coils as described further on in connection with Fig. 13. The purpose of this arch is two fold. First it is intended to reduce the wear on the refractory portions of the arch by the erosive slag contained in the hot gases which pass this point at high velocity. In the second place the arch by suitably deflecting the flow of gas reduces the stratification, thereby producing a more even heating effect in the first convection rows of tubes, which is very important in the case of several parallel flows.

In order to make clear the connections between the several portions of the boiler, reference should be made to Fig. 13. Here the several sections are shown diagrammatically and the connections between them are indicated. Feed water enters the economizer 38, the first portion of the economizer having, for example, two coils in parallel; and after having been heated in the economized to a point approximating the boiling point, the water enters the header 48, beyond which the path of the water is shown divided into four parallel coils forming the evaporating stage 49, the outlets from the header 48 being controlled by individual valves. At some point in this first vaporization stage the number of coils is duplicated in accordance with the showing of Figs. 9 and 10. The six parallel coils emerging from the first vaporizing stage 49 connect into header 50 arranged preferably in a horizontal position, this header being connected by pipes 51 to the inlet headers of the two sets of headers and tubes constituting the furnace envelope as shown and described in connection with Fig. 5. The number of parallel coils in each set is, for example, six, making a total of twelve.

After passing through the furnace envelope, the water and steam is delivered by these twelve coils into the slag screen 41. In flowing through this slag screen, the mixture of steam and water crosses the gas passage several times, for example, four times as shown in Fig. 13. After completing the passage through the slag screen, the steam and water mixture enters the header 52 which forms the inlet header for the arch 44. The steam and water mixture is next delivered into several steam separators 13 arranged in parallel as shown diagrammatically in Fig. 13. In these separators the unevaporated portion of the water, which is a concentrated solution of the salts in the water, is separated out to be withdrawn. Fresh water is added to replace the withdrawn concentrated solution, and the new mixture of the dry steam with the fresh water that has been newly added is led to the final vaporization stage 39. The detail of the separators is shown in Fig. 11 to be referred to hereafter.

After a complete vaporization has occurred, the steam is carried to the radiant heat part 54 of the super-heater placed at the top of the furnace including the roof, and thence into the final convection part 37 of the superheater and thence to the steam main.

It will be understood that the radiant part of the superheater may, if desired, be placed lower down in the path of flame instead of at the top as shown and described.

As will be clear from what was said above, the amounts of heating surface in the different heating zones are so proportioned that after the mixture has passed through the arch only a small percentage of the total weight is still in the form of water.

In the case of an outdoor installation, such as shown in Fig. 5, all of the columns which support the various mentioned parts of the steam generator are fitted with consoles on which the light outer casing 55 is hung. This outer casing is preferably mostly glass windows and is intended

to protect the steam generator and the operating personnel against the weather and to provide a sheltered space for the operator's control instruments, piping, etc.

During short stoppages of feeding and firing, steam may trickle up the bank of tubes in the convection zone while water will be dripping down and this may affect the proper distribution of water and steam in the coil thereby retarding putting the boiler back on the line when the time arrives to do this. To obviate this inconvenience, I preferably insert U-bends in suitable places in pipes connecting different sections of the total coil. Such bends are shown, for example, in the pipes 51 connecting the section 49 to the furnace envelope. These U-bends act during stoppages like air seals and, if required, suitable piping with the necessary valves will be provided to break these air seals, the valves being either operated by hand or automatically. This being a well-understood feature, it will be unnecessary to illustrate it.

The separators 13 referred to above and shown in Fig. 13 are each preferably arranged as the one shown in Fig. 11. In this figure only one separator is shown, it being understood that the others are duplicates. 10 is one end of the coil interrupted at the withdrawal point, 11 being the end of the coil where the steam returns to the coil after the concentrate has been eliminated. The admission of the substitute fresh feed water is controlled by the valve 12. 13 is a centrifugal steam separator although it will be understood that, if preferred, some other type of separator may be used. The concentrated salt solution that is separated out is withdrawn through the trap 14 and may be allowed to go to waste. However, when high steam pressures are used, the heat in this concentrate may be a fairly large quantity and in such cases I prefer to employ a heat saving device to reclaim at least part of this heat. Before sending the water to the heat reclaiming device, I prefer to flash a part of it into steam by reducing the pressure and to use this steam in a feed water heater. This flashing is done in the centrifugal separator 18, the water flowing first through the valve 22 and then through the reducing nozzle 22a. The steam formed is led into the feed water heater 17 containing coils through which the feed water flows. The condensate formed is removed through the trap 19a. The water separated out in the separator 18 is withdrawn through the trap 19.

The valves 20 and 21—21 are provided for use upon starting and shutting down the steam generator. At such times these valves make it possible to cut out this concentrate separating device.

Instead of first flashing a portion of the water withdrawn from the system into steam as just described, I may, as illustrated in Fig. 12, use a heat exchanging device where all of the water flows in contact with the coil 17a carrying the feed water to the boiler.

By the separation of the furnace and the convection stages of the boiler in the manner described into two separate parallel constructions, expensive suspension of the heavy parts on columns is avoided. The furnace is supported by the four pairs of evenly loaded columns described above and the heavy convection bank of tubes and headers is supported in any preferred way. The division of the furnace and the remaining portions as indicated, further reduces the total height of the steam generator thereby reducing the cost of the boiler setting. The trouble from slagging of the first rows of the tubes of the convection bank is eliminated by the provision of the slag screen tubes 41. The furnace can be economically constructed and presents a large volume for a straight flame and a long flame path necessary for complete combustion especially in connection with opposed firing from the burners and additional turbulence provided by the tangential jets of secondary air. The long straight path of the flame eliminates the danger of direct flame impingement on the tubes which often produces blistering. The rectangular form of the furnace, tending to break up the rotary motion produced by the tangential jets of secondary air increases the turbulence and thereby promotes combustion.

In Fig. 14 the means for regulating the output of the generator and the temperature and pressure of the steam are diagrammatically illustrated in connection with the boiler. This will best be explained by first stating the general principle of operation, as follows: First, the amount of water fed per unit of time into the generator and the amount of fuel fired per unit of time are controlled by the demand of steam as indicated by the changes of steam pressure in the mains. This simultaneous control of feed water flow and of the rate of combustion is well known in its application to coil boilers and in fact this principle follows naturally from the operation of a coil boiler not having any considerable water storage. When this problem is studied, however, in connection with boilers of large output and long coils the insufficiency of this simple scheme becomes apparent. Methods in actual use provide an intermittent control and also do not take care of differences between the actual performance of the boiler and the performance theoretically set by the positions of the controls. In long coils this may involve surges, water hammer, uneven quality of steam especially if the quality of fuel and efficiency of combustion is variable and of course beyond control, or when the resistance in tubes is variable due to clogging, different inlet feed water temperatures, improper functioning of the feed pump, and so forth. In large coil boilers these secondary factors are becoming of great importance and this led me to the invention of the differential control, the scheme of which is shown in Fig. 14. The boiler shown diagrammatically in this figure is the same as that of Fig. 5. The control system has been shown in a separate figure merely for purposes of clarity.

58 is a feed pump which forces the water into the economizer section 38. The water then passes successively, as described before, through the first vaporization section 49, the second vaporization stage 28 in the furnace, the slag screen 41, the arch 44, the steam separator 13, the last vaporization stage 39 where fresh water is added through the valve 12, the radiant heat superheater 54, and the convection superheater 37, being finally delivered to the main 59. The course of the flame and hot gases is shown by the lines 45—45.

Before starting, the steam generator should be full of water. It will be understood that during filling, the boiler is thoroughly vented at any places where air may collect. Next, the full pressure of feed water is put on by opening the feed by-passes 65 and the combustion is started. At the same time the throttling valve 60 is opened to discharge water into the open make-up water tank 61. The vaporization starts in stages 28

and 54 which are exposed to direct radiation, and water from the vaporization stages 41, 44, 39 and superheater stages 54 and 37 is quickly expelled into the tank 61. Any steam generated at this period is led into the water of the tank 61 and is there condensed until the temperature of this water reaches about 212 deg. F., after which the steam passes into the water without condensing and to the air through the open vent 62. After an interval the lagging heating effect in the convection surface will produce the proper proportions of the steam and water in the several stages corresponding to the established flow and rate of firing judged by the attainment of normal steam temperature, and then the boiler can be connected to the main by opening the non-return and stop valves 63 and 64 respectively. During the starting up period, the fixed rate of feed is maintained by the feed by-pass valve 65 while the main feed controlling valve 66 is kept closed. During starting the steam separators are cut out as explained above, the by-pass valve 20 being open and the valves 21—21 being closed. After running conditions have been attained, the steam separators are put on the line by opening the valves 21—21 and closing the valve 20 and opening the valve 12 for adding the fresh feed water. The master regulator 67 through relays 68 and 69 respectively controls the feed group of apparatus and the combustion group of apparatus. The first group consists of feed pump speed regulator 70 and of the feed valve regulator 71. The second group consists of the fuel feed regulator 72 and regulators for the induced forced draft fans and primary air fan respectively 73, 74, 75. Thus the several apparatuses which enter into regulation of the boiler output are connected to operate simultaneously that is to respond instantly and together to the master regulator 67. But in large boilers this is not sufficient and I am introducing the differential regulators 76 for the feed group and 77 for the combustion group of apparatus. These are differentially connected to the respective relays and to the master regulator, for instance, by means of floating levers with adjustable arms, which are shown in Fig. 14 or by other means known to the art. According to my invention the differential regulator 76 of the feed group is actuated by the difference between the actual rate of heat liberation and the rate of heat liberation set by the master regulator, this difference being preferably taken by a device 78 made sensitive to the total rise of steam temperature between the inlet and outlet headers of the superheaters, because of its insignificant time lag in respect to combustion. So, for instance in case of suddenly poor fuel the rate of feeding water into the boiler will be reduced by lesser superheat to correspond to the actual heat liberation. Similarly the differential combustion regulator 77 is actuated by the difference between the actual flow of water and the flow as set by the master controller. This difference is taken at the feed valve by device 79 as difference between the static head in the valve or pipe and the dynamic head in the throat of the valve, as shown diagrammatically on a somewhat enlarged scale on Fig. 14. Thus said differential regulator 77 will not operate if said difference in hydraulic heads and hence the velocity at the feed valves is normal. In case, for instance, of clogging of tubes and increased total resistance to the flow, the flow and the velocity through the valve will decrease, hence the hydraulic head difference will also decrease and the regulator 77 will decrease the rate of combustion thus restoring the proper relation of water flow to combustion rate. The action of differential regulators will affect the output of the boiler which will be corrected by the next movement of the master regulator 67. The differential effect as compared with the main effect given by the master regulator will be achieved by a lesser range and amplitude of movement of the relays by the differential regulators. In the scheme as invented by me the chances of regulation hunting are not only reduced but also means in the form of differential regulators 76 and 77 are provided to dampen the hunting if such arises.

For proper functioning of the control system the substitute water valve 12 is controlled by a device 80 which acts in response to the rate of concentrate discharge from separator 13.

Devices diagrammatically shown in Fig. 14 and referred to in the description of that figure are all commercial devices obtainable on the market.

For boilers of this type, designed to have a very large output, it will be necessary to have toward the end of the apparatus as many as thirty to forty parallel coils and it becomes necessary to ensure uniformity of water distribution among these coils. For this purpose a series of valves 81—81 is inserted in the connection of the economizer stage and the first vaporization stage where the number of coils is not yet large. Preferably these valves have associated with them flow indicators. The valves are preferably manually operated to effect an even distribution of water among the initial coils, but an automatic operation known to the art may also be resorted to.

The proper behavior of a steam generator built in accordance with my invention during emergencies such as failures of the regulating system itself, requires also the provision of a minimum flow of water through the tubes and a minimum amount of combustion, these two being so proportioned that the minimum deliveries of water and fuel maintain the proper distribution of water and steam in the coils. These flows of water and fuel must of course be independent of the regulating system and are provided in the following manner: The minimum combustion is obtained from one or more suitably placed burners in continuous operation at a uniform rate. The minimum flow of water is arranged also for emergencies when the main stop valve or the non-return valve are closed. For this purpose a by-pass outlet into the feed water tank 61 is arranged and its valve 82 besides being loaded to open at excess pressure is interlocked with the main stop and non-return valves as indicated in Fig. 14 so that when the latter are closed, the by-pass valve is opened. The by-pass inlet is by valve 65, already described. This minimum flow of water and fuel is preferably also used during so-called banking periods when the boiler is maintained in a state of readiness to be brought up to substantial steaming capacity from its practical minimum.

The novel features of this control of operation for coil boilers without water storage or natural circulation may be summed up as follows:

With the usual methods of coil boiler control, when the demand for steam changes, the feed water valve, the fuel feeding and draft devices are set in new positions to handle the required changed amounts of water, fuel and gas. The usual methods do not go beyond this and with their application the temperature of steam is va-

riable. I am proposing to use this regulation only as a first approximation and for the final mutual adjustment of the water feed, fuel feed and gas movement I am using additional devices, differentially introduced, so that the rate of water feed is adjusted by the difference between the actual rate of heat liberation and the rate of heat liberation necessary for the uncorrected water feed. In this scheme the additional differential device will operate until the proper balance is reached and said difference in heating rates becomes zero. Similarly the rate of feeding fuel is adjusted by the additional differentially introduced device made sensitive to the difference between the actual velocity of water through the feed valve opening and the velocity at which the valve operates correctly with the master regulator. In other words the rate of feeding fuel, which is first set to correspond to the rate of feeding water, is further corrected to correspond to the amount of water actually delivered to the boiler. In this scheme the additional differential device will operate until the proper balance is reached. By making said differential devices sensitive to the differences between the rates of feeding water and fuel as actually obtained and as set by the master regulator and by connecting them as described I am avoiding regulation hunting when both corrections or adjustments are made simultaneously.

Good performance of large coil boilers depends upon continuous maintenance of proper proportions of steam and water in evaporating coils at all steam demands. With the usual methods of control this is possible only at steady loads, clean boiler, uniform fuel, i. e., in conditions rarely met in actual operation and the consideration of these actual conditions led me to the invention of the differential control. With such control as described any sudden irregularity in the water feed or in the combustion will automatically correct combustion or water feed respectively and the danger of flooding the coils or overheating them will be eliminated.

Under usual type of control a coil boiler would maintain steam pressure (deliver proper quantities of steam) but the temperature of superheated steam will be variable, while a coil boiler having the differential control invented by me will deliver proper amounts of steam at uniform both pressure and temperature.

What I claim is:

1. A steam generator of the class described comprising a furnace whose walls are lined with water tubes, means to feed fuel adapted to be burned in suspension from points adjacent to the top of the furnace, a separate vertical bank of substantially horizontal tubes, a gas passage to carry the products of combustion from the lower end of the furnace to the bottom of the separate bank of tubes, an off-take for the gases at the top of said separate bank of tubes, a slag screen in said passage comprising a plurality of horizontal tubes set across the gas flow, said tubes all being connected to present a closed path through which the water to be vaporized travels unidirectionally.

2. A steam generator according to claim 1, and including in addition an arch above the slag screen to protect the roof of the said gas passage, said arch comprising tubular elements connected to form part of the said closed path.

3. The method of generating steam comprising forcing the water to be evaporated through a tubular structure in a continuous stream from inlet to outlet, heating the water first in a zone of low heating effect to a point where a substantial part of the water has been evaporated thereby accelerating the rate of flow, thereafter heating the mixture in zones of most intense heating effect until all but a relatively small part of the water has been evaporated, withdrawing said small part of unevaporated water from the boiler and replacing it by a similar amount of fresh feed water.

4. The method according to claim 3 and further comprising automatically regulating the rate of adding the fresh feed water responsively to the amount of concentrate removed to make the two equal.

5. The method according to claim 3 and further comprising superheating the steam, and regulating the rate of fuel feed to keep the final steam temperature constant, whereby the fraction of water remaining unevaporated at the point of withdrawal remains substantially constant.

6. The method according to claim 3, and further comprising superheating the steam in part in the zone of low heating effect and in part in the zone of intense heating effect so as to keep substantially constant the proportional part of the coil used for superheating, and regulating the rate of fuel feed to keep the final temperature constant.

7. In a boiler of the class described, the combination of an assembly comprising two tiers of short vertical headers at opposite corners of the furnace, the several headers of one tier being staggered relatively to those of the other tier, tubes connecting the headers serially and together with them forming a continuous closed path, there being a plurality of parallel tubes connecting each header with the next lower opposite header, the tubes extending along the furnace wall, and a second assembly similar to the first the two tiers of headers of the second assembly being at the other two corners of the furnace and the tubes of the second assembly being arranged to occupy spaces between the tubes of the first assembly.

8. Apparatus in accordance with claim 7, and further comprising vertical columns adjacent to the tiers of headers and shelves secured to the columns upon which the headers rest, there being some clearance between each header top and the shelf above it.

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