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P. C. TEMPLE

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FLUID CONTROLLING AND DISTRIBUTING APPARATUS

Filed Jan. 22, 1935

3 Sheets-Sheet 1

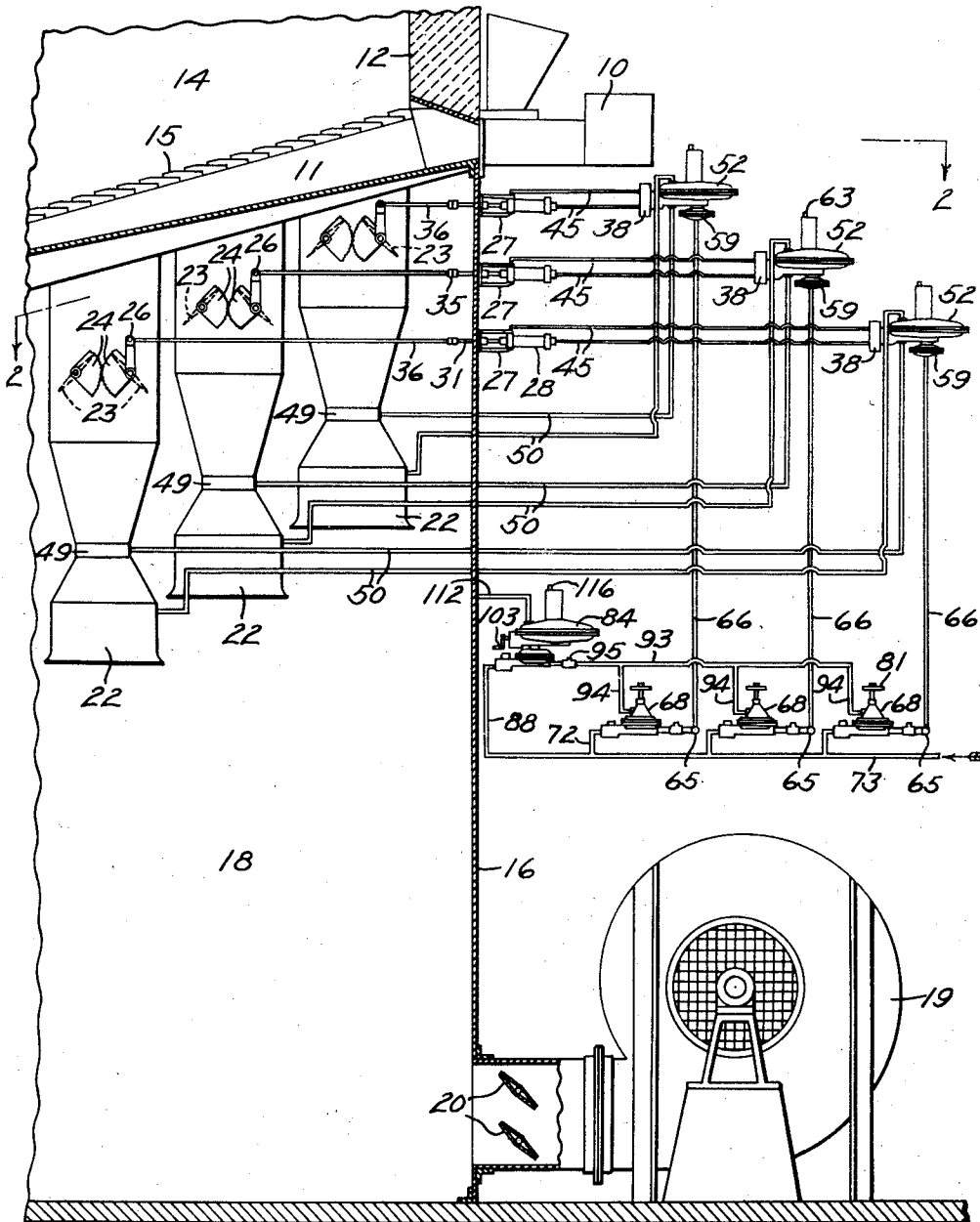


Fig. 1

Inventor

PAUL C. TEMPLE

By *Albert G. Blodgett*
Attorney

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Fig. 2

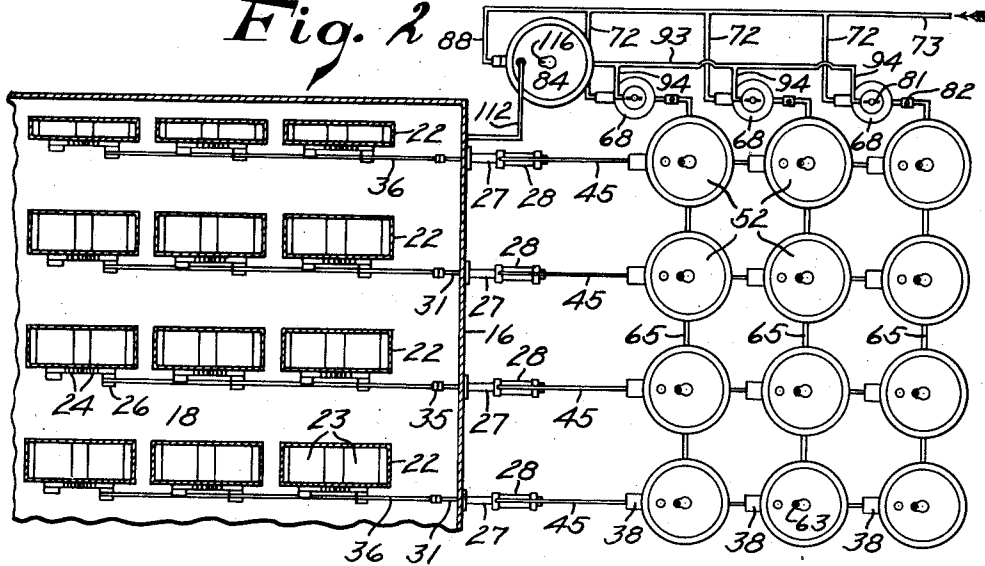
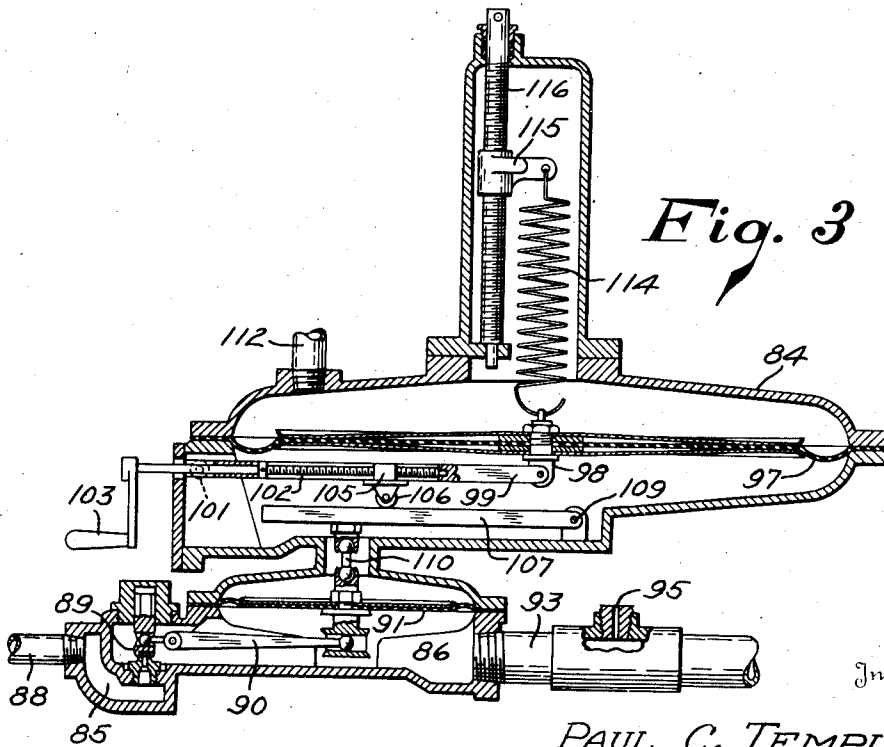


Fig. 3



Inventor

PAUL C. TEMPLE

By *Albert G. Blodgett*
Attorney

Dec. 22, 1936.

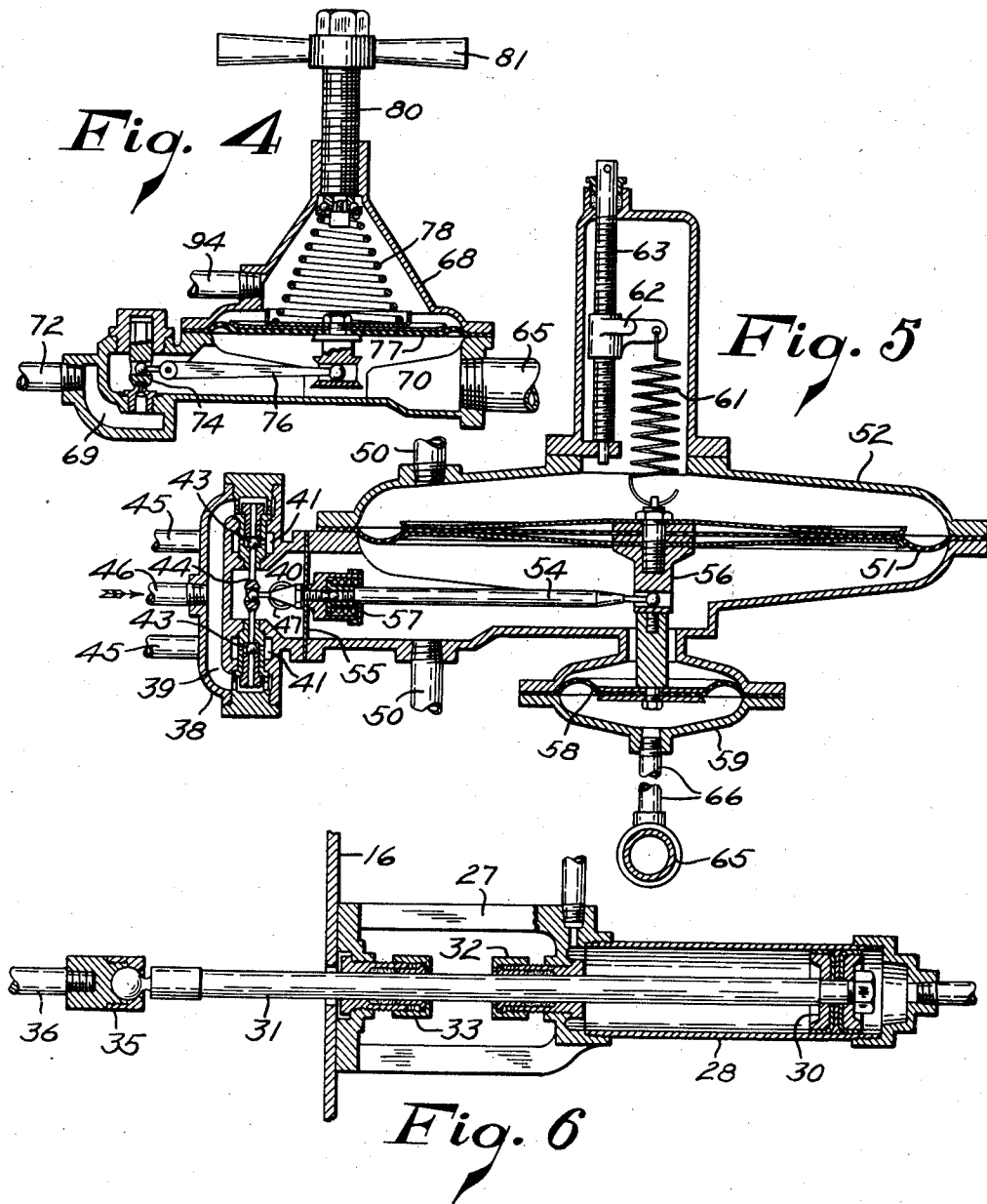
P. C. TEMPLE

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FLUID CONTROLLING AND DISTRIBUTING APPARATUS

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3 Sheets-Sheet 3



Inventor

PAUL C. TEMPLE

By *Albert G. Blodgett*
Attorney

UNITED STATES PATENT OFFICE

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FLUID CONTROLLING AND DISTRIBUTING APPARATUS

Paul C. Temple, Decatur, Ill., assignor to A. W. Cash Company, Decatur, Ill., a corporation of Delaware

Application January 22, 1935, Serial No. 2,945

14 Claims. (Cl. 137-78)

This invention relates to fluid controlling and distributing apparatus, and more particularly to apparatus for controlling the flow and distribution of air for combustion of fuel on an automatic stoker.

In the operation of multiple retort underfeed stokers, the fuel is delivered to the front ends of spaced parallel retorts separated by rows of tuyère blocks. The tuyère blocks are supplied with air under pressure from an air chamber beneath the retorts, and the fuel is burned as it moves slowly toward the rear of the furnace, where the ash is discharged. Since combustion proceeds slowly and progressively, the portion of the fuel bed at the front of the furnace has widely different characteristics from the portion at the rear of the furnace. Consequently, the air requirements for the best combustion conditions likewise differ from front to rear of the furnace. Moreover, the rate of air flow to any small portion of the fuel bed is largely a function of the resistance of the fuel, which in turn depends upon its degree of fineness, its compactness, and its thickness. The air tends to flow more rapidly through thin spots in the fuel bed, increasing the rate of combustion over small localized areas, and thus aggravating the condition. As a result groups of tuyère blocks may become exposed to the heat of the furnace and thus be destroyed. Similar problems are encountered in other fluid distributing systems.

It is accordingly the main object of the present invention to overcome these difficulties and to provide automatic apparatus which will distribute fluid accurately and in a desired manner among a plurality of conduits.

It is a further object of the invention to provide fluid distributing apparatus which can be depended upon to maintain a desired rate of flow in each of a plurality of conduits irrespective of variations in the resistance to such flow.

It is a further object of the invention to provide fluid distributing apparatus which will not only maintain a desired rate of flow in each of a plurality of conduits, but which can also be easily adjusted to vary the rate of flow in certain groups of conduits as compared with other groups of conduits.

It is a further object of the invention to provide apparatus which will distribute fluid among a plurality of conduits, and which can be readily adjusted to vary the total fluid flow without altering the relative distribution.

It is a further object of the invention to provide apparatus which will distribute fluid from

a main supply among a plurality of conduits, and which will automatically vary the flow in the conduits as the main supply is varied, while maintaining a predetermined relative distribution of the fluid.

It is a further object of the invention to provide apparatus which will automatically control the distribution of air to the tuyère blocks of an underfeed stoker, and particularly to provide means whereby the relative quantities of air supplied to various groups of tuyère blocks may be independently adjusted.

With these and other objects in view, as will be apparent to those skilled in the art, the invention resides in the combination of parts set forth in the specification and covered by the claims appended hereto.

Referring to the drawings illustrating one embodiment of the invention, and in which like reference numerals indicate like parts.

Fig. 1 is a longitudinal section through a portion of an underfeed stoker furnace having automatic means for controlling the flow and distribution of the air for combustion;

Fig. 2 is a section on the line 2-2 of Fig. 1; Fig. 3 is a section through the primary regulator;

Fig. 4 is a section through one of the zone regulators;

Fig. 5 is a section through one of the flow-responsive regulators; and

Fig. 6 is a section through one of the hydraulic motors used for damper operation.

In the drawings I have shown an underfeed stoker 10 having retorts 11 which extend rearwardly from the front wall 12 of a furnace 14. The retorts are separated by the usual rows of tuyère blocks 15 which support the fuel bed and distribute air thereto. Beneath the wall 12 is a vertical plate 16 which forms the front wall of an air chamber 18 located beneath the retorts. Air is supplied to the chamber 18 at a suitable pressure by means of a fan 19, the rate of supply being controlled by dampers 20. Vertical ducts 22 extend downwardly from the tuyère blocks 15 into the air chamber 18, each duct connecting at its upper end with a comparatively small group of tuyère blocks. As shown particularly in Fig. 2, the ducts are arranged in rows both transversely and longitudinally of the stoker, three transverse rows and four longitudinal rows being illustrated. It will be understood that the total number of rows required will depend upon the length and width of the stoker. The ducts at the side of the

stoker may be somewhat narrower than the other ducts, as shown in Fig. 2, since the corresponding tuyère blocks supply air to half a retort only.

5 It will now be apparent that with the construction so far described the rate of air flow in any particular duct will depend not only upon the pressure in the air chamber 18 but also upon the resistance of the fuel bed above the corre-
10 sponding group of tuyères. If the fuel bed becomes thin or porous in a small localized area, the resistance will decrease and more air will flow therethrough, accelerating combustion and decreasing the resistance still further. This may
15 result in exposure and burning of the tuyère blocks as well as the setting up of a localized blast of air into the furnace, thereby greatly lowering the efficiency of combustion.

In order to overcome these difficulties, I provide means for maintaining a predetermined rate of air flow in each duct irrespective of variations in the resistance of the fuel bed. For this purpose each duct is provided with a flow controlling valve device or damper mechanism comprising a pair of pivotally mounted blades 23
25 connected by gear segments 24 and provided with an operating arm 26. Each valve device is controlled by a separate power actuated motor 27, which is preferably of the fluid operated type.
30 The motors 27 are shown mounted upon the front of the plate 16, and each motor comprises a horizontal cylinder 28, a piston 30 slidable therein (Fig. 6) and a piston rod 31 extending rearwardly from the piston through a stuffing
35 box 32 at the rear end of the cylinder and a stuffing box 33 at the plate 16. The rear end of each piston rod is located in the air chamber 18 and carries a ball-and-socket joint 35 which is connected to the corresponding operating arm
40 26 by means of a rod 36.

The motors 27 are preferably of the double-acting type, and each is controlled by a four-way pilot valve mechanism 38 shown in detail in Fig. 5. Each valve mechanism comprises walls forming an inlet chamber 39, an exhaust chamber
45 40 and two intermediate chambers 41. Communication between the intermediate chambers and the inlet and exhaust chambers is controlled by a pair of ball valves 43 which are actuated by a reciprocable valve stem 44. The intermediate chambers 41 are connected to the
50 opposite ends of the corresponding cylinder 28 by means of pipes 45. A suitable fluid, such as oil, is delivered under pressure to the inlet chamber 39 through a pipe 46. Oil is free to escape from the exhaust chamber 40 through an opening 47 to which a pipe (not shown) may be connected. This four-way valve mechanism is dis-
55 closed and claimed in my prior Patent No. 1,992,048 granted February 19, 1935.

Each valve mechanism 38 is controlled by a device responsive to the slightest variation in the rate of air flow in the corresponding duct 22, so
65 that undesired changes in the air flow will be automatically prevented. For this purpose I prefer to use a suitable pressure-responsive device, and subject this device to a fluid pressure differential which is a function of the rate of
70 air flow. In the embodiment illustrated, each duct 22 is provided with a constricted throat 49 (Fig. 1) forming a venturi, and the pressure differential produced by the venturi is transmitted through two pipes 50 to a flexible diaphragm
75 51 mounted in a casing 52. These pipes have

been omitted from Fig. 2, to avoid the possibility of confusion because of the multiplicity of pipes. The movements of the diaphragm 51 are transmitted to the valve stem 44 by means of
5 the lever 54 fulcrumed on a thin flexible metal plate 55 which forms one wall of the exhaust chamber 40. One end of the lever 54 engages the valve stem 44, and the other end of the lever engages a post 56 secured to the
10 central portion of the diaphragm 51. The lever may be provided with a yieldable joint 57 of the type disclosed in my prior Patent No. 1,992,048 granted February 19, 1935.

Each diaphragm 51 is supported in opposition to the pressure differential by means providing
15 a loading force which can be varied, so that the rate of air flow in the corresponding duct 22 can be altered to afford any desired rate of fuel combustion. Such a variable loading force is provided in the illustrated embodiment by a second
20 diaphragm 58 mounted within a casing 59 and secured to the lower end of the post 56. This diaphragm is subjected to a controlled fluid pressure. A still further control over the loading of the diaphragm 51 may be obtained by providing
25 a coiled tension spring 61 which is connected at one end to the central portion of the diaphragm and at the other end to a nut 62 mounted on a rotatable screw 63. It will be apparent that by turning the screw the nut 62 can be moved and
30 the spring tension thus adjusted in a desired manner.

In an underfeed stoker furnace the fuel bed varies greatly from front to rear, and the air requirements for the best combustion conditions
35 likewise vary. It is therefore desirable to provide means whereby the airflow in the ducts 22 in each transverse row can be controlled independently of the air-flow in the ducts in the other rows. For this purpose separate headers 65 are
40 provided, one for each transverse row of ducts 22, and each header is connected by means of branch pipes 66 to a group of the casings 59. By varying the pressure in the headers independently I am able to control the air flow in separate zones
45 extending transversely of the furnace.

The fluid pressure in each header 65 is controlled by means of a separate zone regulator 68, one of which is shown in detail in Fig. 4. Each zone regulator comprises walls forming an inlet
50 chamber 69 and an outlet chamber 70, the header 65 being connected to the outlet chamber. A suitable fluid, such as air, is supplied under pressure to the inlet chamber 69 by means of a branch pipe 72 leading from a main air supply pipe 73,
55 and the flow from the inlet chamber to the outlet chamber is controlled by a valve 74. This valve is actuated by means of a lever 76 to which a flexible diaphragm 77 is connected, this diaphragm being subjected on one side to the pressure in the outlet chamber. The diaphragm,
60 which serves as a valve actuator, is loaded by means of a coiled compression spring 78 which is supported at its upper end by a screw 80 provided with a handle 81. By turning the handle, the force applied by the spring can be adjusted as desired. A small vent or leak-off 82 (Fig. 2) is provided in each header 65 to improve the pressure regulation and permit a reduction in the pressure when required.

With the construction as so far described, the relative distribution of the air among the respective zones can be controlled manually. However, it is desirable to provide means whereby the air flow to the entire stoker can be adjusted when
75

the demand for heat varies, preferably without affecting the distribution of the air among the zones. For this purpose I provide the primary regulator 84 shown in Fig. 3, which comprises walls forming an inlet chamber 85 and an outlet chamber 86. Compressed air from the pipe 73 is supplied to the inlet chamber 85 by means of a branch pipe 88, and the flow from the inlet chamber to the outlet chamber is controlled by a valve 89. This valve is actuated by means of a lever 90 to which a flexible diaphragm 91 is connected, this diaphragm being subjected on one side to the pressure in the outlet chamber. The outlet chamber communicates with a header 93 having branch pipes 94 each of which connects with one of the zone regulators 68 at a point on the opposite side of the diaphragm 77 from the outlet chamber 70. The diaphragm 77 is thus loaded to a variable degree dependent both upon the pressure in the header 93 and the adjustment of the screw 80. The header 93 is provided with a small vent or leak-off 95 to improve the pressure regulation and permit a reduction in the pressure when required. The rate of air flow to the entire stoker depends upon the pressure in the header 93, and this pressure in turn depends upon the loading of the diaphragm 91 in the primary regulator. It is desirable that this loading should be varied automatically whenever the air supply to the chamber 18 is varied, so that the combustion rate on the entire stoker can be controlled simply by adjusting the main dampers 20. For this purpose I have provided a comparatively large loading diaphragm 97 forming a part of the primary regulator and mechanically connected to the diaphragm 91. The two diaphragms are preferably connected by a lever system having an adjustable mechanical advantage so that the combustion rate can be varied within certain limits without changing the position of the dampers 20. For this purpose I have shown a stud 98 secured to the central portion of the loading diaphragm 97. A lever 99 is pivotally connected at one end to the stud 98 and supported at the other end by a fixed fulcrum 101. A screw 102 is rotatably mounted on the lever 99, a handle 103 being provided at one end of the screw. This screw carries a nut 105 having a roller 106 mounted thereon, and the roller engages a second lever 107 which is supported on a fixed fulcrum 109 at one end. The lever 107 is connected to the central portion of the diaphragm 91 by means of a ball-end link 110. The pressure in the air chamber 18 is transmitted to the diaphragm 97 by means of a pipe 112, and this pressure provides the loading force which determines the pressure to be maintained in the outlet chamber 86. For purposes of adjustment I provide a coiled tension spring 114 which connects the stud 98 to a nut 115 mounted on a rotatable screw 116. By turning the screw, it is possible to vary the spring tension in a desired manner.

The operation of the invention will now be apparent from the above disclosure. Air at a suitable pressure, say 40 pounds per square inch, is supplied to the pipe 73 and flows through the branch pipe 88 to the inlet chamber 85, past the valve 89, through the outlet chamber 86 to the header 93, and escapes to atmosphere through the vent 95. The fan 19 delivers air to the chamber 18 and produces a pressure in this chamber which may vary from say one-half inch water column to perhaps eight inches water column, depending upon the rate at which it is desired to burn the fuel. The air travels upwardly from

the chamber 18 through the ducts 22 to the tuyère blocks 15, which distribute the air to the fuel bed. The pressure in the chamber 18 is transmitted through the pipe 112 to the diaphragm 97, which acts through the levers 99 and 107 to support the diaphragm 91 against the pressure in the outlet chamber 86. So long as the manual adjustments remain unaltered, there will be a definite predetermined pressure maintained in the outlet chamber 86, and this pressure will depend upon the pressure in the air chamber 18. An increase in the air chamber pressure will affect the diaphragm 97 and increase the loading of the diaphragm 91. This will open the valve 89 farther and increase the pressure in the outlet chamber until an equilibrium is again established. A reduction in the air chamber pressure will act in the reverse direction.

The pressure in the outlet chamber 86 is transmitted through the header 93 and branches 94 to the zone regulators 68, and thus acts in conjunction with the springs 78 to establish a loading for the zone regulator diaphragms 77. Compressed air flows from the supply pipe 73 through the branches 72 to the inlet chambers 69, past the valves 74, and through the outlet chambers 70 to the headers 65, escaping to atmosphere through the vents 82. The valves 74 function automatically to maintain definite outlet chamber pressures dependent upon the loading of the respective diaphragms. The pressure in each outlet chamber 70 is transmitted through the corresponding header 65 and branches 66 to the loading diaphragms 58 of a group of the air flow regulators, each group being associated with a transverse row of the ducts 22. The diaphragms 58 provide a loading for the corresponding diaphragms 51, and so long as this loading remains constant a predetermined rate of air flow will be maintained in the corresponding duct 22. If the flow in a particular duct 22 should increase, perhaps because of lessened fuel bed resistance over the corresponding tuyère blocks, the pressure differential transmitted through the corresponding pipes 50 will immediately increase, thus moving the diaphragm 51. This will actuate the valve mechanism 38 and admit oil to one end of the cylinder 28, moving the piston 30 and closing the damper blades 23 until the desired air flow is restored. An increased fuel bed resistance will of course result in opening of the blades 23.

By means of the handles 81 it is possible to adjust the tensions of the springs 78 and thus vary the loading pressure transmitted to one group of air flow regulators relative to the pressure transmitted to other groups. In this way a transverse zoning of the stoker is obtained, and any desired distribution of the combustion air from front to rear of the stoker is made possible. This is very important from the view-point of combustion efficiency.

If the demand for heat increases, the dampers 20 will be opened, increasing the pressure in the air chamber 18 and increasing the loading effect of the diaphragm 97 on the diaphragm 91. This will increase the pressure in the header 93 and the resultant loading of the zone regulator diaphragms 77. The zone regulators will thereupon operate to increase the pressure in the headers 65 and the loading effect of the air flow regulator diaphragms 58. This will unbalance the diaphragms 51 and cause all the dampers 23 to open slightly until the increased flow restores equilibrium under the new conditions. Slight changes in the demand for heat can be met by adjusting

the mechanical advantage of the lever system 99—107 by means of the hand crank 103. This will vary the pressure in the outlet chamber 86 without changing the pressure in the air chamber 18. The spring 114 is preferably adjusted at installation so that the minimum pressure in air chamber 18 will produce the minimum pressure required on the loading diaphragms 58, corresponding to the minimum rate of air flow desired.

It will now be apparent that the invention provides a very accurate and positive control over the flow and distribution of the air for combustion of the fuel. By means of the zone regulators 68 it is a simple matter to vary the relative distribution of the air from front to rear of the stoker in any desired manner, thus making it possible to operate the stoker at high combustion efficiencies. Localized blasting of air through thin spots in the fuel bed is positively prevented, and the stoker can be operated at exceedingly high fuel burning rates without the danger of exposing and burning the tuyère blocks. The invention can be applied to any fluid distributing system in which fluid is delivered from a main supply into branch conduits characterized by variable resistance to flow.

Having thus described my invention, what I claim as new and desire to secure by Letters Patent is:

1. In combination with a plurality of ducts for the flow of fluid and arranged in groups, a flow controlling device for each duct, a motor to actuate each device, pilot means to control each motor, means associated with each duct to provide a fluid pressure differential which is a function of the rate of flow in the duct, a pressure responsive member subjected to the pressure differential and operatively connected to the corresponding pilot means, a pressure responsive device operatively connected to each member, means to supply fluid under pressure to each of the pressure responsive devices, and independently adjustable means for controlling the pressure of the fluid supplied to the pressure responsive devices corresponding to each group of ducts.

2. In combination with a plurality of ducts for the flow of fluid and arranged in groups, a flow controlling device for each duct, a motor to actuate each device, pilot means to control each motor, means associated with each duct to provide a fluid pressure differential which is a function of the rate of flow in the duct, a flexible diaphragm subjected to the pressure differential and operatively connected to the corresponding pilot means, a flexible loading diaphragm operatively connected to each of the first mentioned diaphragms, means to supply fluid under pressure to each of the loading diaphragms, and independently adjustable means for controlling the pressure of the fluid supplied to the loading diaphragms corresponding to each group of ducts.

3. In combination with a plurality of ducts for the flow of fluid and arranged in groups, a flow controlling device for each duct, a fluid operated motor to actuate each device, a pilot valve to control each motor, means associated with each duct to provide a fluid pressure differential which is a function of the rate of flow in the duct, a flexible diaphragm subjected to the pressure differential and operatively connected to the corresponding pilot valve, a flexible loading diaphragm operatively connected to each of the

first mentioned diaphragms, means to supply fluid under pressure to each of the loading diaphragms, and independently adjustable means for controlling the pressure of the fluid supplied to the loading diaphragms corresponding to each group of ducts.

4. In combination with a plurality of ducts for the flow of fluid and arranged in groups, a flow controlling device for each duct, a motor to actuate each device, pilot means to control each motor, means associated with each duct to provide a fluid pressure differential which is a function of the rate of flow in the duct, a pressure responsive member subjected to the pressure differential and operatively connected to the corresponding pilot means, a pressure responsive device operatively connected to each member, means to supply fluid under pressure to each of the pressure responsive devices, a separate valve mechanism for each group of ducts to control the pressure of the fluid supplied to the corresponding pressure responsive devices, and independently adjustable means for controlling the pressure supplied by each valve mechanism.

5. In combination with a plurality of ducts for the flow of fluid and arranged in groups, a flow controlling device for each duct, a motor to actuate each device, pilot means to control each motor, means associated with each duct to provide a fluid pressure differential which is a function of the rate of flow in the duct, a pressure responsive member subjected to the pressure differential and operatively connected to the corresponding pilot means, a pressure responsive device operatively connected to each member, means to supply fluid under pressure to each of the pressure responsive devices, a separate valve mechanism for each group of ducts to control the pressure of the fluid supplied to the corresponding pressure responsive devices, each valve mechanism including a valve actuator responsive to the fluid pressure controlled thereby and subjected to a loading in opposition to said fluid pressure, and independently adjustable means for varying the loading of each valve actuator and thereby varying the fluid pressure.

6. In combination with a plurality of ducts for the flow of fluid and arranged in groups, a flow controlling device for each duct, a motor to actuate each device, pilot means to control each motor, means associated with each duct to provide a fluid pressure differential which is a function of the rate of flow in the duct, a pressure responsive member subjected to the pressure differential and operatively connected to the corresponding pilot means, a pressure responsive device operatively connected to each member, means to supply fluid under pressure to each of the pressure responsive devices, a separate valve mechanism for each group of ducts to control the pressure of the fluid supplied to the corresponding pressure responsive devices, each valve mechanism including a valve actuator responsive to two opposing fluid pressures one of which is the pressure controlled by the valve mechanism and the other of which is a loading pressure, a primary regulator to control the loading pressure supplied to all of the valve actuators, and means to subject each valve actuator to an independently adjustable loading force modifying the effect of the loading pressure thereon.

7. In combination with a plurality of ducts for the flow of fluid, means including a chamber to supply fluid to all of the ducts, a flow controlling device for each duct, a motor to actuate each device, pilot means to control each motor, means associated with each duct to provide a fluid pressure differential which is a function of the rate of flow in the duct, a pressure responsive member subjected to the pressure differential and operatively connected to the corresponding pilot means, a pressure responsive device operatively connected to each member, means to supply fluid under pressure to each of the pressure responsive devices, and means to vary the pressure of the fluid supplied to the pressure responsive devices in accordance with a characteristic of the fluid in the chamber.

8. In combination with a plurality of ducts for the flow of fluid, a chamber communicating with all of the ducts, means to supply fluid under pressure to the chamber, a flow controlling device for each duct, a motor to actuate each device, pilot means to control each motor, means associated with each duct to provide a fluid pressure differential which is a function of the rate of flow in the duct, a pressure responsive member subjected to the pressure differential and operatively connected to the corresponding pilot means, a pressure responsive device operatively connected to each member, means to supply fluid under pressure to each of the pressure responsive devices, and means to vary the pressure of the fluid supplied to the pressure responsive devices in accordance with the pressure of the fluid in the chamber.

9. In combination with a plurality of ducts for the flow of fluid and arranged in groups, means including a chamber to supply fluid to all of the ducts, a flow controlling device for each duct, a motor to actuate each device, pilot means to control each motor, means associated with each duct to provide a fluid pressure differential which is a function of the rate of flow in the duct, a pressure responsive member subjected to the pressure differential and operatively connected to the corresponding pilot means, a pressure responsive device operatively connected to each member, means to supply fluid under pressure to each of the pressure responsive devices, a separate valve mechanism for each group of ducts to control the pressure of the fluid supplied to the corresponding pressure responsive devices, each valve mechanism including a valve actuator responsive to two opposing fluid pressures one of which is the pressure controlled by the valve mechanism and the other of which is a loading pressure, a primary regulator to control the loading pressure supplied to all of the valve actuators in accordance with a characteristic of the fluid in the chamber, and means to subject each valve actuator to an independently adjustable loading force modifying the effect of the loading pressure thereon.

10. In combination with a plurality of ducts for the flow of fluid, means including a chamber to supply fluid to all of the ducts, a flow controlling device for each duct, automatic mechanism to actuate the flow controlling devices and maintain a predetermined rate of flow in each duct, and means to adjust the automatic mechanism in accordance with variations in a characteristic of the fluid in the chamber.

11. In combination with a plurality of ducts for the flow of fluid, means including a chamber to supply fluid to all of the ducts, a flow controlling device for each duct automatic mechanism to actuate the flow controlling devices and maintain a predetermined rate of flow in each duct, and means to adjust the automatic mechanism in accordance with variations in the pressure of the fluid in the chamber.

12. In combination with a plurality of ducts for the flow of fluid, means including a chamber to supply fluid to all of the ducts, a flow controlling device for each duct, automatic mechanism to actuate the flow controlling devices and maintain a predetermined rate of flow in each duct, and means responsive to variations in the pressure of the fluid in the chamber and arranged to adjust the automatic mechanism for an increased rate of flow as said pressure increases.

13. In combination with a plurality of ducts for the flow of fluid, means including a chamber to supply fluid to all of the ducts, a flow controlling device for each duct, a motor to actuate each device, pilot means to control each motor, means associated with each duct to provide a fluid pressure differential which is a function of the rate of flow in the duct, a pressure responsive member subjected to the pressure differential and operatively connected to the corresponding pilot means, a loading device operatively connected to each member, and means to vary the effect of the loading devices in accordance with variations in a characteristic of the fluid in the chamber.

14. In combination with a plurality of ducts for the flow of fluid, means including a chamber to supply fluid to all of the ducts, a flow controlling device for each duct, a motor to actuate each device, pilot means to control each motor, means associated with each duct to provide a fluid pressure differential which is a function of the rate of flow in the duct, a pressure responsive member subjected to the pressure differential and operatively connected to the corresponding pilot means, a pressure responsive device operatively connected to each member, means to supply fluid at a controlled pressure to each of the pressure responsive devices, and means to vary said controlled pressure in accordance with variations in a characteristic of the fluid in the chamber.

PAUL C. TEMPLE.