

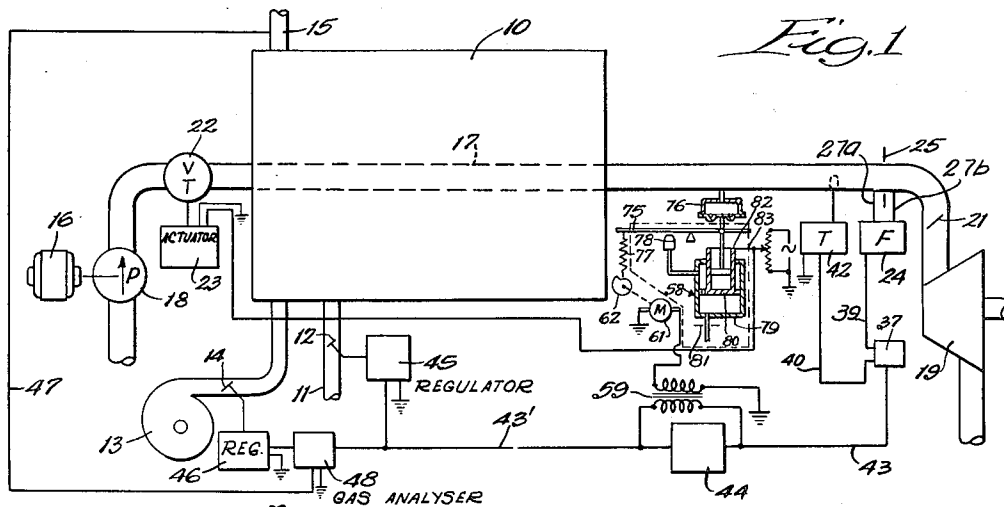
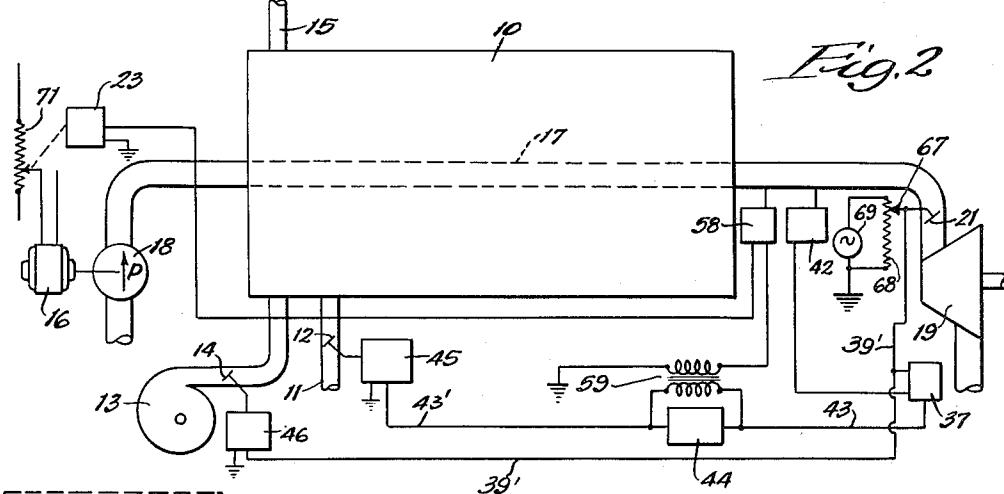
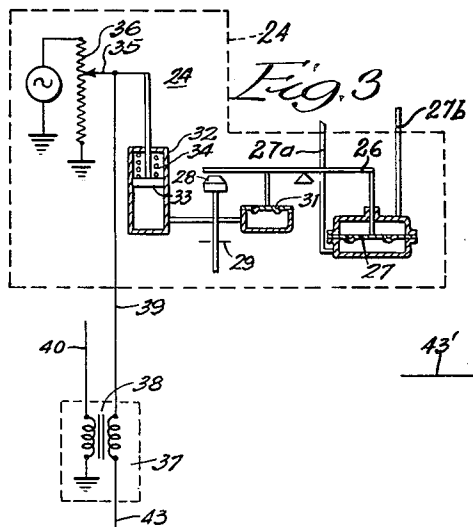
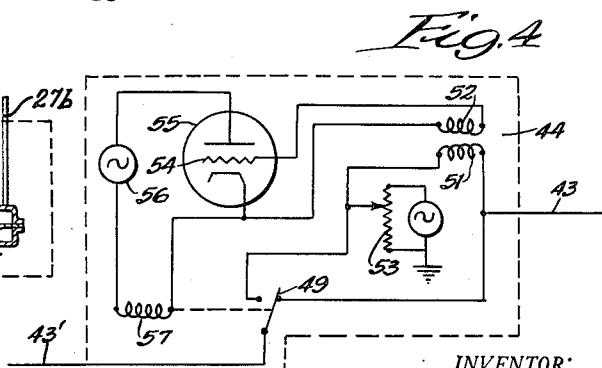
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2,804,851

CONTROL SYSTEM FOR A SUPERCRITICAL PRESSURE BOILER

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2,804,851

CONTROL SYSTEM FOR A SUPERCRITICAL PRESSURE BOILER

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This invention relates to a control system for supercritical pressure boilers and more particularly to the control of the firing rate and water supply for boilers operating in pressure ranges above the critical pressure.

The control of boilers for generating steam and supercritical pressure involves entirely different problems than the control of boilers operating at lower and more conventional pressures. A conventional boiler is partially filled with water and partially with steam at a pressure such that the steam is compressible. Supply of water to the boiler is controlled to maintain a substantially constant water level therein and the firing rate is controlled independently of the water supply to maintain the steam at the desired pressure and temperature. Such boilers normally have a relatively large storage capacity so that changes in demand can be absorbed by the boiler itself for short periods and the control is not required to operate with extreme rapidity. In fact, in most cases, the controls are damped in one way or another to prevent too rapid operation which might result in over-control.

In boilers operating above the critical pressure of about 3200 pounds per square inch absolute, the water and steam form a continuous column of incompressible fluid from the feedwater pump to the load. The boiler therefore has a relatively small storage capacity and reacts very rapidly to changes in demand. Thus the problems of controlling boilers operating at supercritical pressure are entirely different than the problems of controlling conventional boilers.

It is one of the objects of the present invention to provide a control system for a supercritical pressure boiler in which the firing rate and water supply are controlled very rapidly in accordance with changes in demand.

Another object is to provide a control system in which control of the firing rate is modified in accordance with steam temperature to maintain the desired temperature under all load conditions.

Still another object is to provide a control system in which the feedwater supply is modified in response to steam temperature when the firing rate reaches its maximum value.

According to one feature, the firing rate is controlled in response to demand up to the maximum firing limit and above such limit, the feedwater control is modified in accordance with steam temperature and flow to insure that the steam will be maintained at the desired temperature regardless of the fact that demand may exceed the capacity of the boiler. Such control insures that steam at too low a temperature will not be supplied to the load, such as a turbine, which might result in condensation in the turbine and damage thereto.

The above and other objects and features of the invention will be more readily apparent from the following description when read in connection with the accompanying drawing in which:

Figure 1 is a diagrammatic view of a supercritical pressure boiler embodying a control system according to the invention;

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Figure 2 is a view similar to Figure 1 showing a modified form of control;

Figure 3 is a diagrammatic view of a transmitter employed according to the invention and showing means for combining flow and temperature impulses; and

Figure 4 is a diagrammatic view of the limiting device employed in Figures 1 and 2.

The control system, as shown in Figure 1, is applied to a boiler for generating steam at a supercritical pressure. The boiler is generally indicated at 10 and is supplied with fuel through a conduit 11 under the control of a valve 12. Air for combustion with fuel is supplied by a blower 13 under the control of a valve 14. It will be understood, of course, that instead of using the valve 14 the speed of the blower 13 could itself be controlled to vary the air supply. The combustion products leave the boiler through flue 15.

The boiler contains water and steam passages diagrammatically illustrated as a continuous conduit 17 to which water is supplied from any suitable source by a feedwater pump 18 driven in any desired manner, as by a motor 16, and which is connected to a load shown as a turbine 19 to drive it. The supply of steam to the turbine is controlled by a valve 21 and may be operated by the turbine governor or any other desired load control devices independently of operation of the boiler itself. The rate of supply of water to the boiler may be controlled by a throttling valve 22 operated by an actuator 23 which may be a conventional power operated regulator of the type shown in either Figure 5 or Figure 7 of my Patent No. 2,644,642.

The control system of the present invention provides control of the firing rate instantaneously and proportionately in response to variations in demand. For this purpose, a transmitter 24 is provided connected to opposite sides of an orifice 25 through conduits 27a and 27b to be responsive to the pressure drop across an orifice 25 in the conduit 17. The orifice may be placed at any desired position in the conduit since the flow is the same from the pump to the turbine, but is shown as being between the boiler and the turbine. Flow of steam through the conduit to the turbine may be taken as a direct measure of the load or demand and according to the present invention provides the principal factor for control of the firing rate.

As shown in Figure 3, the transmitter 24 may include a balance beam 26 urged in one direction by a diaphragm 27 which is connected on its opposite sides to the opposite sides of the orifice or restriction 25. The beam moves toward or away from a fixed nozzle 28 supplied with fluid, such as air, past a restriction 29 so that pressure back of the nozzle will be varied in accordance with variations in steam flow. The regulating pressure back of the nozzle acts on a diaphragm 31 to rebalance the beam and is transmitted to a positioning device, shown as a cylinder 32 having a piston 33 therein urged in one direction by a spring 34 and in the opposite direction by the regulated pressure. The positioning device adjusts a movable wiper 35 over a potentiometer resistance 36 to produce at the wiper a control voltage proportional to the flow through the conduit 17. As shown, an increase in flow will urge the diaphragm 27 upward and will result in upward movement of the wiper 35 and an increase in the control voltage.

This control voltage is supplied to a totalizing unit 37 which, as shown diagrammatically, comprises a transformer 38, one winding of which is connected in series with the wiper 35. The other winding of the transformer 38 is connected through wire 40 with a regulator 42 which is responsive to the temperature of the steam leaving the boiler. Through the transformer 38, the two voltages are algebraically added and are sent through a line 43 and through a maximum limiting unit 44 to regula-

tors 45 and 46 for controlling the valves 12 and 14, respectively. The regulators 45 and 46 may be identical to the regulator 23.

The signal transmitted to the regulator 46 may, if desired, be modified in accordance with the composition of the combustion gases to maintain the desired combustion. For this purpose, a sample of combustion gas may be tapped off the flue 15 through a conduit 47 and supplied to a gas analyzer 48 connected in series in the line 43 just ahead of the regulator 46. The gas analyzer 48 may modify the control voltage supplied to the regulator 46 to vary the fuel air ratio so that combustion will be controlled properly.

The maximum limiting device 44 is illustrated diagrammatically in Figure 4 as comprising an electric switching circuit connected in the line 43 normally to transmit the voltage in the line 43 directly. In the event the signal voltage in line 43 exceeds a predetermined maximum, the line 43 will be interrupted and the output side thereof connected to the regulators 45 and 46 in Figure 1 will be connected to a constant voltage source so that the maximum signal supplied to these regulators will be limited. Thus the control apparatus can never call on the combustion rate control mechanisms for a higher rate of combustion than their capacity.

As shown in Figure 4, the line 43 is normally connected through a closed switch 49 to the line leading to the regulators, as indicated at 43'. The line 43 is also connected to one end of the primary winding 51 of a transformer including a secondary winding 52. The opposite end of the primary 51 is connected to a constant voltage source shown as a potentiometer 53 which is adjustable to adjust the desired constant voltage value. The secondary winding 52 is connected to the control grid 54 and the cathode of an electronic control tube 55. The anode and cathode of the control tube are connected to an alternating source 56 in series with a relay winding 57. The source 56 is of the same frequency and phase as the sources supplying the potentiometer resistors 36 and 53. The phasing is such that when the voltage in the line 43 is less than the voltage of the source 53, the anode of the tube 55 will be negative when the grid 54 is positive so that the tube will not conduct. If the voltage in the line 43 exceeds the voltage of the source 53, the phasing the transformer will be reversed so that the grid and anode of the tube will be positive at the same time and the tube will conduct. At this time, the relay 57 will be energized to throw the switch 49 to a position in which it is connected to the line 43 only through the winding 51 which may have a relatively high impedance and is connected directly to the source 53. The maximum signal which can be transmitted through the line 43' to the combustion control regulators is therefore that for which the source 53 is adjusted.

The supply of water to the boiler is controlled by the valve 22 and regulator 23 is directly responsive to the pressure in the conduit 17 at the outlet side of the boiler. For this purpose, a regulator 58 (see Figure 1), is provided connected to the conduit 17 and responsive to the pressure therein. The output control voltage developed by this regulator is connected directly to the regulator 23 to control the valve 22 and thus the supply of feedwater to the boiler.

The regulator 58 as shown diagrammatically in Figure 1 is a conventional control regulator including a balance beam 75 urged in one direction by a diaphragm 76 and in the opposite direction by a spring 77. The beam 75 controls a nozzle 78 which is connected to the upper part of a cylinder 79 whose lower part is supplied with air past a restriction 81. The cylinder contains a piston 80 formed with a restricted bleed opening therethrough and carries a tubular dash pot cylinder 82 containing oil or the like and having a loose fitting piston therein connected to the beam 75. When the beam 75 moves away from the nozzle 78 in response to an increase in pressure, the pres-

sure above the main piston 80 will be reduced so that the piston will move up. The dash pot piston will tend to rock the beam toward the nozzle 78 to anticipate correction of the pressure and to introduce a stabilizing time delay.

Movement of the piston 80 is translated into an electrical control force and for this purpose the piston is connected to a potentiometer 83 to adjust it. The potentiometer wiper is connected directly to the regulator 23 to control it as shown. The regulator 42 is identical to the regulator 58 as so far described except that the sensing diaphragm corresponding to 76 responds to the pressure developed in a temperature responsive bulb rather than directly to the pressure in flow conduit 17. Both regulators remain stationary as long as the temperature and pressure conditions remain constant and both will continue to adjust as long as the respective conditions vary from the set point. Their outputs are, therefore, not necessarily proportional to the existing temperature and pressure values.

In the operation of boilers of this type, if the demand should exceed the capacity of the boiler, the feedwater pump would normally continue to function to maintain the desired pressure in the outlet from the boiler. It will be apparent that if the maximum firing rate were insufficient to bring this quantity of water to the desired temperature, the water might not have sufficient temperature to flash into steam in the turbine when the pressure is reduced below the supercritical value so that slugs of water would appear in the turbine and might damage it. To prevent this according to the present invention, the feedwater control is modified when the demand exceeds the capacity of the boiler so that the temperature of the steam leaving the boiler will be above the critical value at all times.

For this purpose a transformer 59 has its primary connected directly across the voltage limiting unit 44 and its secondary connected to a motor 61. The motor 61 is of a known type which will move to a position corresponding to the voltage supplied to it and will return to a known starting position when there is no voltage. A cam 62 is connected to the motor 61 to be turned thereby and to the spring 77 in regulator 58 to vary its tension.

Normally the cam 62 occupies a position to maintain maximum tension on the spring 77 so that the set point of the regulator 58 is at maximum since with switch 49 in the position shown in Figure 4 there will be no voltage drop across the limiting device 44. When this limiting device operates there will be a voltage drop across it which is proportional to both temperature and flow of steam to adjust the motor 61 and reduce the tension of spring 77. This will reduce the set point of the regulator 58 to maintain the steam temperature and flow at safe values at times when the demand exceeds the maximum firing rate of the boiler.

Figure 2 illustrates a modification of the control system of Figure 1 wherein for purposes of brevity of description, the same parts are illustrated by the same reference numerals. In this construction, the load responsive transmitter 24 is omitted and instead a movable wiper 67 movable over a potentiometer resistor 68 supplied by a source 69 is mechanically connected to the steam control valve 21 to be moved therewith. Since the position of the valve 21 is indicative of the demand, the voltage at the wiper 67 will be proportional to demand.

This voltage and the voltage supplied by the temperature responsive regulator 42 are combined in the adding unit 37 and are supplied through the limiting device 44 to the regulator 45 for controlling fuel supply. In this case, however, the air supply regulator 46 is connected directly through the wire 39' to the wiper 67 so that the air supply is solely responsive to demand.

Instead of employing a valve, such as 22, in the water inlet line, the speed of the motor 16 is controlled to vary the rate of water supply. For this purpose, a variable resistor 71 is placed in one of the supply leads to the

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motor 16 and is controlled by the regulator 23. It will be seen that control of the pump speed will regulate the supply of feedwater to the boiler in the same manner as the valve 22 of Figure 1 so that in this respect, operation of the system is the same.

By the present invention, supply of water to the boiler is accurately and rapidly controlled at all times in response to outlet pressure to maintain the outlet pressure at the desired value. The firing rate is instantaneously and proportionately responsive to variations in demand but may be modified in accordance with steam temperature to insure that the temperature will be maintained at the proper value. This is a slow adjustment compared to the demand control. Provisions are also made to protect the safety of the boiler and its connected turbine to prevent overloading the boiler and to insure that no steam at a temperature below that required for safety will be supplied to the turbine.

While two embodiments of the invention have been shown and described in detail herein, it will be understood that these are illustrative only and are not to be taken as a definition of the scope of the invention, reference being had for this purpose to the appended claims.

What is claimed is:

1. A control system for a supercritical pressure boiler comprising means to supply fuel and air for combustion to the boiler, pump means to force water into the boiler at a supercritical pressure, an outlet conduit for steam at supercritical pressure from the boiler, control means responsive to the pressure of steam in the outlet conduit to control the flow of water to the boiler, control means instantaneously and proportionately responsive to the demand for steam from the boiler to control the supply of fuel and air to the boiler, and control means responsive to the temperature of the steam in the outlet conduit to modify control of at least one of said supplies at a slower rate than the control is effected by the demand responsive means.

2. A control system for a supercritical pressure boiler comprising means to supply fuel and air for combustion to the boiler, pump means to force water into the boiler at a supercritical pressure, an outlet conduit for steam at supercritical pressure from the boiler, first control means responsive to the pressure of steam in the outlet conduit to control the flow of water to the boiler, means responsive to the temperature and flow of the steam in the outlet conduit to modify the effect of said first control means, and second control means responsive to the demand for steam from the boiler to control the supply of fuel and air to the boiler.

3. A control system for a supercritical pressure boiler comprising means to supply fuel and air for combustion to the boiler, pump means to force water into the boiler at a supercritical pressure, an outlet conduit for steam at supercritical pressure from the boiler, control means responsive to the pressure of steam in the outlet conduit to control the flow of water to the boiler, means responsive to the temperature of the steam in the outlet conduit to modify the effect of said control means, control means responsive to the demand for steam from the boiler to control the supply of fuel and air to the boiler and a connection from the temperature responsive modifying means to the last named control means to modify the control of at least one of said supplies at a slower rate than the control is effected by the flow responsive means.

4. A control system for a supercritical pressure boiler comprising means to supply fuel and air for combustion to the boiler, pump means to force water into the boiler at a supercritical pressure, an outlet conduit for steam at supercritical pressure from the boiler, control means responsive to the pressure of steam in the outlet conduit to control the flow of water to the boiler, control means responsive to flow of steam through the outlet conduit to control the supply of air to the boiler, and control means jointly responsive to flow of steam through the

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outlet conduit and to temperature of steam in the outlet conduit to control the supply of fuel to the boiler.

5. A control system for a supercritical pressure boiler comprising means to supply fuel and air for combustion to the boiler, pump means to force water into the boiler at a supercritical pressure, an outlet conduit for steam at supercritical pressure from the boiler, control means responsive to the pressure of steam in the outlet conduit to control the flow of water to the boiler, a first control instrument instantaneously and proportionately responsive to demand for steam from the boiler to produce a first control force, a second control instrument responsive to the temperature of steam in the outlet conduit to produce a second control force, control devices responsive to the control forces to control the supply of fuel and air to the boiler, a force limiting device responsive to said control forces to limit the control forces transmitted to the control devices, and means responsive to operation of the force limiting device to change the setting of the first named control means to modify the control of flow of water to the boiler.

6. A control system for a supercritical pressure boiler comprising means to supply fuel and air for combustion to the boiler, pump means to force water into the boiler at a supercritical pressure, an outlet conduit for steam at supercritical pressure from the boiler, control means responsive to the pressure of steam in the outlet conduit to control the flow of water to the boiler, a first control instrument instantaneously and proportionately responsive to demand for steam from the boiler to produce a first control force, a second control instrument responsive to the temperature of steam in the outlet conduit to produce a second control force, means connected to the control instruments to combine the control forces; means in the second control instrument to delay the effect of the second control force on the combined control forces, a control device responsive to the combined control forces to control the supply of fuel to the boiler, a force limiting device responsive to a predetermined maximum value of the combined control forces to limit the value of the combined control force transmitted to the control device, and means responsive to operation of the limiting device to change the setting of the first named control means to modify the control of flow of water to the boiler.

7. A control system for a supercritical pressure boiler comprising means to supply fuel and air for combustion to the boiler, pump means to force water into the boiler at a supercritical pressure, an outlet conduit for steam at supercritical pressure from the boiler, control means responsive to the pressure of steam in the outlet conduit to control the flow of water to the boiler, a first control instrument responsive to demand for steam from the boiler to produce a first control voltage, a second control instrument responsive to the temperature of steam in the outlet conduit to produce a second control voltage, means to combine the voltages, a control device responsive to the combined voltages to control the supply of fuel to the boiler, a voltage limiting circuit connected to the control device and the combining means and energized in response to a predetermined value of the combined voltages to limit the value of the combined voltages supplied to the control device to a predetermined maximum, and means responsive to the voltage drop across the voltage limiting circuit to change the setting of the first named control means to modify the control of flow of water to the boiler.

8. In a control system for a supercritical pressure boiler, means to force water into the boiler at supercritical pressure, an outlet conduit to conduct steam from the boiler, control means responsive to the pressure of steam in the outlet conduit to control the forcing means, means responsive to the demand for steam from the boiler to control the rate of firing of the boiler, means responsive to the temperature of the steam in the outlet conduit,

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means coupling the temperature responsive means to the control means to modify control of the water forcing means in accordance with steam temperature, and means responsive to operation of the demand responsive means when it calls for an excessive firing rate to make the coupling means effective.

9. In a control system for a supercritical pressure boiler, means to force water into the boiler at supercritical pressure, an outlet conduit to conduct steam from the boiler, control means responsive to the pressure of steam in the outlet conduit to control the forcing means, means responsive to the demand for steam from the boiler to produce a first controlling force, means responsive to said controlling force to control the rate of firing of the boiler, means responsive to the temperature of the steam in the outlet conduit to produce a second controlling

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force, means connected to the temperature responsive means and the demand responsive means and operating to combine the controlling forces to modify control of the firing rate in response to changes in steam temperature, and means connecting the temperature responsive means to the first named control means to modify control of the water forcing means in accordance with steam temperature.

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