March 16, 1965 H. BRANDT ETAL 3,173,483

CONTROL METHOD AND SYSTEM FOR DOWNHOLE GAS-AIR HEATER

Filed Nov. 21, 1961

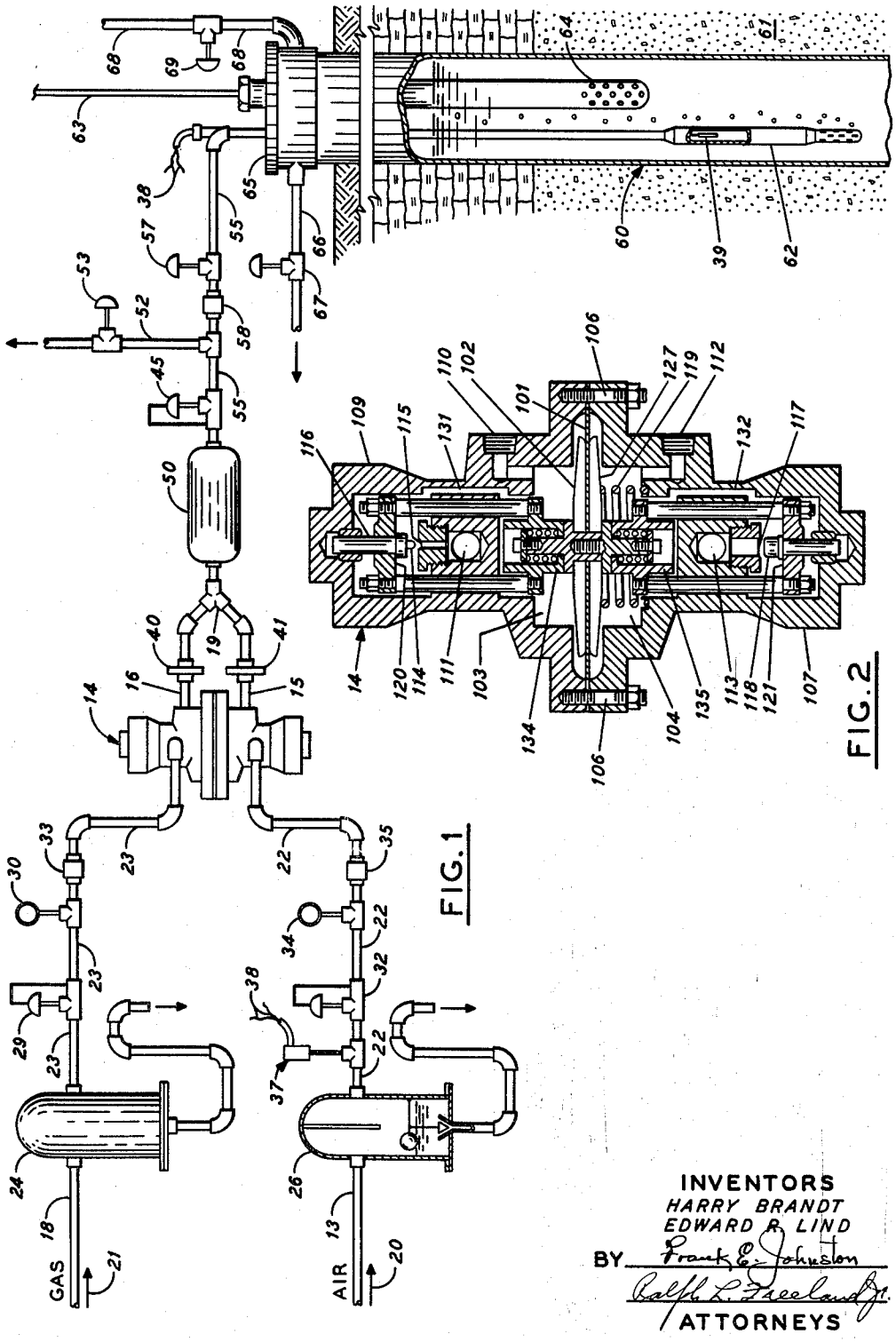



FIG. 1



FIG. 2

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United States Patent Office

3,173,483

Patented Mar. 16, 1965



3,173,483

# CONTROL METHOD AND SYSTEM FOR DOWNHOLE GAS-AIR HEATER

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Filed Nov. 21, 1961, Ser. No. 153,808
9 Claims. (Cl. 166—38)

This invention relates to methods and apparatus for closely controlling the flow of a combustible gas-air mixture to a borehole heater, said heater located in a well adjacent an oil-producing formation.

In the oil-producing art it is common to supply heat to a producing formation in order to reduce the viscosity of the oil therein. Heat is supplied to the portion of the formation adjacent the producing well to improve the flow of oil from the formation into the well. Many methods of heating an oil-producing formation adjacent a producing well have been tried. A method which has been successful in supplying heat to a producing formation provides for burning a combustible, fuel gas-air mixture in a downhole gas-air heater located in the borehole adjacent the producing formation. Apparatus for heating an oil-bearing formation to improve production therefrom is disclosed in U.S. Patent 2,887,160.

Generally, the downhole heater is located in a well adjacent a producing formation. The heater is usually located below the fluid level in the well. In addition to the heater and connecting surface piping, it is common to also find an oil production string and a downhole pump in the well. The production string with sucker rod and pump are useful in pumping the reduced-viscosity oil to the surface. In order to maintain the viscosity of the oil at a desirable level, it is usually necessary that the downhole heater operate continuously during production from the well. A major problem encountered in the continuous operation of downhole heaters has been the supply of the combustible gas-air mixture to the burner. Since the burner is usually totally immersed in oil in the well, the ratio of air to gas in the combustible mixture must be controlled within narrow limits to provide for efficient combustion. Because field sources of fuel gas and air will vary in pressure and because the pressure in the well will vary due to varying oil levels therein, the control of the air and gas flow has heretofore been exceedingly difficult, requiring complex control systems.

It is an important object of the present invention to provide for closely controlling the gas and air ratio of a combustible gas and air mixture for flow to a downhole burner, said control effected independent of pressure fluctuations in either or both the source of air and the source of gas, and said control further providing for substantially stopping all flow in response to loss of flow from either the gas or the air source.

Briefly, the present invention provides a method and apparatus for closely controlling the ratio of a combustible gas and air mixture for flow from the earth's surface to at least one downhole heater. Separate sources of gas and air, both capable of supplying gas and air at pressure above a predetermined minimum pressure, are required. Gas and air are flowed in separate conduits to a gas chamber and an air chamber, respectively, of a pressure balance zone. The pressure balance zone has a diaphragm in air-tight relationship between the gas and the air chambers. The pressure balance zone utilizes the diaphragm and appropriate valve arrangements to substantially equalize the pressure of the gas and the air while retaining said gas and said air in separate conduits. The gas and air, now at equal pressure, are flowed from the pressure balance zone



through presized orifices in each separate conduit. The orifices are selected to pass a desired ratio of gas and air to a common mixing conduit. Because the pressure balance zone maintains the pressure in the separate conduits equal to each other regardless of a change of pressure in either the gas or air source, the orifices will pass a desired ratio to the mixing conduit. The gas and air are flowed together as a combustible mixture in the mixing conduit and then the combustible mixture is directed underground to the combustion section of a downhole heater.

Further advantages and objects of the present invention will become apparent from the following detailed description read in light of the accompanying drawing, in which:

FIG. 1 is a diagrammatic view of one arrangement of apparatus useful in practicing the method of the invention;

FIG. 2 is a sectional view of an embodiment of apparatus useful as the pressure balance zone.

Referring specifically to FIG. 1, a source of field gas is represented by 21. The source of gas may be any conveniently available field supply of combustible gas. For example, combustible gas, primarily methane, is often a product of an oil-producing formation. Field gas, such as is commonly found in producing wells, may initially be at a sufficiently high pressure. If the pressure of the gas is not sufficiently high, a compressor is utilized to insure a supply of gas at above a certain minimum pressure.

A source of air under pressure is represented by the numeral 20. Air is usually supplied from an air compressor which is regulated to maintain at least a suitable desirable minimum pressure. The minimum desirable pressure which must be exceeded by both the air supply and the gas supply is the pressure in the well at the location of the downhole burner to which the gas and air are to be supplied, plus the pressure drop in the supply system.

One skilled in the art can determine a desirable minimum pressure at which the sources of the gaseous constituents of the combustible mixture must be maintained. However, a problem is encountered in maintaining a desirable combustible ratio between the supplied air and gas because of pressure fluctuation above the minimum pressure in either of the gas or air conduits. The pressure fluctuations are caused by changes in pressures in the source of gas or air. For example, an air compressor used as a source of high pressure air may produce compressed air at fluctuating pressure because of design factors. The present invention is directed to providing a constant rate and ratio of gas and air mixture at the downhole heater independent of pressure fluctuations in the source of either air and gas or of both and independent of downhole pressure fluctuations.

It is desirable when operating with field sources of gas and air to utilize liquid-knockout devices, such as represented schematically by device 24, on gas supply line 18 and device 26 on the air supply line 13. As is well known in the art the liquid-knockout device functions to remove liquid from a gas stream by a combination of centrifugal removal and filtering. The liquid-knockout devices are particularly desirable to maintain the pressure balance valve in operable condition when the control system is functioning unattended over an extended period of time. If liquid enters the pressure balance valve, the liquid may impair the operation of the valve.

Conduit 23, leading out of gas line liquid-knockout device 24, provides for flowing gas to the pressure balance zone 14 through pressure regulator 29, and check valve 33. Pressure regulator 29 on gas conduit 23 maintains a substantially constant gas pressure in conduit 23. Pres-

sure gauge 30 is available for setting the pressure of regulator 29. Check valve 33 prevents accidental flow of the combustible mixture into the upstream part of gas line 23. In case of gas pressure failure in conduit 23, check valve 33 will close to prevent an explosive combustible mixture from backflowing in conduit 23.

An important feature of the present invention is automatic shutdown of air flow to the downhole heater if combustion in the heater is lost. Air conduit 22 provides for passing air under pressure from liquid knockout device 26 on air supply conduit 22 to pressure balance zone 14. Air is passed through pressure regulator 32 and check valve 35 in a manner similar to that described above for gas flow. Pressure in conduit 22 is indicated by pressure gauge 34. Also on air conduit 22 is a normally closed, electrically operated, thermostat valve 37. The valve is held open electrically to allow air to pass through conduit 22. Valve 37 is connected with a temperature-measuring or similar instrument 39 inside the downhole heater 62 which provides for actuating mechanism in valve 37 to close valve 37 to stop air flow in conduit 22 if the tempertaure in the upstream section of the combustion chamber of heater 62 falls below a preselected minimum temperature. This temperature is usually selected to be indicative of loss of combustion in the heater. Valve 37 also provides for closing in the event of electrical power failure since the valve is held open electrically. Valve 37 is initially kept open by electrical means during start-up of the heater until the temperature in the combustion chamber of heater 62 is brought up to above the preselected minimum temperature. It is desirable to shut off the supply of air to the heater if combustion is lost therein because, as is well known in the art, spontaneous combustion of the formation petroleum often results when air is contacted with the oil. Combustion is very likely when the air encounters petroliferous material already at an elevated temperautre. Serious damage may be done to the well equipment and the formation if this occurs.

The critical pressure balance between the gas and air supply is accomplished in pressure balance zone 14. In order that the method of the present invention provides for effectively operating a field downhole burner unit, it is desirable that the pressures in the air supply conduit 15 and gas supply conduit 16 downstream of the pressure balance zone 14 be equal within approximately ten percent or less of the pressure drop across orifices 40 and 41. For example, if the pressure drop across orifice 40 and orifice 41 is 5 p.s.i. the pressure balance zone would need to provide pressures in air supply conduit 15 and in gas supply conduit 16 equal to each other within 0.1 to 0.5 p.s.i. If the pressure were allowed to fluctuate as much as 1.0 to 2.0 p.s.i. in this example, the burner would not operate efficiently or reliably. The close control on the pressure in the supply conduits is needed to insure that the combustible ratio of gas and air that pass respectively gas supply orifice 40 and air supply orifice 41 located downstream of pressure balance zone 14 is such that efficient combustion is maintained in the downhole heater.

A preferred embodiment of apparatus useful as pressure balance zone 14 will be fully described hereinafter. Generally, however, operation of the pressure balance zone is accomplished by means of a single diaphragm that is loaded on one side by gas and on the other by air. The pressure balance zone has an inlet and outlet on each side of a single diaphragm. A single valve stem is actuated by the diaphragm. The diaphragm takes a position that depends on the difference in downstream pressures in the gas and air conduits. The diaphragm will always move to a position that tends to close the entry port of either gas or air, depending on which fluid is at the higher pressure. More simply stated, the diaphragm is loaded on opposite sides by the air and the gas. As long as the air and the gas pressures are equal, the amount of air and gas entering the pressure balance zone is unchanged. However, should the air supply pressure, for example, suddenly exceed the pressure of the gas supply, the diaphragm will be overloaded on the air side and will move to reduce the amount of air flow and increase the amount of gas flow through the pressure balance zone, thus tending to bring the downstream pressure of the gas and air back to equilibrium.

Another important feature of the present control system is the manner in which the pressure balancing zone 14 operates in conjunction with thermostat valve 37 to provide for complete shutdown of air flow and substantially complete shutdown of gas flow to the downhole heater should combustion be lost at the burner. Thermostat valve 37 is normally closed to air flow. It is held open electrically, however, to permit air to flow. If the electrical power should fail, or if the temperature inside downhole heater 62 at temperature measuring instrument 39 falls below a predetermined minimum, then thermostat valve 37 closes to stop air flow to pressure balance zone 14. The pressure balance zone 14 then senses a decreasing air pressure, and therefore zone 14 acts to decrease gas pressure. Finally, the pressure balance zone 14 will substantially shut off the flow of gas to downhole heater 62. It is desirable that the thermostat valve 37 be on the air line 22, so that flow of air is stopped, thereby reducing the combustion-supporting environment in the well adjacent the producing formation, in order that the possibility of spontaneous ignition be reduced.

As has been discussed, it is vital to effective control of a downhole heater as contemplated by the method of the present invention that the pressure in the gas supply line at point 16 be substantially equal to the pressure in the air supply line at point 15. When the pressures at points 15 and 16 are equal and the air and gas lines meet at point 19, the pressure drop across orifice 41 in the air supply line is equal to the pressure drop across orifice 40 in the gas supply line. Orifices 40 and 41 are sized in such a relationship that a predetermined mixture of air and gas results in mixing conduit 50. The orifices are desirably selected so that a combustible mixture of gas and air results in mixing conduit 50. The combustible mixture is preferably slightly richer in gas than a stoichiometric gas and air mixture to insure that all the oxygen is consumed during combustion so that no free oxygen enters the well from the heater. The mixing conduit 50 should have sufficient storage capacity to prevent pressure surging at pressure balance zone 14 when zone 14 is acting to equalize the pressure in the air and gas lines.

The accuracy with which a particular gas-to-air ratio is maintained on the downstream side of the orifices depends on many factors, such as the pressures upstream of the orifices, the pressure downstream of the orifices, the coefficients of polytropic expansion, the temperature of the gases, the areas of the orifices, and empirical orifice coefficients. The formulae that express the flow of gases through orifices are well known, however. The flow of air and gas can be determined from mormulae such as are described in Power Test Code 19.5, ASME, 1949. When mixing gas and air in combustible mixture, it has been found that the variation in pressure between the two gases upstream of the orifices must be maintained to within approximately ten percent or less of the pressure drop across orifices 40 and 41, respectively, in order that efficient combustion of the mixture in the heater may be maintained. To provide for continual, efficient combustion in the combustion chamber of a downhole burner, it is necessary that a predetermined ratio of gas and air be supplied thereto, regardless of changes of pressure of either or both the gas or air supplies. The present method provides for supplying a constant-ratio mixture for combustion, even in the event of supply pressure fluctuations.

It is desirable to include a back-pressure regulator 45

in supply conduit 55 to prevent pressure fluctuations in the well from having an injurious effect on the gas and air mixture control. The back-pressure regulator 45 is desirably positioned downstream of the mixing conduit 50. A diaphragm-operated back-pressure valve which is well known in the art is suitable for use as back-pressure regulator 45. This regulator 45 holds the pressure downstream of orifices 40 and 41 constant, independent of pressure fluctuations occurring in the downhole heater portion of the combustible gas supply system.

For continual efficient operation of the down-hole heater the flow rate of the combustible mixture as well as the mixture ratio must be maintained at a predetermined value depending on the amount of heat desired. To achieve a predetermined flow rate, check valve 33 and check valve 35 and pressure equalizing zone 14 are sized so that the pressure drops across these components are substantially less than the pressure drops across orifices 40 and 41. The gas and air mixture flow rate is controlled primarily by the pressure drop across orifices 40 and 41 or by pressure drops between respectively the downstream side of pressure regulator 29 and point 19 and the downstream side of pressure regulator 32 and point 19. The mixture rate can be increased by increasing the difference in pressure settings of regulator 29, regulator 32, and regulator 45. Pressure regulators 29 and 32 are set at the same pressure. However, as discussed above, pressure balance zone 14 is also needed to make the pressures upstream of orifices 40 and 41 equal to each other within narrow limits.

Conduit 52 and valve 53 lead to displacement or other flow meters for calibrating the flow of the mixture through the system. Alternatively, conduit 52 may be connected with appropriate piping to one or more other borehole heaters. Conduit 55 provides for flowing the combustible mixture through check valve 58 and valve 57 to the combustion chamber of a downhole heater 62 located adjacent producing formation 61. Also in well casing 60 are a sucker rod string 63 and production pump 64. Oil which is pumped to the surface is removed from well head 65 by means of conduit 66 through valve 67. If the well produces only brine and crude oil, the combustion gases from the burner are bled from well head 65 through conduit 68 and valve 69. When field gas is produced in addition to crude oil and brine, the field gas and the combustion gases are taken from the well through conduit 68 and valve 69. Procedures and apparatus well known in the art are then used to separate petroleum gas from the combustion gases, and the crude oil from the brine. A thermo-couple 39 is located in downhole heater 62 to measure the temperature in the heater. Temperature information is sent back to thermostat valve 37 by means of appropriate wiring such as cable 38.

Referring now to FIG. 2, a vertical section of an embodiment of apparatus useful as pressure balance zone 14 is shown. As there illustrated an air chamber 104 is provided in the interior of housing 107. A gas chamber 103 is provided in the interior of housing 109. Housing 107 and housing 109 are held together by suitable means such as bolts 105. Air chamber 104 is separated from gas chamber 103 by diaphragm 101 which is secured in air-tight relationship between gas housing 109 and air housing 107. Diaphragm 101 may be strengthened by means of appropriate stiffeners 102 and 127. Diaphragm 101 forms an air and gas-tight seal between the two chambers. Air from an air source enters air chamber 104 through inlet 113 in housing 107. Gas from a gas source enters gas chamber 103 through inlet 111 in housing 109.

When air pressure in air chamber 104 is equal to gas pressure in gas chamber 103, diaphragm 101 is in a neutral position as shown in FIG. 2. When diaphragm 101 is in this position, air will flow out of air chamber 104 through outlet 112 and gas will flow out of gas chamber 103 through outlet 110. An air passageway 132 is provided in the interior of housing 107 for air flow. Air must pass through the valve means formed by receptacle 117 and by post 118 which is carried on frame 121. Frame 121 is mechanically connected by coupling 135 to diaphragm 101. Therefore frame 121 moves responsive to change in the position of diaphragm 101 to change the valve opening between receptacle 117 and post 118. In a similar manner gas also flows out of gas chamber 103 through outlet 110 when diaphragm 101 is in the position shown in FIG. 2. A gas flow passage 131 is provided in the interior of the housing 109. Gas flow proceeds through a valve means provided by receptacle 115 and post 114. Post 114 is carried on frame 120 which is mechanically connected to diaphragm 101 by coupling 134. Therefore the setting of the valve means provided by receptacle 115 and post 114 is changed responsive to changes in pressure in either the gas or air chambers.

As long as the pressure in air chamber 104 remains equal to the pressure in gas chamber 103, air and gas will pass through the pressure balance zone as has been described heretofore. However, if for example, the air pressure for some reason momentarily exceeds the gas pressure, an uneven force will be exerted on diaphragm 101, causing movement of the diaphragm away from air chamber 104. Since frame 121, which carries post 118 of the needle valve arrangement, is mechanically coupled to diaphragm 101, a movement of the post 118 toward receptacle 117 will result. Air flow into chamber 104 will be partially or totally restricted, depending on the amount of pressure difference. At the same time an air flow is being restricted as described above, gas flow is increased through inlet 111 by means of frame 120 responding to the diphragm motion to carry post 114 away from receptacle 115, to thereby provide a greater area for gas flow in the valve means provided by post 114 and receptacle 115. As the pressure in air chamber 104 and gas chamber 103 become substantially equal, diaphragm 101 moves back toward the neutral position illustrated by FIG. 2 to retain the downstream pressures substantially equal. It may be desirable in some applications to provide a spring such as spring 119 to aid in returning diaphragm 101 to a neutral position. This is especially desirable when the weight of diaphragm 101 and the mechanical couplings thereof are large since spring 119 substantially neutralizes the weight. Receptacle 115 and receptacle 117 are provided with flow areas respectively in accordance with the particular ratio of gas and air that is to be flowed through the valve. If, for example, nine volumes of air are to be mixed with one volume of gas, the air flow area of receptacle 117 in air housing 107 is desirably larger than the corresponding gas flow area of receptacle 115 in gas housing 109.

The invention having been fully described herein, we claim:

1. A method of supplying a combustible gas-air mixture to a downhole burner positioned in a well bore comprising flowing air and gas in separate conduits through a pressure balance zone to substantially equalize the pressure of said air and said gas in said separate conduits leaving said pressure balance zone, flowing said air through a normally closed thermostat valve prior to flow through said pressure balance zone, said thermostat valve caused to remain open to allow air flow provided a predetermined temperature is maintained in said downhole burner after combustion has been established therein, passing said air and said gas still in separate conduits and substantially at equal pressure through presized restricted openings in said separate conduits, said restricted openings selected to pass a predetermined ratio of gas and air, flowing said air and gas together as a combustible mixture in a common mixing conduit on the earth's surface, and passing said combustible mixture to said downhole burner for combustion therein.

2. The method of controlling the flow of air and gas to a burner located in a borehole comprising flowing a predetermined ratio of air and gas to a common surface

mixing conduit to form a combustible mixture therein, flowing said combustible mixture to said burner located in said borehole, igniting said combustible mixture at said burner to cause combustion therein, continuing the flow of said combustible mixture to said burner to elevate the temperature in said burner to above a predetermined minimum, thereafter stopping the flow of air to said common surface mixing conduit when said temperature in said burner falls below said predetermined minimum, and substantially stopping the flow of said gas to said common surface conduit in response to the stopping of said air flow.

3. A method of closely controlling the flow of a combustible gas-air mixture from the surface of the earth to at least one borehole heater comprising elevating the pressure of a combustible gas above a predetermined minimum pressure, elevating the pressure of said air to above said minimum pressure, flowing said gas and said air in separate conduits through a pressure balance zone to substantially equalize the pressure of said air and said gas leaving said pressure balance zone in said separate conduits, passing a combustible ratio of gas and air in said separate conduits leaving said pressure balance zone, flowing said air and said gas together as a combustible mixture in a single conduit, and passing said mixture through a back pressure regulator to maintain constant pressure in the conduits downstream from said pressure balance zone independent of pressure fluctuations occurring downstream of said back pressure regulator prior to flowing said mixture to at least one borehole heater for combustion therein.

4. Apparatus for improving fluid flow from an oil-bearing formation penetrated by a borehole comprising a downhole burner positioned in said borehole adjacent said formation, a combustible-mixture conduit in said borehole extending from said burner to the earth's surface, means defining a source of gas at an elevated pressure, a gas conduit in operable relationship between said source of gas and said combustible-mixture conduit, means defining a source of air at elevated pressure, an air conduit in operable relationship between said air source and said combustible-mixture conduit, pressure balance means on said air and said gas conduits, said means adapted to produce substantially equal pressure in said air and said gas conduits, orifice means in said gas conduit and in said air conduit downstream of said pressure balance means, said orifice means having preselected areas to provide passage of a combustible mixture of air and gas to said combustible-mixture conduit, and back pressure regulator means in said combustible mixture conduit, whereby equal pressure is maintained in said gas conduit and said air conduit downstream of said orifices during pressure fluctuations in said downhole burner.

5. Apparatus for controlling the flow of a combustible gas and air mixture to a downhole burner comprising an air supply conduit and a gas supply conduit in operable relationship with a combustible mixture supply conduit, pressure balance means in said air supply conduit and said gas supply conduit to substantially equalize the pressure in said air supply conduit and the pressure in said gas supply conduit, presized orifices in said air supply conduit and said gas supply conduit downstream of said pressure balance means, said orifices sized to pass a predetermined ratio of air and gas to said combustible mixture supply conduit, valve means in said air supply conduit, said valve means adapted to stop air flow in said conduit responsive to a preselected minimum temperature indicating loss of combustion in said downhole burner, and means substantially stopping flow in said gas conduit responsive to loss of air flow in said air supply conduit.

6. Apparatus for controlling the flow of a combustible gas and air mixture to a downhole burner comprising means defining a source of air, an air supply conduit receiving air from said source of air, means defining a source of gas, a gas supply conduit receiving gas from said source of gas, a combustible mixture conduit operably connected to both said air supply conduit and said gas supply conduit, pressure balance means in said air supply conduit and said gas supply conduit to substantially equalize the pressure in said air supply conduit and said gas supply conduit, valve means in said air supply conduit between said source of air and said pressure balance means, said valve means adapted to stop air flow in said air supply conduit responsive to a preselected minimum temperature in said downhole burner whereby said pressure balance means substantially stops flow in said gas conduit responsive to loss of air flow in said air supply conduit.

7. Apparatus as in claim 6 further characterized by back pressure regulator means in said combustible mixture conduit.

8. Apparatus for controlling the flow of a combustible mixture to a downhole burner position in a well comprising a combustible mixture conduit extendible from the earth's surface to a downhole burner positioned in a well, means defining a source of air, an air conduit connected between said source of air and said combustible mixture conduit, means defining a source of gas, a gas conduit connected between said source of gas and said combustible mixture conduit, pressure balance means producing substantially equal pressure in said air conduit and said gas conduit, orifice means in said air conduit and in said gas conduit, said orifice means having presized areas to provide passage of a combustible mixture of gas and air to said combustible mixture conduit and back pressure regulator means in said combustible mixture conduit, said back pressure regulator means preventing pressure fluctuations in the well from disrupting the pressure balance in said gas conduit and said air conduit whereby a closely controlled combustible mixture is supplied to the downhole burner.

9. Apparatus as in claim 8 further characterized by a mixing conduit in said combustible mixture conduit upstream of said back pressure regulator means, said mixing conduit having sufficient storage capacity for combustible mixture to prevent pressure surging in the combustible mixture conduit when said pressure balance means act to produce equal pressure in the air conduit and the gas conduit.

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