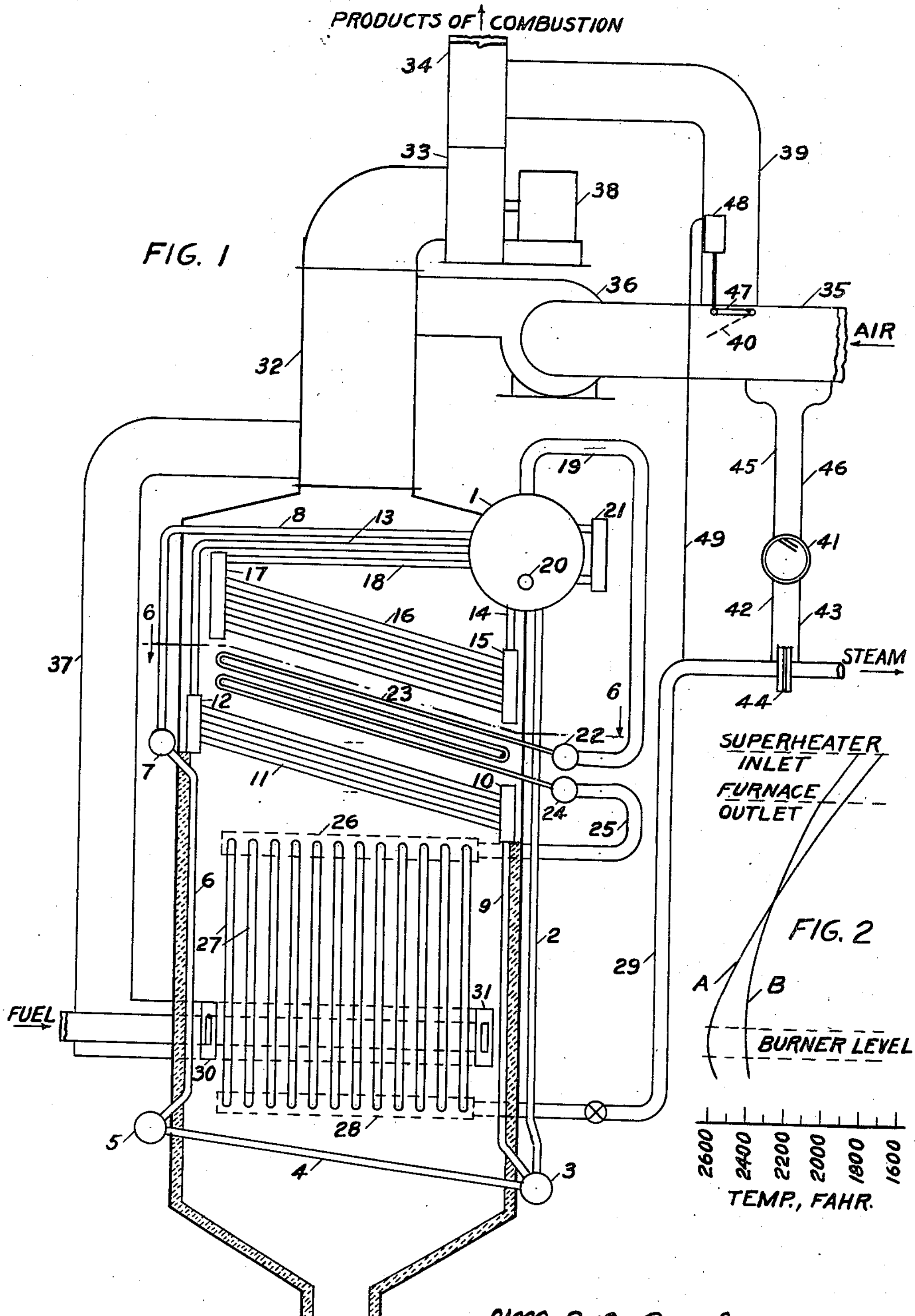
Jan. 28, 1941. W. L. DE BAUFRE 2,229,643

METHOD AND APPARATUS FOR CONTROLLING TEMPERATURE OF SUPERHEATED STEAM

Filed Jan. 2, 1937 3 Sheets-Sheet 1

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Filed Jan. 2, 1937 3 Sheets-Sheet 2

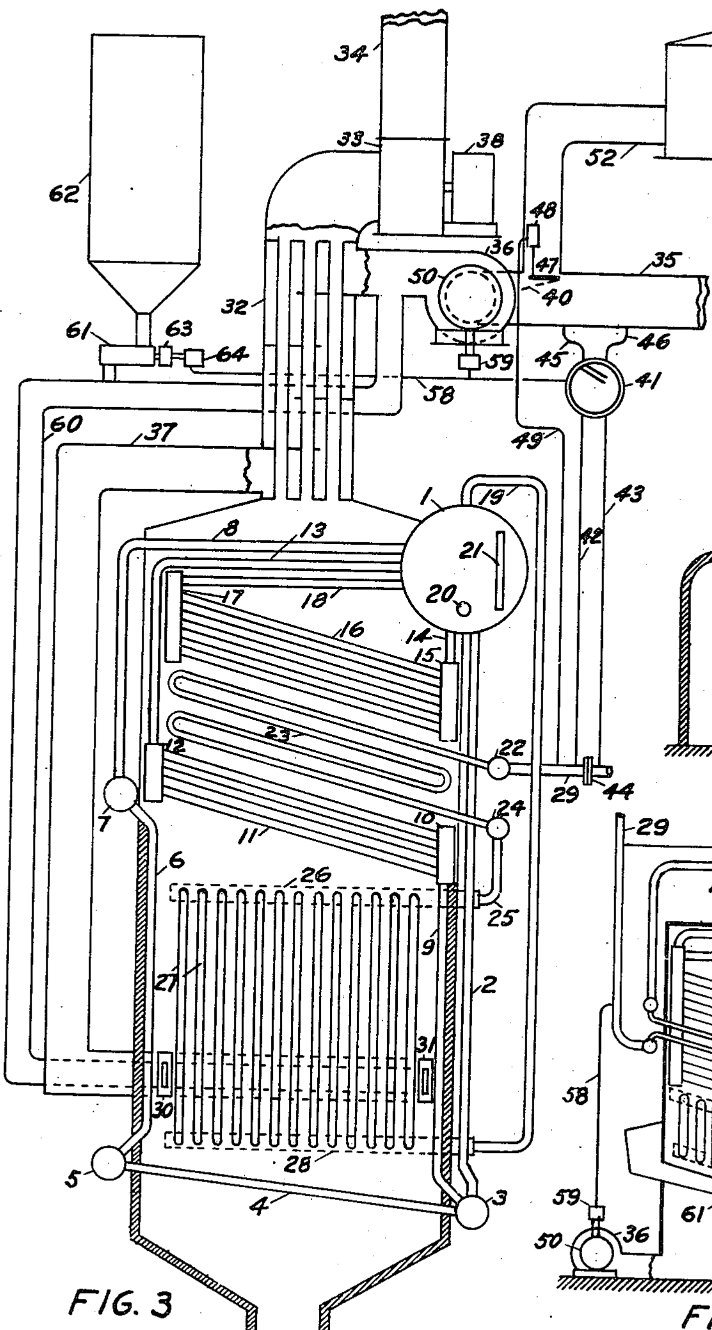


FIG. 3

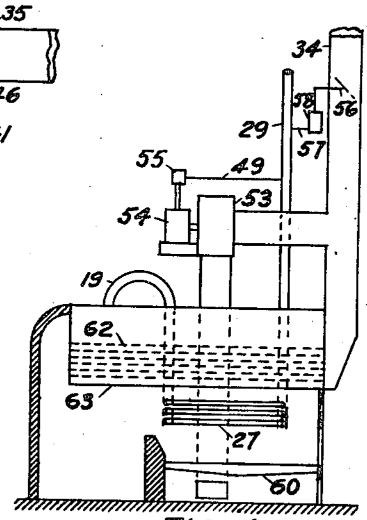


FIG. 4

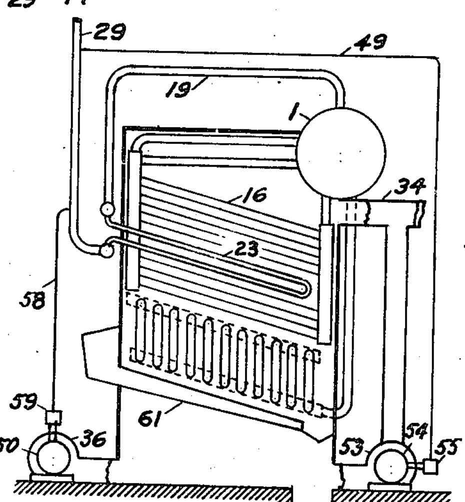


FIG. 5

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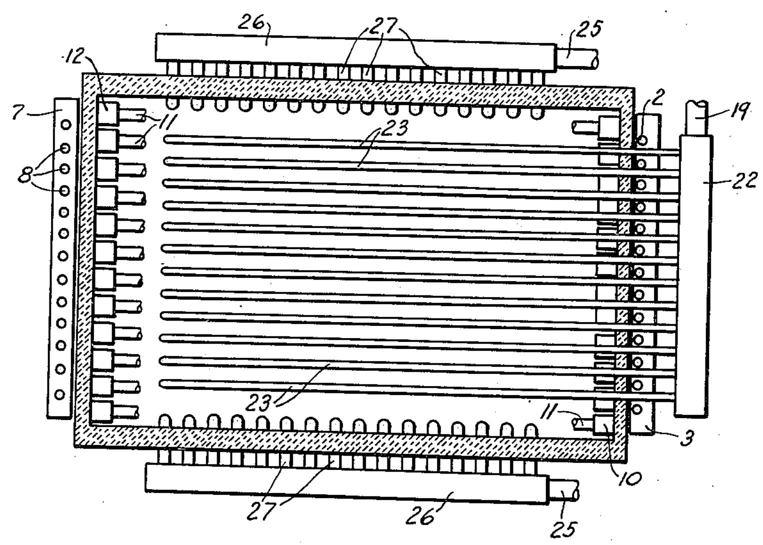
Filed Jan. 2, 1937 3 Sheets-Sheet 3

FIG. 6



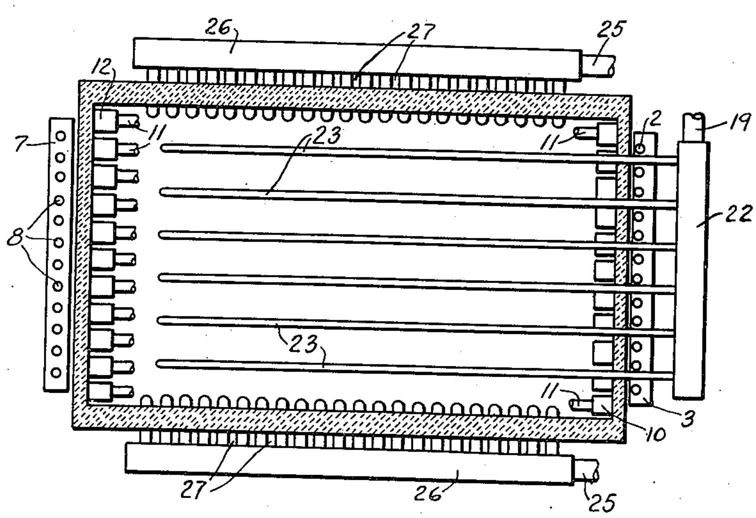




FIG. 7

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# UNITED STATES PATENT OFFICE

2,229,643

## METHOD AND APPARATUS FOR CONTROLLING TEMPERATURE OF SUPERHEATED STEAM

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Application January 2, 1937, Serial No. 118,906

13 Claims. (Cl. 122—479)

This invention relates to steam boilers and is particularly applicable where the steam generated is superheated to a high temperature.

In some of the most modern steam power plants, for example, the steam generated is superheated to a temperature of 900° Fahrenheit. This high superheated steam temperature is desired in order to attain high efficiency of conversion of heat energy into mechanical work and also to reduce condensation of steam in the last stages of expansion in steam turbines. This high steam temperature cannot be safely exceeded appreciably, however, even with the alloy steel used in the superheater elements.

To reach this high superheated steam temperature but not exceed it, requires exceedingly careful proportioning of the heat absorbing surfaces, both for generating steam and for superheating it. But even if the desired superheated steam temperature be just attained initially by very careful designing, the superheated steam temperature will vary during operation by reason of changes in cleanliness of the heat absorbing surfaces. Thus, slag will form and adhere to the heat absorbing surfaces in the boiler furnace, thereby reducing the effectiveness of such surfaces and raising the furnace outlet temperature of the products of combustion. The furnace outlet temperature will also change with the percentage of excess air supplied for combustion, with the characteristics of the fuel burned, and with the rate of combustion and the corresponding rate of steam generation. All these things will therefore affect the temperature reached by the superheated steam, whether the superheating elements are located within the furnace where they absorb heat by radiation from the burning fuel and products of combustion or whether they are located beyond the furnace where they absorb heat by convection from the products of combustion after these products have left the furnace.

One object of the present invention is to attain almost exactly the superheated steam temperature desired without the necessity of so carefully proportioning the heat absorbing surfaces for generating steam and for superheating it.

Another object of the invention is to maintain a substantially constant superheated steam temperature with fluctuations in cleanliness of the heat absorbing surfaces, in the excess air supplied for combustion, in the characteristics of the fuel burned, and in the rate of combustion and steam generation.

Another object of the invention is to maintain a high efficiency of combustion and of steam generation while maintaining the superheated steam temperature substantially constant.

The foregoing together with such other advantages as hereinafter appear or are incident to the invention, are realized by the construction illustrated in preferred form in the drawings, wherein Fig. 1 shows a steam boiler with convection and radiant superheaters in series arranged to maintain a substantially constant superheated steam temperature by recirculating products of combustion, Fig. 2 illustrates the accompanying variations in temperature of the burning fuel and products of combustion, Fig. 3 shows a steam boiler with convection and radiant superheaters in reversed order to that in Fig. 1 arranged to maintain a substantially constant superheated steam temperature by oxygen enrichment of the air supplied for combustion, Fig. 4 shows a steam boiler with radiant superheater only and Fig. 5 shows a steam boiler with convection superheater only, the latter two steam boilers being arranged to maintain a substantially constant superheated steam temperature by recirculating products of combustion. To illustrate different types of firing, Fig. 1 and Fig. 2 indicate pulverized coal burners, Fig. 4 shows grates for hand firing and Fig. 5 indicates a stoker. Fig. 6 is a sectional plan view on the line 6—6 in Fig. 1 illustrating an arrangement in which the convection superheater predominates, i. e. has more heat absorbing surface than the radiant superheater, while Fig. 7 is a similar view illustrating an arrangement in which the radiant superheater predominates, it being assumed that in each figure the convection superheater is made up of looped tubes 23 having a like number, say 4, of vertically spaced traverses as shown in Figs. 1 and 3.

Referring to Fig. 1 and Fig. 2, the steam and water drum of the boiler is shown at 1. Water from drum 1 flows through downcomers 2 to header 3. From header 3, a portion of the water flows through screen tubes 4 to header 5 and thence through wall tubes 6 to header 7. Within screen tubes 4 and wall tubes 6, steam is generated due to heat absorption by radiation from the burning fuel and products of combustion within the furnace. The commingled steam generated and remaining water flow through tubes 8 to drum 1.

Another portion of water flows from header 3 through wall tubes 9 to vertical headers 10 and thence through tubes 11 to vertical headers 12. Steam is generated within wall tubes 9 by radiation from the burning fuel and products of combustion within the furnace. Steam is also generated within tubes 11 partly by radiation of heat from the furnace and partly by convection of heat from the products of combustion flowing between tubes 11. The commingled steam generated and remaining water flow through tubes 13 to drum 1.

Water also flows from drum 1 through tubes 14 to vertical headers 15 and thence through tubes 16 to vertical headers 17. Within tubes 16, steam is generated by convection of heat from the products of combustion flowing between tubes 16. The commingled steam generated and remaining water flow through tubes 18 to drum 1.

Within drum 1, the steam generated is separated from the remaining water, which is recycled. The saturated steam generated leaves through pipe 19. Feed water to maintain the desired water level within drum 1 is supplied through pipe 20. The water level within drum 1 is shown by means of gage glass and column 21.

In Fig. 1, the saturated steam generated flows through pipe 19 to header 22 and thence through tubes 23 to header 24. Within tubes 23, the steam is superheated by convection of heat from the products of combustion flowing between tubes 23. From header 24, the steam flows through pipe 25 to header 26 and thence through tubes 27 to header 28. Within tubes 27, the steam is further superheated by radiation of heat from the burning fuel and products of combustion within the furnace. The superheated steam finally leaves through pipe 29.

Instead of the steam being superheated first by convection and then by radiation, it may be superheated first by radiation and then by convection by flowing through tubes 27 before flowing through tubes 23, as in Fig. 3, pipe 19 being connected to header 28 and pipe 29 to header 22. This latter arrangement is preferable in certain cases in order to reduce the temperature of the metal in tubes 27 which are exposed to direct radiation from the burning fuel and products of combustion within the furnace.

Instead of two superheaters in series, one superheater only may be employed, as shown in Fig. 4 and Fig. 5. Then, in flowing through tubes 27, Fig. 4, the steam will be superheated only by radiation of heat from the burning fuel and products of combustion within the furnace; or, in flowing through tubes 23, Fig. 5, the steam will be superheated only by convection of heat from the products of combustion after they have left the furnace.

In Fig. 1 and Fig. 3, the furnace is bounded by screen tubes 4, wall tubes 6, wall tubes 9, tube bank 11 and superheater tubes 27. Fuel in the form of pulverized coal and air for combustion are injected into the furnace through burners 30 and 31. At the burner level, the burning fuel and products of combustion reach a temperature of say 2600° Fahrenheit as indicated by curve A in Fig. 2 relative to the temperature scale shown. As the burning fuel and products of combustion swirl upwards through the furnace and radiate heat to the surrounding heat absorbing surfaces, the temperature drops as indicated by curve A. At the furnace outlet, the temperature of the products of combustion is say 1900° Fahrenheit. In flowing between tubes 11, the temperature of the products of combustion is further reduced by convection heat transfer to say 1700° Fahrenheit, at which temperature the products of combustion enter the convection superheater 23. Similar temperature conditions exist in the furnaces and boilers of Fig. 4 and Fig. 5.

For superheating the steam by convection of heat to tubes 23 beyond the furnace, products of combustion are thus available at 1700° Fahrenheit after the products of combustion have left the furnace. For superheating the steam by radiation of heat to tubes 27 within the furnace, burning fuel and products of combustion are available at temperatures reaching a maximum of 2600° Fahrenheit.

In Fig. 1 and Fig. 3, after giving up heat by convection to superheater tubes 23, the products of combustion flow between tubes 16, 18, 13 and 8, where the products of combustion are further cooled by convection in generating steam within these tubes. The products of combustion then flow through air preheater 32 where these products are further cooled by heating the air for combustion. The products of combustion are finally discharged by induced draft fan 33 through breeching 34 to a stack not shown. In Fig. 4 and Fig. 5, no air preheater nor induced draft fan is shown. In Fig. 4, the products of combustion flow through tubes 62 in the return tubular boiler 63.

In Fig. 1 and Fig. 3, air for combustion is supplied from duct 35 by forced draft fan 36 which forces the air through air preheater 32 and duct 37 to burners 30 and 31. In Fig. 4, air for combustion is drawn into the ashpit under grates 60, while in Fig. 5, air for combustion is forced by forced draft fan under stoker 61.

Induced draft fan 33 is driven by motor or turbine 38 and forced draft fan 36 is driven by a motor or turbine not shown in Fig. 1 but indicated at 50 in Fig. 3.

In Fig. 1 breaching 34 is connected to duct 35 by duct 39 with damper 40 arranged to vary the relative openings from ducts 35 and 39 for flow of air and products of combustion respectively to forced draft fan 36. When damper 40 is moved up to close duct 39, air only will be forced into the furnace by forced draft fan 36 and the temperature of the burning fuel and products of combustion will vary as explained by reference to curve A in Fig. 2. When damper 40 is moved down to restrict the flow of air for combustion through duct 35 and to permit products of combustion to be drawn through duct 39 from breeching 34, these products of combustion will be recirculated by being mixed with the air for combustion and the temperature of the burning fuel and products of combustion will then vary as indicated by curve B in Fig. 2 for the following reasons.

The presence of carbon dioxide and additional nitrogen commingled with the air injected into the furnace with the fuel, reduces the maximum furnace temperature. This reduction in temperature is due partly to heat absorbed in dissociating the carbon dioxide but mainly to the additional inert material to be heated by combustion. The heat absorbed in dissociation later becomes sensible heat when the carbon dioxide recombines as the temperature is reduced by radiation of heat from the burning fuel and products of combustion. Dilution likewise retards combustion and lengthens the flames.

The amount of heat radiated from the burning fuel and products of combustion varies approximately as the fourth power of the absolute temperature of the hot material. A small reduction in the maximum furnace temperature therefore appreciably reduces the heat radiated at the burner level. But due to the larger amount of material present and to dissociation and later association when products of combustion are recirculated, the drop in temperature is less rapid to the furnace outlet than when no products are recirculated. In fact, with the maximum furnace temperature reduced by recirculation from 2600° to say 2400° Fahrenheit, the products of combustion may leave the furnace at 2000° instead of 1900° Fahrenheit. With recirculation of products of combustion, the temperature of the burning fuel and products of combustion will therefore be represented by a curve such as B in Fig. 2 and the products of combustion will reach convection superheater **23** at say 1700° Fahrenheit as compared with 1600° Fahrenheit without recirculation.

Therefore, in superheating steam by radiation of heat from burning fuel and products of combustion within a furnace, the temperature of the superheated steam is reduced by recirculating more products of combustion due to a reduction in the maximum temperature attained by the burning fuel and products of combustion within the furnace. On the other hand, in superheating steam by convection of heat from products of combustion after they have left the furnace, the temperature of the superheated steam is increased by recirculating more products of combustion due to an increase in temperature of the products of combustion reaching the convection superheater.

When both radiant and convection superheating elements are employed in series, the net effect will depend upon the relative amounts of superheating acomplished in the two elements. If the radiant element predominates, as shown in Fig. 7, the maximum superheat temperature will decrease with increase of recirculation. If the convection element predominates, as shown in Fig. 6, the maximum superheat temperature will increase with increase in recirculation. For the purpose of illustrating that the convection superheater predominates in Fig. 6 and the radiant superheater predominates in Fig. 7, it is to be assumed that the convection tubes **23** are of looped form having a like number of vertically spaced traverses in each figure, say 4, such traverses being serially connected by return bends as illustrated in Fig. 1.

It is to be understood that recirculation of products of combustion for this purpose is not excessive. With large amounts of products recirculated, the maximum superheat temperature with a convection superheater will decrease instead of increase with increase in recirculation by reason of the diluting effect of the products recirculated more than counteracting the effect of retardation of combustion.

Variation in the amount of products of combustion recirculated is accomplished by varying the position of damper **40** which is moved by arm **47** operated by mechanism **48**. Mechanism **48** is automatically controlled by the temperature of the superheated steam in pipe **29** through distant type thermometer **49**. When the radiant type superheater **27** predominates, mechanism **48** moves arm **47** downwards to open damper **40** when the superheated steam temperature rises. When the convection type superheater **23** predominates, mechanism **48** moves arm **47** upwards to close damper **40** when the superheated steam temperature rises. That is, with both radiant superheater **27** and convection superheater **23** in series, mechanism **48** is arranged to move arm **47** in the direction corresponding to the superheater having the predominant effect.

The use of air preheater **32** is desirable with recirculation of products of combustion for controlling the superheated steam temperature because the reduction in efficiency due to the products of combustion escaping from the steam generating surfaces at a slightly higher temperature with recirculation is compensated somewhat by the use of the air preheater. In an air preheater, conditions of heat transfer are adversely affected without recirculation due to the fact that the air to be heated is appreciably less in amount than the products of combustion to be cooled. With recirculation, this ratio is nearer to unity with resulting improvement in heat transfer conditions. This improved heat transfer helps to maintain the high efficiency of steam generation as the amount of products recirculated is increased.

When products of combustion are recirculated, the draft loss due to flow of the products of combustion from the furnace over the heat absorbing surfaces should not be maintained in proportion to the pressure drop of the steam generated flowing through a nozzle, as is customary when products of combustion are not recirculated in order to maintain high combustion efficiency. When products of combustion are recirculated, the draft loss is not a measure of the air supplied for combustion. It is therefore proposed to compare the pressure drop of the air supplied for combustion as it flows through duct **35** to forced draft fan **36** before recirculated products of combustion are mixed therewith, with the pressure drop of the steam generated as it flows through a nozzle **44** in steam pipe **29**.

Flow meter **41** compares the rate of steam generated with the rate of air supplied for combustion. Tubes **42** and **43** are connected before and after nozzle, or orifice, **44** in steam pipe **29**. Tubes **45** and **46** are connected to two points on duct **35**, between which points an orifice may be located. The two pens in flow meter **41** draw curves on a revolving chart of air flow and steam flow. As the fuel fired is varied to maintain a constant steam pressure with varying demand for steam from the boiler, forced draft fan **36** is varied in speed to maintain variations in the air flow curve on meter **41** corresponding with the variations in the steam flow curve.

Another way of regulating the superheated steam temperature by varying the relative amount of inert material mixed with the active fuel and oxygen, would be to inject more or less nearly pure oxygen with the air for combustion and then vary the amount of oxygen so injected relative to the air supplied for combustion as to maintain a substantially constant superheated steam temperature, as indicated in Fig. 3 where **51** is a storage tank for nearly pure oxygen. The nearly pure oxygen flows through duct **52** and is drawn into duct **35** past damper **40** which is automatically controlled by mechanism **48** arranged to move arm **47** in the direction corresponding to the superheater **27** or **23** having the predominant effect, so as to maintain the superheated steam temperature substantially constant in pipe **29**. Recirculation of products of combustion is preferable, however, by reason of the cost of installing and operating a plant for producing oxygen. The increased efficiency of combustion and steam generation by using oxygenated air would not be sufficient to compensate for the additional cost of the oxygen.

A pulverized fuel furnace has been illustrated in Fig. 1 for convenience. The method and apparatus claimed, however, may be applied to steam boilers fired with gas, oil or solid fuel or stokers or grates with essentially the same results. In the boilers with stokers and with grates in Fig. 5 and Fig. 4 respectively, an additional fan 53 is shown with driving motor 54 because some such device would obviously be required to recirculate the products of combustion, particularly with no forced draft fan in Fig. 4. This recirculating fan 53 is then automatically controlled by mechanism 55 operated by distant type thermometer 49 so as to maintain the superheated steam temperature substantially constant in pipe 29. The steam pressure is customarily maintained constant when fuel is fired on stokers or grates by automatically controlling the supply of air for combustion. In Fig. 4, this is accomplished by damper 56 in duct 34 automatically operated by damper controller 57 in order to maintain the steam pressure substantially constant in pipe 29 to which pressure tube 58 is connected. In Fig. 5, it is accomplished automatically by the speed of forced draft blower 36 driven by motor 50 under the control of mechanism 59 with pressure tube 58 to pipe 29. All details required with pulverized fuel are not shown, such as the use of some of the preheated air for drying in the mill and transporting the pulverized coal to the burners. These details are omitted as unessential to the invention. In Fig. 3, however, the automatic control of fuel and air for combustion is indicated. Thus, some of the air for combustion is utilized to convey the pulverized coal through duct 60. Pulverized coal is fed to duct 60 by feeder 61 from bin 62. This feeder is driven by motor 63 automatically controlled by mechanism 64. Both mechanism 59 for motor 50 driving forced draft fan 36 and mechanism 64 for motor 63 driving pulverized feeder 61 are automatically operated to maintain the steam pressure substantially constant in pipe 29 by pressure tube 58 extending to mechanisms 59 and 64 from boiler meter 41. This arrangement is diagrammatic of control elements which are well known in the art.

In the operation of a steam boiler with recirculation of products of combustion varied in accordance with my invention to maintain a substantially constant superheated steam temperature, fuel and air for combustion are supplied in the usual manner to maintain the desired steam pressure. Instead of using the draft loss of the products of combustion from the furnace to measure the supply of air for combustion, some more direct method is employed as described. Feed water is supplied to maintain the desired water level within the steam drum. The temperature of the superheated steam is maintained substantially constant by means of some device which automatically varies the amount of products of combustion recirculated until the superheated steam temperature returns to the desired normal value when it deviates therefrom.

Recirculation of products of combustion is not new; but it is believed to be new to utilize this means for controlling the temperature of superheated steam in steam boilers. Recirculation of products of combustion in steam boilers has been proposed for recovering unconsumed fuel and returning it to the furnace for combustion. But this is impractical because a furnace which is too small to burn the fuel completely without recirculation, is further overloaded when the unconsumed fuel is thus returned to the furnace. In oil cracking stills, recirculation of products of combustion has been employed to lower the temperature of the products of combustion as they leave the furnace, but the temperature within the furnace is unaffected. In the present proposal, the temperature of the products of combustion leaving the furnace is increased and the maximum furnace temperature is decreased. Other proposed applications of recirculation of products of combustion to industrial furnaces differ still more from the present proposal.

I claim:

1. The method of generating and superheating steam which includes the steps of delivering fuel and air to a furnace, burning the fuel in the furnace, and conveying away the products of combustion; transferring heat by radiation from the burning fuel and products of combustion within the furnace and by convection from the products of combustion after they leave the furnace to water thereby evaporating it to steam; varying the rate of fuel and air delivery to the furnace to maintain the pressure of the steam generated substantially constant; returning some of the products of combustion from a point beyond the furnace to the furnace whereby the maximum temperature in the furnace is lowered, the amount of heat absorbed by radiation in the furnace reduced, and the temperature of the gases leaving the furnace raised; transferring heat by convection from the products of combustion after they have left the furnace to the steam to superheat it; and regulating the amount of products of combustion returned to the furnace to keep the final temperature of the steam substantially constant.

2. The method of generating and superheating steam which includes the steps of delivering fuel and air to a furnace, burning the fuel in the furnace, and conveying away the products of combustion; transferring heat by radiation from the burning fuel and products of combustion within the furnace and by convection from the products of combustion after they leave the furnace to water thereby evaporating it to steam; varying the rate of fuel and air delivery to the furnace to maintain the pressure of the steam generated substantially constant; returning some of the products of combustion from a point beyond the furnace to the furnace whereby the maximum temperature in the furnace is lowered, and the amount of heat absorbed by radiation in the furnace reduced; transferring heat by radiation from the burning fuel and products of combustion in the furnace to the steam to superheat it; and regulating the amount of products of combustion returned to the furnace to keep the final temperature of the steam substantially constant.

3. The method of generating and superheating steam which includes the steps of delivering fuel and air to a furnace, burning the fuel in the furnace, and conveying away the products of combustion; transferring heat by radiation from the burning fuel and products of combustion within the furnace and by convection from the products of combustion after they leave the furnace to water thereby evaporating it to steam; varying the rate of fuel and air delivery to the furnace to maintain the pressure of the steam generated substantially constant; returning some of the products of combustion from a point beyond the furnace to the furnace whereby the

maximum temperature in the furnace is lowered, the amount of heat absorbed by radiation in the furnace reduced, and the temperature of the gases leaving the furnace raised; transferring heat both by radiation from the furning fuel and products of combustion in the furnace and by convection from the products of combustion after they have left the furnace to the steam to superheat it; and regulating the amount of products of combustion returned to the furnace to keep the final temperature of the steam substantially constant.

4. The method defined in claim 3, the greater part of the heat transfer for superheating the steam being by convection from the products of combustion after they have left the furnace.

5. The method as defined in claim 3, the greater part of the heat transfer for superheating the steam being by radiation from the burning fuel and products of combustion in the furnace.

6. The method defined in claim 1, said transfer of heat by convection from the products of combustion after they have left the furnace to superheat the steam constituting at least the predominant part of the heat transferred to the steam to superheat it.

7. The method of generating and superheating steam which includes the steps of delivering fuel and oxygen and inert material to a furnace, burning the fuel in the furnace and conveying away the products of combustion; transferring heat by radiation from the burning fuel and products of combustion in the furnace and by convection from the products of combustion after they leave the furnace to water thereby evaporating it to steam; varying the rate of fuel and oxygen delivered to the furnace to maintain the pressure of the steam generated substantially constant; transferring heat by convection from the products of combustion after they have left the furnace to the steam to superheat it; and maintaining the final temperature of the steam substantially constant by increasing the amount of inert material relative to the amount of oxygen as the temperature tends to fall, whereby the maximum temperature in the furnace is lowered, the amount of heat absorbed by radiation in the furnace reduced, and the temperature of the gases leaving the furnace raised, and vice versa.

8. The method of generating and superheating steam which includes the steps of delivering fuel and oxygen and atmospheric air to a furnace, burning the fuel in the furnace and conveying away the products of combustion; transferring heat by radiation from the burning fuel and products of combustion in the furnace and by convection from the products of combustion after they leave the furnace to water thereby evaporating it to steam; varying the rate of fuel and oxygen and atmospheric air delivered to the furnace to maintain the pressure of the steam generated substantially constant; transferring heat by convection from the products of combustion after they have left the furnace to the steam to superheat it; and maintaining the final temperature of the steam substantially constant by increasing the amount of atmospheric air relative to the amount of oxygen as said temperature tends to fall, whereby the maximum temperature in the furnace is lowered, the amount of heat absorbed by radiation in the furnace reduced, and the temperature of the gases leaving the furnace raised, and vice versa.

9. The method of generating and superheating steam which includes the steps of delivering fuel and oxygen and atmospheric air to a furnace, burning the fuel in the furnace and conveying away the products of combustion; transferring heat by radiation from the burning fuel and products of combustion in the furnace and by convection from the products of combustion after they leave the furnace to water thereby evaporating it to steam; varying the rate of fuel and oxygen and atmospheric air delivered to the furnace to maintain the pressure of the steam generated substantially constant; transferring heat by convection from the products of combustion after they have left the furnace to the steam to superheat it; and maintaining the final temperature of the steam substantially constant by enriching the mixture of fuel, oxygen, and atmospheric air through increase in the amount of oxygen as said temperature tends to rise, whereby the maximum temperature in the furnace is lowered, the amount of heat absorbed by radiation in the furnace reduced, and the temperature of the gases leaving the furnace lowered, and vice versa.

10. Apparatus for generating and superheating steam including a furnace, means for supplying fuel to said furnace, a forced draft fan for supplying air to said furnace for burning said fuel, steam generating surface absorbing heat by radiation from the burning fuel and from the products of combustion in the furnace and heat by convection from the products of combustion beyond the furnace, means for maintaining the pressure of the steam generated substantially constant by varying the rate of combustion, heat absorbing surfaces for superheating the steam through heat transfer by radiation from the burning fuel and from the products of combustion in the furnace, an induced draft fan for withdrawing products of combustion from said furnace, means for recirculating products of combustion from said induced draft fan to said forced draft fan, and means for regulating the amount of recirculated products of combustion operable to increase the amount returned whereby the maximum temperature in the furnace may be lowered and the heat absorbed by radiation in the furnace be decreased so as to compensate for a rise in the final temperature of the steam.

11. Apparatus in accordance with claim 10 and further including a preheater for transferring heat from the products of combustion leaving the furnace to the commingled combustion air and recirculated products of combustion on their way from the forced draft fan to the furnace.

12. Apparatus for generating and superheating steam including a furnace, means for supplying fuel to said furnace, a forced draft fan for supplying air to said furnace for burning said fuel, steam generating surface absorbing heat by radiation from the burning fuel and from the products of combustion in the furnace and heat by convection from the products of combustion beyond the furnace, means for maintaining the pressure of the steam generated substantially constant by varying the rate of combustion, heat absorbing surface for superheating the steam through transfer by convection from the products of combustion after they have left the furnace, an induced draft fan for withdrawing products of combustion from said furnace, means for recirculating products of combustion from said induced draft fan to said forced draft fan, and means for regulating the means for recirculated products of combustion operable when final tem-

perature of the steam falls to increase the amount of products of combustion recirculated so that the maximum temperature in the furnace may be lowered, the heat absorbed by radiation in the furnace be decreased, and the temperature of the gases leaving the furnace be raised so as to increase the final temperature of the steam.

13. The apparatus in accordance with claim 12 and further including a preheater for transferring heat for the products of combustion leaving to the furnace to the commingled combustion air and recirculated products of combustion on their way from the forced draft fan to the furnace.

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