

June 1, 1954

E. S. BRISTOL
BOILER LOAD CONTROL

2,679,979

Filed March 24, 1950

4 Sheets-Sheet 1

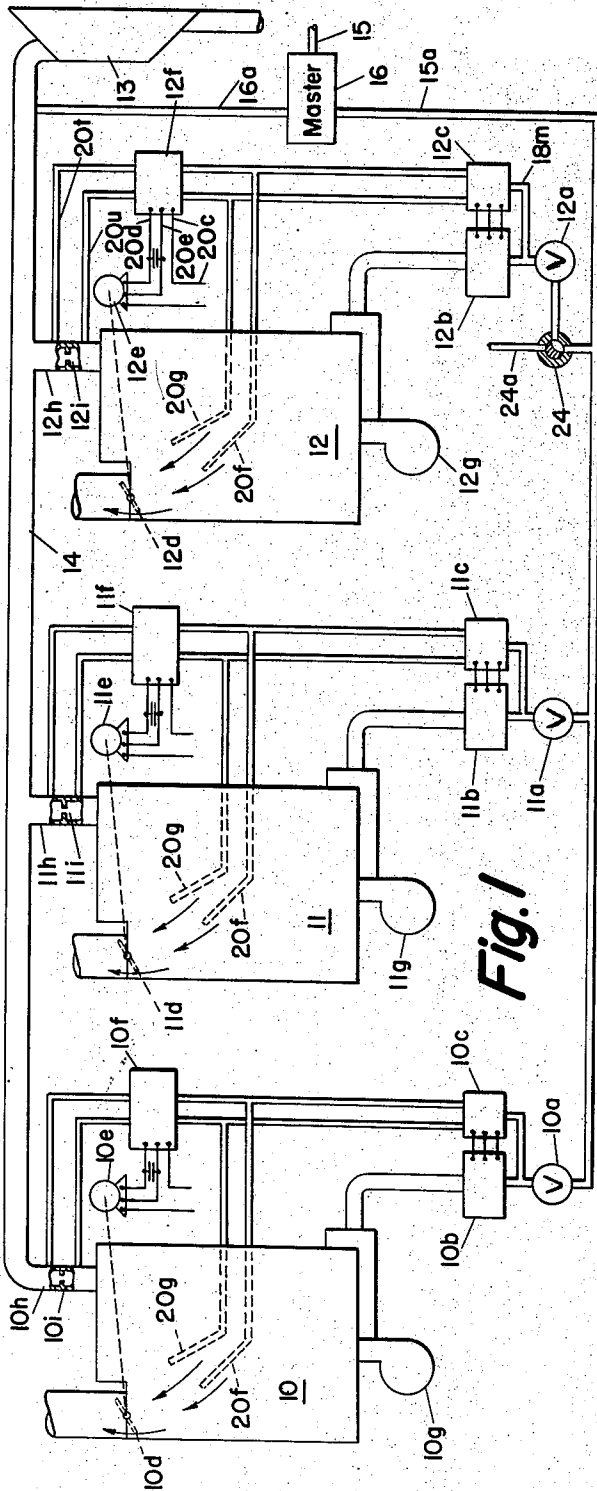


Fig. 1

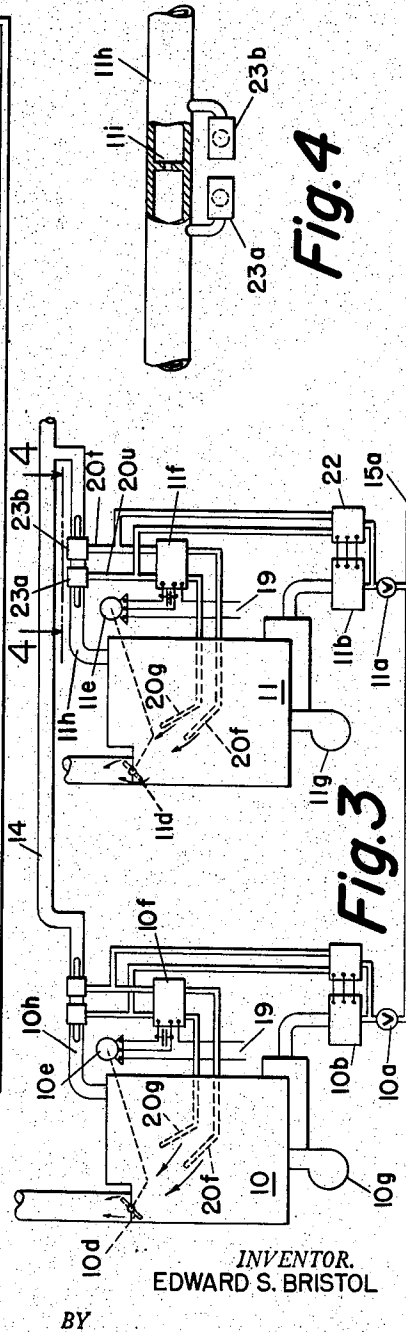


Fig. 3

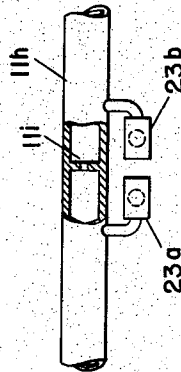


Fig. 4

INVENTOR.
EDWARD S. BRISTOL

BY

Woodcock and Chelan
ATTORNEYS

June 1, 1954

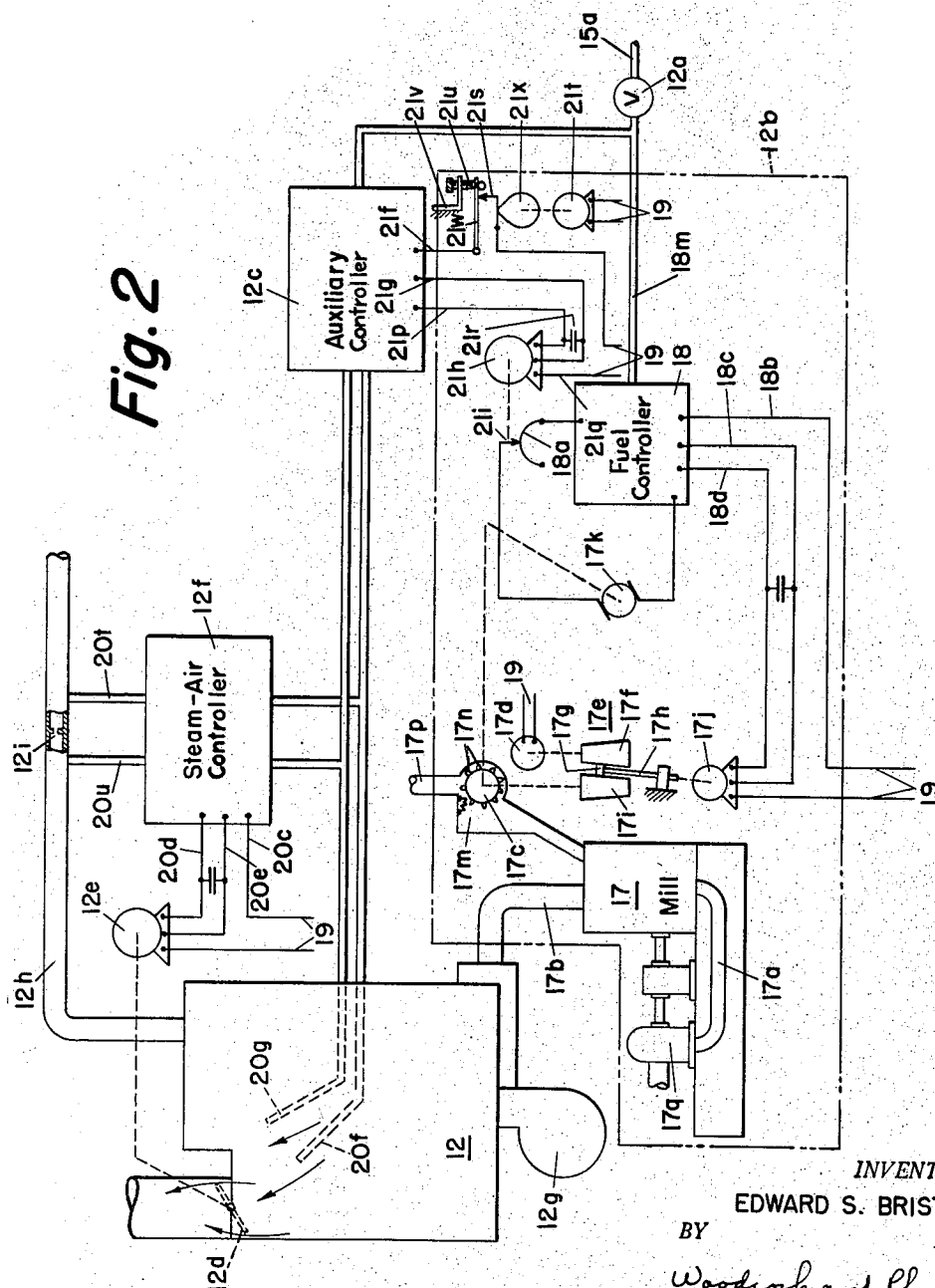
E. S. BRISTOL
BOILER LOAD CONTROL

2,679,979

Filed March 24, 1950

4 Sheets-Sheet 2

Fig. 2



INVENTOR.
EDWARD S. BRISTOL
BY
Woodcock and Chelan
ATTORNEYS

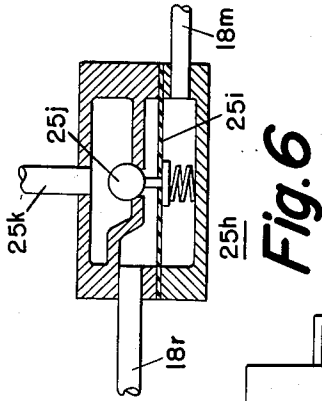
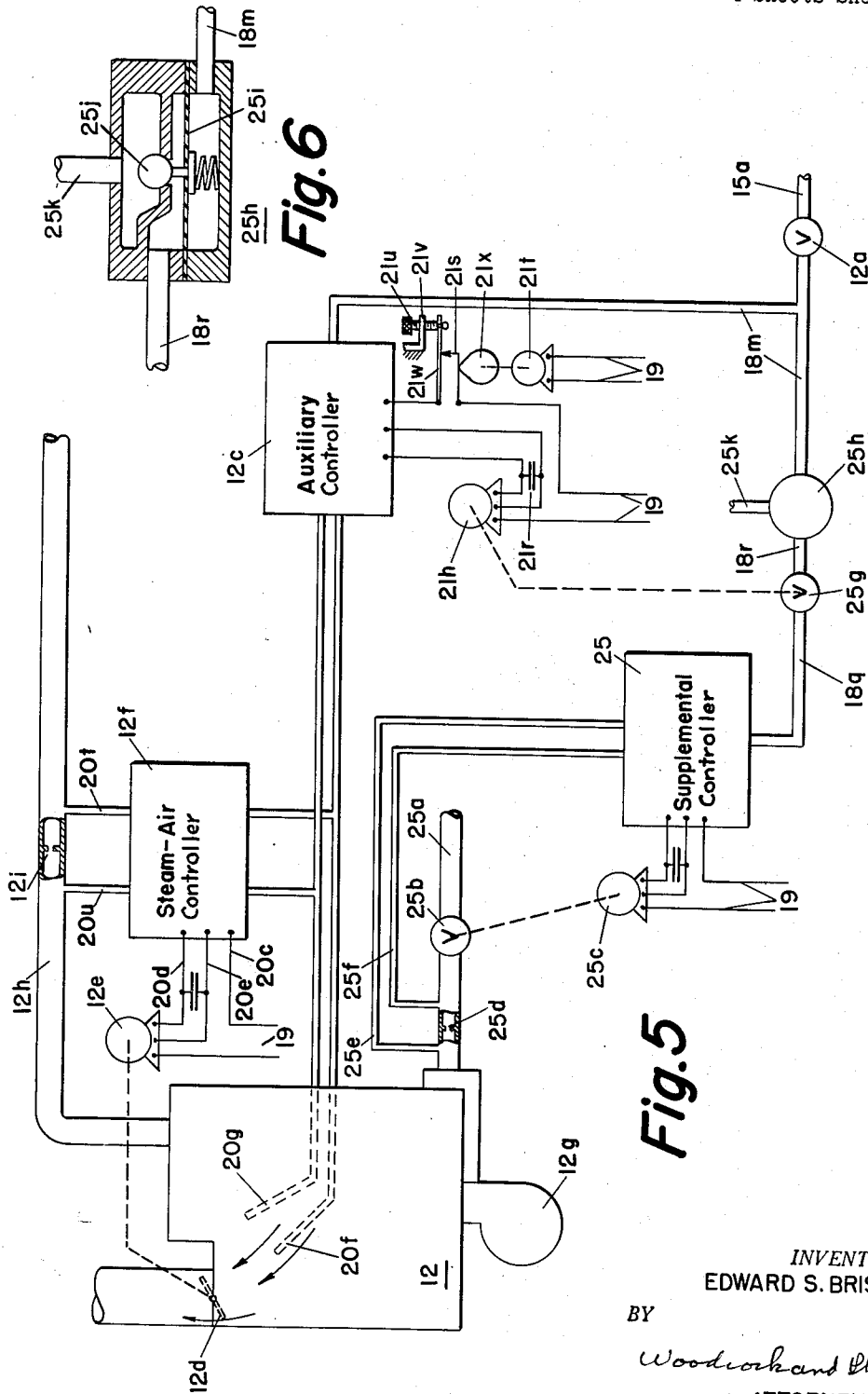
June 1, 1954

E. S. BRISTOL
BOILER LOAD CONTROL

2,679,979

Filed March 24, 1950

4 Sheets-Sheet 3



June 1, 1954

E. S. BRISTOL

2,679,979

BOILER LOAD CONTROL

Filed March 24, 1950

4 Sheets-Sheet 4

Fig. 7

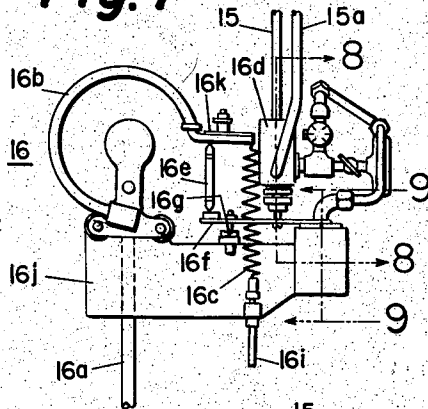


Fig.10

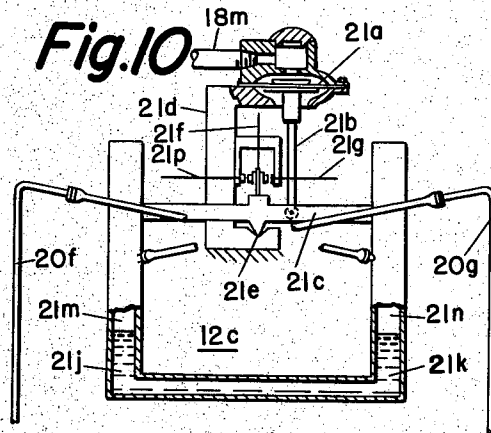


Fig. 8

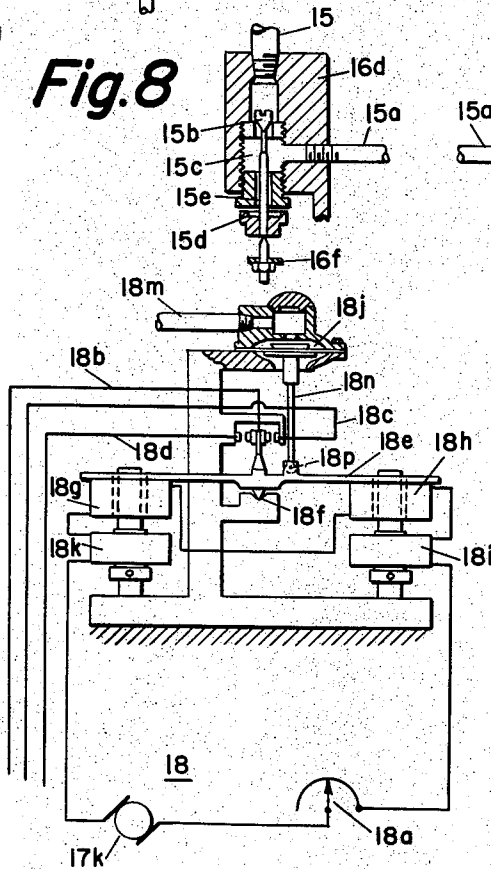


Fig.9

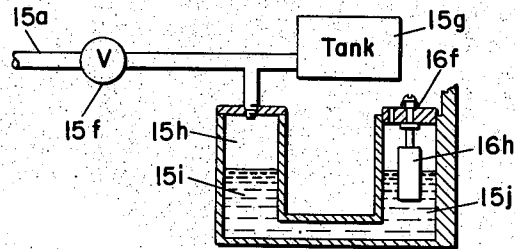
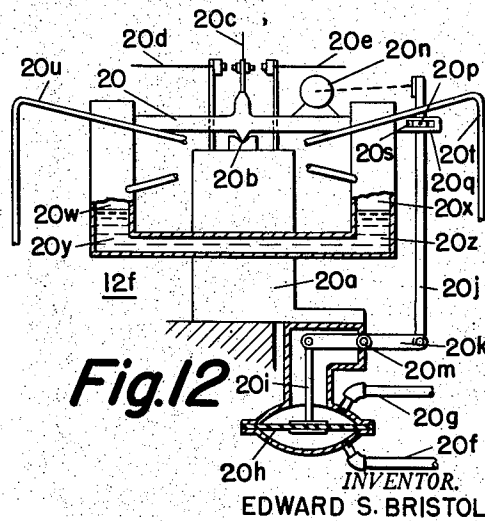


Fig.12



20h INVENTOR.
EDWARD S. BRISTOL

BY

Woodcock and Phelan
ATTORNEYS

UNITED STATES PATENT OFFICE

2,679,979

BOILER LOAD CONTROL

Edward S. Bristol, Philadelphia, Pa., assignor to
Leeds and Northrup Company, Philadelphia,
Pa., a corporation of Pennsylvania

Application March 24, 1950, Serial No. 151,650

13 Claims. (Cl. 236-14)

1

This invention relates generally to control systems for steam boilers and particularly to systems for controlling the flow of combustibles to the boiler furnaces. It is particularly useful in certain types of installations where, in the absence of the invention, objectionable fluctuations in boiler output would result from variations in certain factors which, for convenience, will be referred to as fuel quality.

Steam boiler control apparatus has heretofore been devised for controlling the flow of combustion air to the furnace for efficient combustion of fuel. Control apparatus has been devised also for controlling the flow of fuel to the furnace to maintain substantially constant the steam pressure from the boiler. These systems are useful in single-boiler installations where the problem is to maintain steam pressure under varying loads with good combustion efficiency. The effect of varying fuel quality in a single-boiler installation merely is to vary slightly the steam pressure, and the flow of fuel then is corrected automatically in response to this slight change.

In certain important types of boiler control installations, however, it is not feasible to rely upon variations in steam pressure alone to bring about compensation for varying fuel quality. One example of such an installation is where multiple boilers supply steam to a common load. In this case a change to poor fuel in only one boiler would produce a change in the steam pressure of the whole system that would affect all boilers alike causing a proportionate increase in fuel flow to all boilers. As a result the boiler receiving poor fuel would supply less than its intended share of the steam load. The principal object of the invention is to so control the flow of fuel to the boilers of a multiple-boiler installation that each boiler supplies its predetermined share of the steam load regardless of ordinary variations in fuel quality at individual boilers.

Another example of a condition under which variations in steam pressure cannot be relied upon to control fuel flow is where it is desired to maintain constant the steam flow from an individual boiler. Suppose that one boiler in a multiple-boiler installation has higher efficiency than others and that, therefore, it is desired to operate it continuously at its full-load capacity, fluctuations in system load being met by other boilers. This boiler may be disconnected from the steam-pressure control, as described more fully hereinafter, and connected to the equivalent of a constant-fuel-flow control thereby achieving constant steam flow from the boiler if fuel quality

2

does not vary. To maintain constant the steam flow from such a boiler despite varying fuel quality is another object of the invention.

To accomplish the aforesaid objects, in accordance with the invention, fuel flow to a steam-boiler furnace is controlled in response to two control quantities usually acting with different response times. The first control quantity, exemplified by air-loading pressure as a measure of steam system load, by itself would cause the fuel flow to vary in response to slight variations in steam pressure, such as are produced by changes in steam system load, to maintain the steam pressure substantially constant by changing the rate of fuel feed in response to the changes in steam system load. The second control quantity, exemplified by the resistance of a rheostat, automatically causes the fuel flow to vary in response to any change in the relative value of this first control quantity and the steam flow from the boiler to maintain the proper relationship between steam system load and steam flow despite variations in fuel quality. Such a change in relative value of the first control quantity and steam flow ordinarily would be due to a change in fuel quality, although it might be due to a change in other factors some of which are described hereinafter.

Stated otherwise, the usual fuel control is provided for maintaining steam pressure having inherent therein a quantity that may be used as a measure of steam system load and an auxiliary fuel control is provided for maintaining a predetermined distribution of steam flow from the boilers. Steam flow is maintained constant despite variations in fuel quality when the air-loading pressure is constant; the auxiliary fuel control operates only when steam flow fluctuates independently of air-loading pressure, as it would do when fuel quality varies. Such fluctuation is measured by comparing the steam flow from the boiler, either directly or indirectly, with the first control quantity which might be, in a typical case, air-loading pressure. Any deviation from a predetermined relation between these compared quantities due to varying fuel quality produces the second control quantity which adjusts the fuel flow to compensate for the varying fuel quality.

Inasmuch as air is a substantially constant-heating-value component of combustion, it is supplied to the boiler furnace in proportion to the steam flow from the boiler in accordance with the invention. Since air flow is thus proportional to steam flow it may be substituted as a measure

of steam flow in the foregoing remarks without change of principle. Thus in accordance with another aspect of the invention, and as an object thereof, air flow, instead of steam flow, is compared to the air-loading pressure to derive the above-mentioned second control quantity with resultant practical advantages to be described hereinafter.

Other objects and advantages of the invention will be apparent from the following more detailed description thereof with reference to the accompanying drawings, in which:

Fig. 1 is a diagrammatic view of a multiple-boiler control system embodying the invention;

Fig. 2 is a more detailed diagrammatic view of a unit shown in Fig. 1;

Fig. 3 is a fragmentary diagrammatic view of a modification of apparatus illustrated in Fig. 1;

Fig. 4 is a fragmentary detail view taken substantially along the line 4—4 in Fig. 3, portions thereof being shown broken away;

Fig. 5 is a diagrammatic view of a modification of the unit shown in Fig. 2;

Fig. 6 is a vertical sectional detail view of a portion of the structure shown in Fig. 5;

Fig. 7 is a diagrammatic detail view of a portion of the apparatus shown in Fig. 1;

Fig. 8 is a fragmentary detail view taken along the line 8—8 in Fig. 7;

Fig. 9 is a fragmentary diagrammatic detail view taken along the line 9—9 in Fig. 7; and

Figs. 10, 11, and 12 are diagrammatic detail views of portions of the apparatus shown in Fig. 2.

Referring to Fig. 1, boilers 10, 11 and 12 supply steam to turbine 13, or other suitable load, through a common steam pipe or header 14. Master controller 16, described more fully hereinafter, regulates compressed air entering the system through pipe 15 from any suitable source, not shown, as a function of the steam pressure in header 14 to produce a fluid pressure in pipe 15a which is a measure of the steam demand or load on the multiple-boiler installation. The resultant compressed air, known as loading air in distinction from the combustion air mentioned hereinafter, controls the rate of feeding fuel to boilers 10, 11, and 12 through loading valves 10a, 11a, and 12a, respectively; these loading valves are manually adjustable for apportionment of load as desired among the three boilers. Valves 10a, 11a, and 12a may be of any suitable well-known type, such as throttle-and-bleed valves, adapted to produce individual-boiler loading-air pressures of any desired magnitude commensurate with the output loading-air pressure from master controller 16.

Fuel control units 10b, 11b, and 12b, described more fully hereinafter, normally supply fuel to boilers 10, 11 and 12, respectively, at a rate determined by the individual-boiler loading-air pressure from loading valves 10a, 11a, and 12a. The relation between loading-air pressure and fuel flow at fuel control units 10b, 11b, and 12b may be varied by auxiliary control units 10c, 11c, and 12c, described more fully hereinafter. The flow of combustion air through each of boilers 10, 11, and 12 is maintained proportional to steam flow from each boiler by dampers 10d, 11d, and 12d controlled by motors 10e, 11e, and 12e, respectively, each of which is controlled by a steam-air unit 10f, 11f, or 12f, described hereinafter.

It will be understood that, as used herein, the expressions "steam flow," "air flow," and "fuel

flow" refer to the rate at which the respective substances pass toward or away from a boiler or other point, and "fuel flow" is intended to apply to any form of fuel, whether solid or fluid, except where a specific form of fuel is indicated.

Referring to Figs. 7, 8, and 9 as exemplary of a suitable master controller, pipe 16a connects header 14 to Bourdon tube 16b which expands under steam pressure against spring 16c to actuate loading-air valve 16d through push-rod 16e and lever 16f supported on pivot 16g. Counterweight 16h, Fig. 9, acting through lever 16f and push rod 16e opposes spring 16c so that extension under steam pressure of Bourdon tube 16b is opposed by the net force of spring 16c and counterweight 16h and this net force may be adjusted by any suitable screw means 16i by which spring 16c is anchored to frame member 16j thereby adjusting as desired the midpoint of pressure about which controller 16 operates. Bourdon tube 16b transmits force to push rod 16e through leaf spring 16k which yields under the contractive force of Bourdon tube 16b when steam pressure is removed from pipe 16a without yielding, however, during the normal operation of controller 16.

Compressed air entering through pipe 15 is reduced in pressure, and thus converted to loading air, and applied to pipe 15a by valve 15b, Fig. 8, actuated by the cumulative effect of two forces applied to lever 16f. One force originating in Bourdon tube 16b tends to produce air-loading pressure in pipe 15a having a pressure varying inversely with that in steam pipe 16a. As will be described more fully hereinafter the other force, originating in counterweight 16h, magnifies variations in loading-air pressure in pipe 15a according to the product of the duration and extent of deviations of steam pressure in pipe 16a from a predetermined value, an effect known as reset action. As changes in system load produce changes in steam pressure, the loading-air pressure in pipe 15a may be taken as a measure of system load.

When Bourdon tube 16b expands in response to an increase in steam pressure in pipe 16a, as would result from a decrease in system load, the right-hand end of lever 16f, as viewed in Fig. 7, is tilted downward slightly to close by a slight amount valve 15b thereby tending to reduce the air pressure in chamber 15c to which pipe 15a connects. Simultaneously cup 15d moving with valve 15b permits air to leak at a slightly increased rate through passageway 15e so that loading-air pressure in chamber 15c decreases in response to an increase in steam pressure in pipe 16a by the double effect of closing valve 15b and increasing the leakage rate through passageway 15e thus producing a substantial decrease in loading-air pressure with a very slight increase in steam pressure.

Conversely, upon a decrease in steam pressure spring 16c predominates over the force from Bourdon tube 16b slightly to open valve 15b and simultaneously to reduce the leakage rate through passageway 15e by moving cup 15d upward thereby increasing the loading-air pressure. These changes in air-loading pressure effect changes in the fuel supply as mentioned above and more fully described hereinafter.

As thus far described the operation of master controller 16 would provide a definite air-loading pressure and therefore a definite fuel flow for each value of steam pressure. The system normally would be so adjusted that this fuel flow

would supply a normal demand for steam at the desired steam pressure. Any deviation from this demand, however, would require a corresponding change in fuel flow which might be brought about by an appropriate change, from that previously mentioned, in the air-loading pressure for the particular steam pressure being maintained. This adjustment of fuel flow to maintain constant steam pressure at varying boiler loads, as distinguished from the adjustment of fuel flow to meet varying fuel quality in accordance with the invention, is known as reset action and may be produced by the following-described reset means.

Referring to Fig. 9, loading air from pipe 15a is applied through valve 15f to storage tank 15g at a rate depending upon the setting of valve 15f and the difference in pressure across it. The air pressure of storage tank 15g is applied to chamber 15h of the master controller and to a mercury column 15i therein to force the mercury column downward thereby raising the opposite mercury column 15j to partially support, and therefore reduce the effective weight of, counterweight 16h. This reduction in the effective weight of counterweight 16h permits spring 16c to further open valve 15b. It is apparent that the pressure of air in storage tank 15g, by reducing the effective weight of counterweight 16h, will cause Bourdon tube 16b and spring 16c to be in equilibrium under a given steam pressure at a position of valve 15b and cup 15d which results in increased air-loading pressure in chamber 15c and at pipe 15a.

As mentioned, an increase in steam demand or load on the boiler results in a somewhat decreased steam pressure which increases the air-loading pressure in chamber 15c. The further gradual increase in air-loading pressure as air from chamber 15c flows through valve 15f into tank 15g, and the consequent gradual increase in fuel flow to the boiler, continues until the steam pressure returns to its proper constant value which acting through Bourdon tube 16b causes the pressure in chamber 15c to equal that in tank 15g whereupon reset action ceases, leaving fuel flow properly adjusted for the increased demand as a result of increased air-loading pressure. On a decrease in steam system load or demand this action is reversed. The final result of this reset action is to adjust the air-loading pressure to compensate for variations in steam demand or total load on the steam boilers or for certain other factors that similarly change the fuel requirements for a predetermined steam pressure. It cannot, however, compensate for varying fuel quality at one particular boiler of a multiple-boiler installation since it necessarily affects all boilers alike, whereas, in accordance with the invention, individual boiler steam flow also is controlled.

Referring to Fig. 2, boiler 12 may be supplied with fuel from any suitable fuel supply means such as, for example, coal pulverizer mill 17. A portion of the combustion air for the furnace of boiler 12, supplied by any suitable well-known source, such as blower 17g, is blown through conduit 17a to pulverizer mill 17 to carry the pulverized coal output thereof through conduit 17b to boiler 12. The rate at which fuel is thus supplied to boiler 12 is determined by the speed at which feeder 17c is rotated by constant-speed motor 17d through a variable-speed transmission such, for example, as transmission 17e.

Variable-speed transmission 17e comprises a 75

cone 17f driven, directly or through any suitable reduction gearing, by motor 17d, idler 17g adapted to be moved along cone 17f by rotation of worm 17h, and cone 17i arranged parallel to cone 17f in contact with idler 17g so that rotation of cone 17f rotates idler 17g which in turn rotates cone 17i at a ratio determined by the position of idler 17g. Thus to vary the speed of feeder 17c a certain amount, it is only necessary to rotate worm 17h a certain amount.

Rotation of worm 17h is accomplished by reversible motor 17j controlled as described hereinafter. The speed of feeder 17c, and hence the rate at which fuel flows to boiler 12, is measured by tachometer generator 17k rotatably connected thereto and adapted to generate an output voltage proportional to its speed of rotation. Such generators are well known and need not be described further herein.

Fuel feeder 17c rotates within housing 17m which is so arranged that movement of each of its blades 17n past fuel inlet conduit 17p preferably should feed a predetermined volume of coal to pulverizer mill 17. In practice, this volume may vary somewhat due to such things as wet coal sticking in the corners at the base of the blades. It is apparent that the weight of coal in this predetermined volume will depend to a certain extent on the size of the lumps of coal, and its heating value will depend on its moisture content. Thus lump size and moisture content, in a coal feeder of the type described herein by way of example, constitute some of the above-mentioned quality factors which, like fuel heating value, tend by their variation to cause the fluctuations in boiler output which are corrected in accordance with the invention. As used herein the expression "fuel quality" is intended to include anything that affects the amount of heat produced in the furnace at a given speed of the fuel feeder or equivalent measure of fuel flow.

Referring to Figs. 2 and 11, fuel-feed controller 18, forming part of fuel control unit 12b, controls motor 17j to rotate worm 17h to vary the speed of feeder 17c thereby to control the fuel flow to boiler 12. This operation of controller 18 is in concurrent response to, first, the voltage output from tachometer generator 17k, this being proportional to fuel flow to boiler 12, as previously described. Second, it responds to the air-loading pressure from master controller 16 by way of conduit 15a. Third, its operation depends upon the resistance of rheostat 18a which is a function of the unbalance between air-loading pressure and a quantity representative of steam flow, as described more fully hereinafter.

Motor 17j may be of any suitable reversible type; for convenience it will be considered to be a two-phase induction motor operable from power line 19 in one direction when conductor 18b engages conductor 18c, and in the other direction when conductor 18b engages conductor 18d, all in a well-known way. Movement of conductor 18b to cause motor 17j to rotate in one direction or the other is brought about by the rotation of frame 18e, to which conductor 18b is attached, about pivot 18f under the net torque of solenoids 18g, 18h, 18i, and 18k opposed by torque from diaphragm 18j actuated by air-loading pressure from pipe 18m and acting through push rod 18n pivotally connected to frame 18e in any suitable manner such as by pin 18p.

Solenoids 18g and 18k are so connected electrically that their magnetic fields are additive whereas solenoids 18h and 18i are so connected

7

electrically that their magnetic fields are in opposition, all four solenoids being connected in series with each other and with tachometer generator 17k and rheostat 18a by suitably insulated conductors. Thus motor 17j will be operated whenever there is a departure from a predetermined relation between air-loading pressure and fuel flow as measured by tachometer generator 17k, and it will be operated in the proper direction to restore that relation. The aforesaid predetermined relation may be varied, however, by adjustment of rheostat 18a as described hereinafter.

For the purpose of maintaining the air flow through each of boilers 10, 11, and 12 proportional to its steam flow, steam-air units 10f, 11f, and 12f are provided (Fig. 1).

Referring to Fig. 12 as exemplary of a suitable steam-air unit, it is desired to rotate frame 20 pivotally supported on stationary frame 20a by pivot 20b to cause conductor 20c to make contact with conductor 20d to cause motor 12e (Figs. 1, 2) to rotate in one direction or to make contact with conductor 20e to cause the motor to rotate in the opposite direction thereby to adjust damper 12d to control the flow of combustion air through boiler 12. Of course other suitable well-known means for controlling the flow of combustion air through the boiler may be employed, if desired. For example motor 12e may adjust a suitable speed control, not shown, for the corresponding one of blowers 10g, 11g, and 12g.

It will be understood that the following-described means for measuring the flow of combustion air may, in practice, be so positioned that they measure the flow of all gaseous products of combustion instead of only air. The relation of these products of combustion to combustion air is well known and, therefore, measurement of one is equivalent for present purposes to a measurement of the other.

As is well known, air flow through a furnace may be measured by a pair of properly positioned tubes, commonly known as draft taps, such as taps 20f and 20g, shown partly schematically in the drawings. Air under pressure from these taps is applied to opposite sides of diaphragm 20h, Fig. 12, to apply torque to frame 20 through push rods 20i and 20j and lever 20k pivotally mounted by pin 20m. When it is desired to change the ratio of air flow to steam flow because, for some reason such as the formation of boiler scale, the amount of heat produced in the furnace for a given steam flow from the boiler changes, this torque must be varied. For such purpose, motor 20n of any suitable well-known type is mounted on frame 20 and operatively connected by any suitable mechanical linkage to push rod 20j to move the upper end thereof toward or away from pivot 20b, thereby adjusting the distance from pivot point 20b to the point where pin 20p engages wall 20q of slot 20s which is the effective lever arm whereby diaphragm 20h tends to rotate frame 20.

Motor 20n may be actuated by any suitable power supply and control apparatus such as a servo or push-button system, not shown. It will be understood that Fig. 12 is a diagrammatic view illustrating the principles of steam-air unit 12f and that, in a practical application, certain parts thereof preferably should be rearranged from the position in which they are shown for clearness: particularly motor 20n may be located near the center of gravity of frame 20 with suitable counterbalancing of it and other parts; and

8

steam tubes 20t and 20u, described hereinafter, may be coiled about the axis of pivot 20b to facilitate the free movement of frame 20 in response to slight unbalance torque.

As mentioned, the difference in pressure in taps 20f and 20g is a measure of the air flow in boiler 12 (Figs. 1, 2) so that the torque applied to frame 20 by diaphragm 20h is a function of the air flow. Steam flow from each of boilers 10, 11, and 12 may be measured in a well-known way by providing restrictions 10i, 11i, and 12i in steam pipes 10h, 11h, and 12h, respectively extending from the individual boilers to the header 14 (Fig. 1). Steam tubes 20t and 20u, connected to steam pipe 12h (Fig. 2) on opposite sides of restriction 12i are connected (Fig. 12) to pressure chambers 20w and 20x, respectively, above mercury columns 20y and 20z, respectively. Combustion-air flow through boiler 12 results in a clockwise torque on frame 20 while steam flow from boiler 12 will displace mercury column 20z toward column 20y to cause a counterclockwise torque on frame 20.

When these two torques are balanced, as a result of a predetermined relation between steam flow and air flow, conductor 20c occupies a position intermediate conductors 20e and 20d so that motor 12e (Figs. 1, 2) is de-energized and damper 12d remains stationary. A relative increase in steam flow over air flow will cause frame 20 to rotate counterclockwise so that conductor 20c contacts conductor 20d to cause motor 12e to open damper 12d sufficiently to re-establish the predetermined relation between steam flow and air flow thereby to rebalance steam-air controller 12f to disconnect conductor 20c from conductor 20d. Conversely, a relative decrease in steam flow compared to air flow will unbalance steam-air unit 12f oppositely to cause motor 12e to close damper 12d sufficiently to rebalance the unit.

Referring to Fig. 10 as exemplary of one of the auxiliary controllers 10c, 11c, 12c (Figs. 1, 2), loading air from valve 12a (Fig. 1) is applied to diaphragm 21a of auxiliary control unit 12c through pipe 18m to apply a clockwise torque through push rod 21b to frame 21c pivotally supported on stationary frame 21d by pivot 21e. By itself this clockwise torque would cause conductor 21f attached to frame 21c continuously to engage conductor 21g thereby to energize motor 21h, Fig. 2, to adjust contact 21i of rheostat 18a toward its maximum-resistance position thereby requiring tachometer generator 17k to rotate at a high speed corresponding to fast fuel flow. However, counterbalancing the above-mentioned clockwise torque is a counterclockwise torque due to the unbalance of mercury columns 21j and 21k which, in magnitude and sense, depends on the air flow through boiler 12. Chamber 21n over mercury column 21k is connected to draft tap 20f and chamber 21m over mercury column 21j is connected to draft tap 20g which, being downstream of draft tap 20f, has the lower pressure and consequently the greater height and weight of mercury. It will be understood that other liquids may be employed wherever mercury is referred to herein, if desired.

When the aforesaid counterclockwise and clockwise torques are equal so that conductor 21f assumes a position intermediate conductors 21g and 21p, contact 21i of rheostat 18a will remain stationary and the fuel flow to boiler 12 will be controlled in the usual way solely by master controller 16 and fuel-feed controller 18. Suppose now that the quality of fuel at boiler 12 becomes poorer than that at boilers 10 and 11 re-

sulting in a reduction in steam flow from boiler 12 and a slight reduction in the system steam pressure. Master controller 16 (Fig. 1) will then cause the fuel flow to all three boilers to increase slightly to maintain the system steam pressure by increasing slightly the loading-air pressure in pipe 15a thereby increasing correspondingly the loading-air pressure in pipe 18m. This increase in fuel flow for boilers 10, 11, and 12 brought about by master controller 16 will maintain the system steam flow but it will not offset completely the assumed reduction in heating value of the fuel supplied to boiler 12 so that steam flow from boiler 12 will necessarily be reduced and that from boilers 10 and 11 correspondingly increased if only master controller 16 and fuel-feed controller 18 (Fig. 2) are relied upon for control.

However, in accordance with the invention, auxiliary control unit 12c will be unbalanced to cause complete offsetting of the assumed poor fuel quality at boiler 12 for two reasons. First, the air-loading pressure on diaphragm 21a (Fig. 10) will be increased slightly to increase the clockwise torque on frame 21c; and, second, the counterclockwise torque on frame 21c will be reduced due to the reduced air flow through boiler 12, the air flow in boiler 12 following the reduced steam flow therefrom as previously described.

This unbalancing of auxiliary controller 12c in response to the decrease in steam flow from boiler 12 relative to the air-loading pressure on diaphragm 21a causes conductor 21f to make contact with conductor 21g thereby energizing motor 21h (Fig. 2) and causing it to rotate contact 21i of rheostat 18a to the left, as viewed in Fig. 2, thereby increasing the fuel flow to boiler 12 by requiring a greater voltage from tachometer generator 17k to balance fuel-feed controller 18 as previously described.

This increase in fuel flow to boiler 12 over and above that brought about by master controller 16 continues until it is sufficient to restore the steam output of the boiler and therefore the air flow therethrough to balance auxiliary controller 12c whereupon conductor 21f (Fig. 10) resumes its position intermediate conductors 21g and 21p, and the auxiliary controller then remains inoperative until there occurs another change in quality of the fuel supplied to that particular boiler. As boiler 12 assumes its proper share of the load upon operation of auxiliary controller 12c, the extra load on boilers 10 and 11 disappears and the air-loading pressure resumes its normal value leaving as the sole result of the decrease in fuel quality at boiler 12 the readjustment of rheostat 18a (Fig. 2) to offset the poor fuel quality.

Of course the operation of auxiliary controller 12c is reversible so that, if unusually good fuel is supplied to boiler 12, a counterclockwise torque is applied to frame 21c (Fig. 10) to cause motor 21h (Fig. 2) to reduce the resistance of rheostat 18a so that a slower flow of fuel and hence a lower voltage from tachometer generator 17k will suffice to balance fuel-feed controller 18 for that particular boiler. Motor 21h for adjusting rheostat 18a may be of the well-known two-phase type having its common phase-winding connection more or less permanently connected to conductor 21q of power line 19, the opposite ends of its two phase-windings being connected to conductors 21g and 21p with a suitable capacitor 21r in shunt relation thereto. As is well known, connection of conductor 21f to conductor 21p will

cause rotation of motor 21h in one direction, while connection of conductor 21f to conductor 21g will cause rotation in the opposite direction.

As will be readily understood by one skilled in the art, other well-known controllers may be employed instead of the specific controller units 12b, 12c, and 12f. Particularly, controllers depending for their operation on the relation of positions of elements, rather than upon forces or torques, are well-known substitutes and need not be described herein in detail.

In accordance with the invention it is contemplated that substantially independent adjustments of fuel flow shall result from, first, variations in steam pressure operating through the resultant variation in air-loading pressure and, second, deviation from a predetermined, substantially permanent relation between air-loading pressure, a measure of steam demand, and steam flow or air flow, a measure of steam supply. Ordinarily this first adjustment of fuel flow in response to a change in air-loading pressure will be as rapid as possible, but a certain amount of delay in the completion of such adjustment may occur due to such factors as the above-described reset action.

It may be desired to delay completion of the aforesaid second adjustment in order that it may not objectionably affect completion of the first adjustment. In other words, it may be desired to make the second adjustment in response to only sustained deviations in the relation of air-loading pressure to steam flow rather than to transient deviations. To this end, make-and-break element 21s (Fig. 2) is interposed in conductor 21f of transmission line 19 to interrupt the application of power to motor 21h periodically. Make-and-break element 21s may be driven by motor 21t of any suitable well-known type. Other delay means may be employed, if desired.

In order that the aforesaid delay readily may be adjusted screw 21u threaded in any suitable frame member 21v is provided for adjusting the position of conductor 21w relative to the axis of rotation of cam or eccentric 21x. If conductor 21w is closer to cam 21x, make-and-break element 21s will remain closed longer at each revolution of the cam thereby operating motor 21h for a greater portion of the time, whereas if screw 21u is adjusted to move conductor 21w farther from cam 21x motor 21h will operate only a small portion of the time auxiliary controller 12c is unbalanced, and the correction of fuel flow due to operation of controller 12c will proceed slowly.

As previously described, in accordance with the invention it is desired to balance some quantity representative of steam flow from boiler 12 against air-loading pressure in pipe 18m, a quantity representative of total steam system load, to adjust the fuel flow to boiler 12 to compensate for variations in fuel quality. There has been described a system in which the quantity representative of steam flow is the difference in pressure in draft taps 20f and 20g. This differential pressure, being a measure of air flow through boiler 12, is a satisfactory representation of steam flow through boiler 12 because, as described, steam-air unit 12f maintains a fixed relation between steam flow and air flow. This air flow arrangement is advantageous since the draft taps supply a convenient low pressure whereas steam pressure sometimes is too high for control purposes.

However, if desired, steam flow as measured by the differential steam pressure in steam tubes 20t and 20u connected on opposite sides of restriction 11i may be balanced against loading-air pressure in pipe 18m directly in auxiliary control unit 22, Fig. 3, corresponding exactly to auxiliary control unit 12c in principle and differing therefrom only in proportion and therefore not separately described herein. Preferably condensers 23a and 23b are interposed in steam tubes 20u and 20t, respectively, which are functionally interchangeable at control unit 22 with draft taps 20f and 20g, respectively, at control unit 12c. Preferably condensers 23a and 23b are positioned near steam pipe 11h in order that pressure of water condensing therein and in tubes 20t and 20u will be substantially independent of temperature.

As hereinbefore mentioned, it may be desirable to isolate one of boilers 10, 11, or 12 from master controller 16 in order that the isolated boiler may be operated at a substantially constant load as, for example, when it is desired to operate one of the boilers continuously at substantially its full rated load. To this end a transfer valve 24, Fig. 1, is interposed between valve 12a and pipe 15a whereby valve 12a may be disconnected from the air-loading pressure in pipe 15a and connected to a suitable source of constant air pressure, not shown, through pipe 24a. This source of air pressure to which pipe 24a is connected preferably should be precisely regulated at a pressure comparable to the maximum pressure in pipe 15a in order that pressure-reducing valve 12a may be so adjusted that the constant air-loading pressure in pipe 18m will cause auxiliary control unit 12c to balance at the desired steam flow from boiler 12. Any fluctuation in the air pressure in pipe 24a would result in uneven operation of boiler 12.

It should be noted that, in accordance with the invention, auxiliary control unit 12c functions to maintain constant the output from boiler 12 despite varying fuel quality supplied thereto when transfer valve 24 is set to connect pipe 18m through valve 12a to pipe 24a. If poor fuel quality tends to reduce the steam flow from boiler 12, control unit 12c will cause rheostat 18a to be adjusted to increase the fuel flow to boiler 12 sufficiently to increase the steam flow therefrom to rebalance auxiliary unit 12c against the air-loading pressure in pipe 18m.

Referring to Fig. 5, in case the invention is applied to the burning of liquid or gaseous fuel the flow of which more appropriately may be measured by a pressure differential than by a tachometer generator voltage, a supplemental control unit 25 may be substituted for fuel-feed controller 18. Supplemental control unit 25 may be like auxiliary control unit 12c structurally and therefore need not be described herein. It functions like the auxiliary control unit 12c of Fig. 5 except, first, the air-loading pressure supplied to it by pipe 18g is modified as described hereinafter; second, the motor 25c which it controls serves a different purpose; and, third, it balances against the modified air-loading pressure a differential pressure that is a measure of fuel flow instead of air flow.

By way of example, in the embodiment shown in Fig. 5, boiler 12 is supplied with gaseous fuel from any convenient source, not shown, through pipe 25a having a control valve 25b of any suitable well-known type interposed therein. When actuated, motor 25c positions valve 25b through

any suitable gearing to control the flow of fuel to boiler 12. Restriction 25d in fuel pipe 25a and tubes 25e and 25f connected on opposite sides thereof serve to measure the flow of fuel to boiler 12 and to apply to supplemental control unit 25 a differential pressure representative thereof.

Tubes 25f and 25e may be connected to unit 25 in the same way that draft taps 20f and 20g, respectively, are connected to unit 12c. They function differently, however, being analogous to the tachometer generator 17k of Fig. 2 in that they both measure fuel flow. Thus unit 25 balances air-loading pressure against a quantity representative of fuel flow and, through motor 25c, adjusts fuel flow in response to variations in air-loading pressure just as would be done by the equivalent apparatus shown in Fig. 2. As thus far described there is lacking in Fig. 5, however, a substitute for rheostat 18a whereby, in accordance with the invention, fuel flow is additionally controlled in response to the unbalance of auxiliary control unit 12c to control the output of boiler 12.

This additional control may be accomplished by modifying the air-loading pressure from pipe 18m by means of valve 25g which may be of the well-known throttle-and-bleed type like valve 12a. It should have the characteristic of reducing the air pressure from pipe 18m to a lower but proportionate value in pipe 18g. In other words variations in air-loading pressure from master controller 16 will appear in pipe 18g, but they will be scaled down by manually adjusted loading valve 12a and by similar valve 25g adjusted by motor 21h. Valve 25g may be actuated by motor 21h through any suitable gearing.

When auxiliary control unit 12c is unbalanced due to a decrease in air flow, representing a decrease in steam flow, motor 21h will open valve 25g slightly to increase the loading-air pressure in pipe 18g thereby unbalancing supplemental control unit 25 to cause motor 25c to increase the fuel flow to boiler 12 to restore its steam flow. Conversely, an increase in steam flow from boiler 12 without a corresponding increase in air-loading pressure would unbalance unit 12c oppositely to cause motor 21h to close valve 25g slightly thereby unbalancing unit 25 in the direction to cause motor 25c to decrease the fuel flow to boiler 12 by adjustment of valve 25b. It will be apparent to one skilled in the art that valve 25g could be interposed in pipe 18m in the apparatus shown in Fig. 2, and that this valve when actuated by motor 21h would serve the same purpose as rheostat 18a, namely, the adjustment of fuel flow in response to an unbalance of steam flow and steam pressure, this adjustment of fuel flow being in addition to the usual control of fuel flow by master controller 16.

It is contemplated that valves 25g and 12a, Fig. 5, may be of the well-known throttle-and-bleed type in which case operation of one would disturb the adjustment of the other by changing the rate of bleeding air to the atmosphere, which would be an undesired result. To avoid this result pressure regulator 25h is connected between pipes 18m and 18r thus being connected between valves 12a and 25g. Regulator 25h includes a spring-loaded diaphragm 25i (Fig. 6) actuating a ball valve 25j to pass air from any suitable source, not shown, entering through pipe 25k to pipe 18r at a pressure proportionate to the air pressure in pipe 18m. Any other type of regulator that will pass to pipe 18r air pressure proportionate to that in pipe 18m without passing

13

objectionable quantities of air may be employed instead of valve 25h, if desired.

It will be understood that, as used herein, the word "steam" is intended to include the vaporous or gaseous phases of water and substances other than water such, for example, as mercury.

While preferred embodiments of the invention have been described it will be understood that modifications thereof may be made within the spirit and the scope of the invention as set forth in the appended claims.

What is claimed is:

1. Control apparatus for maintaining substantially constant the steam pressure and relative steam outputs of a plurality of boilers adapted to supply a common variable steam load, said boilers utilizing fuel subject to independent variation in quality at each of said boilers comprising the combination of common pressure-responsive means for said boilers for producing a control quantity varying in magnitude in response to variations in said common steam load, means associated with each of said boilers for measuring steam flow therefrom, means associated with each of said boilers and operatively connected to the steam-flow measuring means associated therewith and to said common pressure-responsive means for comparing said measured steam flow and said control quantity, and an automatic fuel-feed controller for each of said boilers operatively connected to said comparing means associated therewith and to said common pressure-responsive means to adjust the fuel flow to said boilers in response to said control quantity and in response to deviations from a predetermined relation between said compared quantities.

2. The method of maintaining constant the rate of flow of steam from a boiler despite varying quality of fuel supplied to said boiler which comprises varying the flow of combustion air to maintain the balance of effects respectively corresponding with the rate of flow of steam and the rate of flow of combustion air, varying the rate of supply of fuel normally to maintain the balance of effects respectively corresponding with the rate of supply of fuel and a reference, and upon deviation from a predetermined magnitude of said air flow effect correspondingly changing the relationship of balance between said fuel effect and said reference effect in a compensating sense.

3. In the control of a group of steam generators supplying a common steam load, the method of compensating for variations in quality of fuel fed to the respective generators in avoidance of disturbing the sharing of said common load which comprises varying the rate of fuel supply to an individual generator of the group in accordance with variations in said common steam load, and effecting a supplemental control of the rate of fuel supply to said individual generator each in accordance with the unbalance of the relationship of the rate of generation of steam by said individual generator and said common steam load of the group.

4. A method as in claim 2 in which for effecting supplemental control of the rate of fuel supply, the combustion air flow of said individual generator is balanced against its rate of generation of steam and the rate of fuel supply modified in accordance with the unbalance of combustion air of said individual generator and said common steam load of the group.

5. A method as in claim 2 in which for effecting the supplemental control of the rate of fuel

14

supply, the rate of fuel supply to said individual generator is modified in accordance with the unbalance of steam flow from said individual generator and said common steam load of the group.

6. Apparatus for controlling the operation of a group of steam generators supplying a common steam load to compensate for variations in the quality of fuel supplied to the individual generators comprising means for varying the rate at which fuel is supplied to a generator of the group in accordance with variations of said common steam load, and means for effecting a supplemental control of the rate at which fuel is supplied to said generator in accordance with the unbalance of the relationship of the steam supplied by said individual generator and the common steam load supplied by said group of steam generators.

7. An apparatus as in claim 6 in which the first-named means for varying the fuel includes pressure-responsive means for producing a first control quantity varying in accordance with system load, in which a controller maintains balance between the combustion air to and the steam output of the individual generator and provides a second control quantity corresponding with deviation from a predetermined relation between said first control quantity and said combustion air, and in which the second-named means for varying the fuel includes a second controller responsive to unbalance of said first and second control quantities.

8. In the control of a plurality of steam generators adapted to supply a common variable steam load apparatus for compensating for variations in the quality of fuel fed to said generators to maintain the predetermined share of said common load to be carried by each of said generators despite variations in fuel quality supplied to the individual generators comprising means responsive to said common steam load for producing a control quantity varying in magnitude and sense in accordance with variations in said common steam load, means for controlling the flow of fuel to each of said generators in accordance with the balance between said control quantity and rate at which fuel is supplied to each of said generators, and means for modifying the rate of supply of said fuel in accordance with the balance between said control quantity and a quantity representative of the steam flow supplied by each of said generators as its share of said common steam load.

9. The method of maintaining the rate of flow of steam from a boiler at a constant value despite varying quality of fuel supplied thereto which comprises upon departure of the rate of flow of steam from said constant value varying the rate of flow of combustion air in accordance with the sense and extent of such departure from said constant value of the rate of flow of steam, comparing the air flow so varied with respect to a reference, varying the rate of flow of fuel in sense opposite to such departure of the rate of steam flow and depending upon the sense of the deviation of the air flow from said reference, and continuing such variation of the rate of flow of fuel in said opposite sense until such time that the steam flow is restored to said constant value and the air flow corresponds with said reference.

10. Apparatus for maintaining the rate of flow of steam from a boiler at a constant value despite varying quality of fuel supplied thereto comprising regulating means for varying the rate of flow of combustion air in the same sense as

15

departure of the rate of flow of steam from said constant value, and a controller responsive to deviation of said air flow from a predetermined value to vary the rate of flow of fuel in sense opposite to the departure in steam flow from said constant value and continuously to effect variation of fuel in such opposite sense until such time that the air flow is restored to said predetermined value.

11. In control of a generator supplying steam to a system, the method of insuring said generator shall supply its share of the system load under varying system load conditions and despite varying quality of its fuel which comprises producing a first control quantity representative of the system load, varying the rate of fuel flow to said generator in response to said first control quantity and in sense corresponding with the change in system load, comparing said first control quantity with the steam flow from said generator to produce a resultant second control quantity in sense corresponding with the deviation from a predetermined relation between said first control quantity and the steam flow from said generator, and further adjusting the rate of fuel flow to the generator continuously in sense corresponding with the aforesaid deviation of the second control quantity until such time that said predetermined relation is reestablished.

12. An arrangement for controlling the flow of fuel to a steam generator in a system to insure it shall supply its share of the varying system load despite varying quality of fuel supplied to that generator comprising pressure-responsive means for producing a control quantity varying in accordance with system load, a balanceable controller for comparing said control quantity with the steam flow from said generator, and automatic means operatively connected to said first-named means for varying the fuel flow in accordance with said control quantity and in

16

sense corresponding with the change in system load, and operatively connected to said balanceable controller to effect further variation in the rate of flow of fuel in sense compensatory of variation in fuel quality of the generator and continuing until such time that a predetermined relation of the steam flow of the generator to said control quantity is reestablished.

13. In the control of a group of steam generators supplying a common load, said group including a first sub-group of one or more generators to supply a fixed amount of steam and a second sub-group of one or more generators to supply the remainder of the common load demand, the method of compensating for variations in quality of fuel fed to the respective generators in avoidance of disturbing the sharing of said common load which comprises varying the rate of fuel supply to each generator of the second sub-group in accordance with variation of the load common to both sub-groups, effecting a supplemental control of the rate of fuel supply to each generator of the second sub-group in accordance with the unbalance of the relationship of its steam output to the load common to both sub-groups, and varying the rate of fuel supply of each generator of the first sub-group in accordance with the unbalance of the relationship of its steam output to a constant reference.

References Cited in the file of this patent

UNITED STATES PATENTS

Number	Name	Date
1,967,988	Dickey	July 24, 1934
2,047,234	Smith	July 14, 1936
2,052,375	Wunsch	Aug. 25, 1936
2,218,454	Midyette	Oct. 15, 1940
2,259,417	Gorrie	Oct. 14, 1941
2,328,499	Saathoff	Aug. 31, 1943