

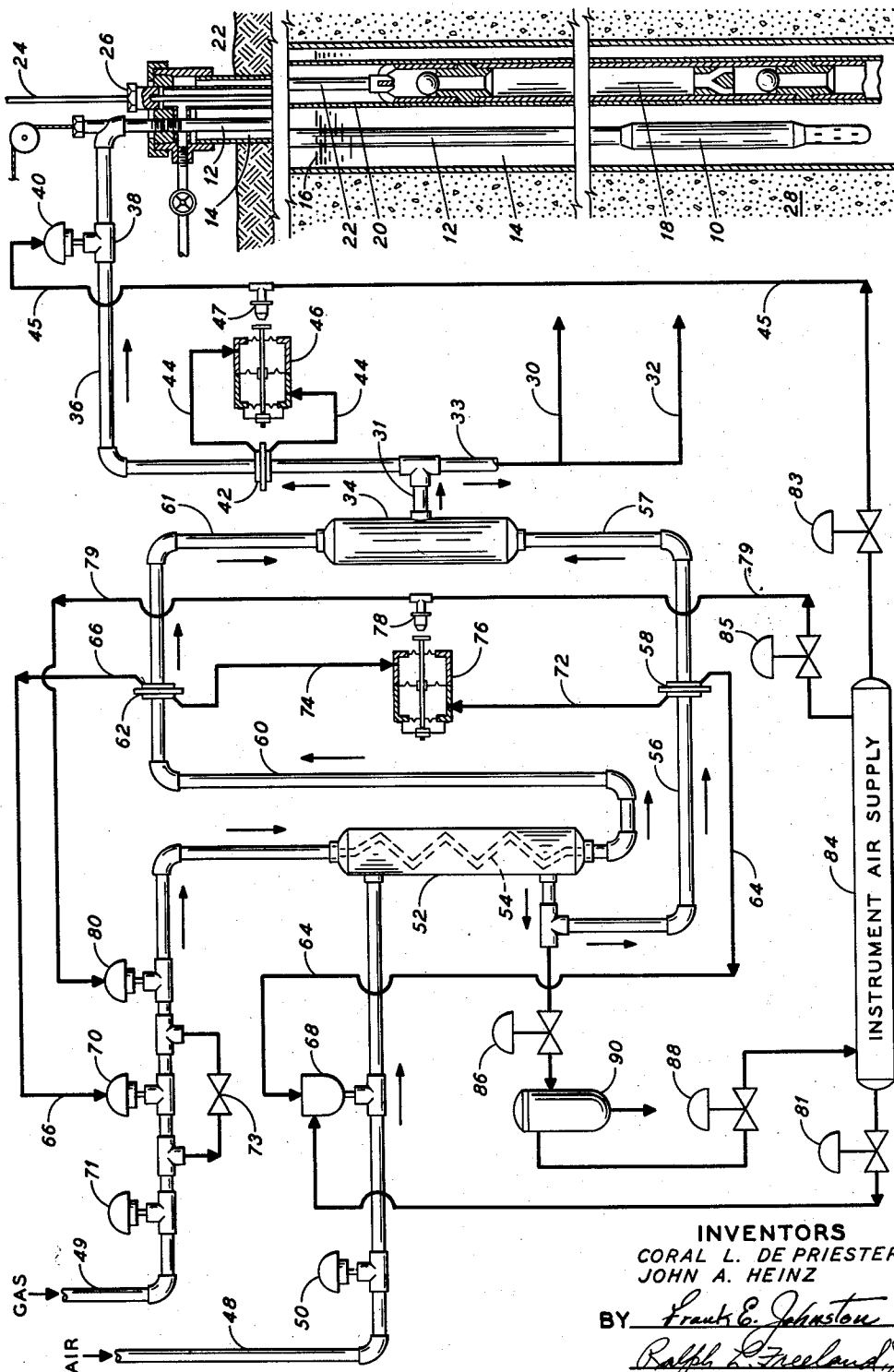
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FUEL CONTROL SYSTEM FOR BOREHOLE HEATERS

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FUEL CONTROL SYSTEM FOR BOREHOLE HEATERS

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The present invention relates to a method of controlling the mixing of gas and air supplied to borehole heaters, such as those used to stimulate oil recovery from an underground reservoir. More particularly, the invention relates to a control system for supplying a combustible gas-air mixture from a mixing chamber at the earth's surface to a plurality of wells under non-explosive conditions so that preset operating conditions can be maintained in each individual well, independently of conditions in the remaining plurality of wells supplied by said system.

In borehole heaters used to heat oil in an underground reservoir, it has been common to supply compressed air alone to the heater so that a part of the oil in the well bore is burned. Such heaters create undesired combustion products in the producible oil and tend to produce coke deposits in the burner. For this reason, it has been found desirable to burn fuel gas, such as that stripped from oil production and known as field gas. This gas is normally supplied by another pipe connected to the downhole burner. When a pump is required in the borehole to aid production, the fuel gas tube is the third pipe or tubing to run into the well bore. While it has been proposed heretofore to use a combined mixture of gas and air in the burner, the gas and air must be mixed at the earth's surface if a single pipe is to be used to supply the downhole burner. Since gas must be mixed with a large amount of air to be efficiently combustible, the mixture becomes explosive. For this reason, the danger of mixing gas and air has been considered too great to use it as a fuel supply for a borehole heater unless expensive construction surrounds the mixing vessel. In accordance with the present invention, the foregoing difficulty has been overcome by using a mixing system for the gas and air in which the dimensions of the gas-air mixing chamber are restricted and the dimensions of the rest of the supply system is selected to limit the maximum velocity of flame travel therein to a value less than that required for detonation, or explosion, of the mixture. As more fully set forth hereinafter, the diameters of the supply and mixing lines do not greatly exceed about three inches in diameter so that at any point therein, the volumetric capacity of the supply system is limited from the air and gas supply through the mixing system and the interconnected burners in a plurality of wells, supplied by the system. However, due to these dimensional limitations on the gas-air supply system, it is difficult to maintain individual well pressures at stable values such that the pressure in each well is exceeded by that of the combustion gases emitted by the burner without applying pressure that is excessive enough to prevent fluid from reaching an oil production string in the hole. Accordingly, it is important that the flow to each heater be as constant as possible to maintain this balance in fluid pressures. Additionally, even when a plurality of wells are close together, the well pressures may vary widely in individual wells and stable combustion in burners in the remaining wells, normally supplied by such a system is difficult to control.

While it has been proposed heretofore to regulate closely and individually the gas and air supplied separately to an underground burner, it has been found that even

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individual well control is quite difficult to achieve where the capacity of the supply system must be limited to make it safe. For this reason it has been found desirable to mix the gas and air at the earth's surface in a vessel not over about two to three inches in diameter. Since such a mixture is highly combustible, it must be carefully regulated both before and after mixing. To do this it is particularly necessary that close control be maintained of the gas-air ratio before mixing. However, since the air must be supplied at a rate between about $8\frac{1}{2}$ and 10 parts to one part of gas, it has been found desirable to automatically regulate the gas supply to a known flow ratio relative to a given air flow rate. The gas and air are desirably brought to similar temperatures before the gas-air ratio is measured. For this reason, a heat exchanger is interposed between the air and gas supply lines ahead of the gas-air ratio measuring means. Each of said lines has its own flow control means, but said ratio measuring means automatically controls the gas flow control means ahead of said heat exchanger to maintain a preselected ratio. In accordance with the invention, the gas-air ratio measuring means is connected to the system immediately ahead of a mixing tank, or pipe section, from which the fuel gas-air mixture is individually controlled by demand of each borehole heater.

In accordance with a preferred form of the invention, a gas-air burner positioned in the bottom of a well bore is supplied by a line having a diameter such that the maximum rate of flame propagation possible from the well back through said line to the gas-air mixing chamber will not exceed the detonation velocity for said mixture. Said supply line is connected to said mixing chamber through an individual well control flow meter also located at the earth's surface. The mixing chamber has a diameter greater than said supply line, but its volumetric capacity is likewise selected so that the maximum rate of flame propagation therethrough will not exceed the explosive velocity for the mixture of gas and air mixed therein. In practice the diameter of the mixing tank would not be larger than four times the diameter of the larger of the incoming air and gas supply lines.

Further, in accordance with the preferred form of the present invention, the flow of said combustible gas-air mixture to a plurality of borehole heaters is controlled by the demand of said heaters. To meet such variable demand of the system, the flow of compressed air from a supply line is set at a known value and automatically regulated to maintain said value. The compressed air is then passed in heat exchange relationship to the fuel gas to be mixed therewith. The difference in flow rates between the air supply and the fuel gas is measured to regulate the flow of fuel gas in accordance with the predetermined difference in said flow rates. Said control is exerted on said fuel gas flow prior to passing said gas in heat exchange relationship to the air supply. Then, said fuel gas and air are mixed to supply said plurality of borehole heaters, each of which are individually controlled to a preset table value established by the desired output therefrom.

Further objects and advantages of the present invention will become apparent from the following description and taken in conjunction with the accompanying drawing which forms an integral part of the present application.

FIG. 1 illustrates the gas-air supply system for a borehole heater wherein the features of the invention are exemplified by control of flow of a gas-air mixture to one well of a multi-well system.

Control of the flow of a combustible gas-air mixture to borehole heater 10 in accordance with the invention includes supplying a gas-air mixture of known and closely controlled proportions by line 12 that supports heater 10 on its lower end in well 14. The diameter of line 12 is

preferably about one to two inches so that with a mixture of field gas (generally a mixture of ethane and methane) and air at a ratio of about $8\frac{1}{2}$ to 10 parts of air to one part of gas, the maximum velocity of flame propagation therein is less than the explosive velocity of the gas-air mixture. However, due to said restriction in size of line 12, the balance of pressures in the well bore is made more difficult. To maintain continuous fluid production and obtain the economic advantage of borehole heating, fluid level 16 in well 14 must be held above both borehole heater 10 and a production pump unit 18. A fluid level below pump 18 can cause inefficient operation including gas blocking of the pump. As shown, pump 18 is supported at the lower end of production tubing 20 and may include a sucker rod string 22 actuated by a conventional pump unit (not shown). Sucker rod string 22 is raised and lowered by polish rod 24 acting through stuffing box 26 at the well head.

In accordance with the invention, the gas-air mixture flowing in line 12 is controlled to maintain this required dynamic fluid balance between the gas-air pressure in burner 10 and the fluid pressure exerted by the well head pressure, represented by fluid column rising to level 16. Obviously, if gas-air burner pressure does exceed that of formation 28 fluid will not enter well bore 14. On the other hand, if the pressure is insufficient, combustion cannot be maintained in heater 10 and ignition will be required at frequent intervals, particularly when flow conditions are varied by changes in the pressure of reservoir formation 28 by conditions in other operating wells, such as those fed by lines 30 and 32 from gas-air mixing tank 34. As one crucial step in the process of maintaining this pressure constant, there is provided in the feed line 36 connected to gas-air flow line 12, the differential pressure control unit that includes a control valve 38 and a pressure control unit 40 operable in response to the flow through orifice 42. As illustrated, the flow across orifice 42 is measured by a pair of pressure taps 44 which control the operation of flow control unit 40 through a pressure differential sensing device 46 that modulates air pressure in line 45 by flow from nozzle 47.

As indicated hereinabove, the variable pressure conditions in each of the wells supplied by lines 30, 32 and 36 can individually upset the pressure balance conditions of the gas-air mixture flowing to the other heaters and the production of fluids from the other wells.

It would appear that such upset conditions could be easily withstood by merely providing a sufficient reservoir capacity of gas and air in a mixing vessel, illustrated herein as pipe section 34. However, as further discussed above, this expedient cannot be used due to the danger of explosion when such a vessel is located at the earth's surface unless the vessel or its enclosure is especially constructed to withstand explosion. In accordance with the present invention, it has been found that by limiting the volume of mixing tank 34 explosion hazard can be reduced so that accidental ignition or flash-back of the flame from burner 12 will not cause explosions. In practice, tank 34 is limited to an inner diameter of about three inches, but may be increased in diameter up to not over about four inches for a gas-air mixture as specified above. Thus, the size of mixing tank 34 can be restricted in both its space requirements and fewer safety precautions must be taken in operating it. With such reduced size and capacity, an adequate control system must be maintained to sense and correct any upset in the system caused by changes of flow and pressure in individual wells supplied from said mixing tank.

To prevent such upset by individual well operating changes, supplied by the gas-air mixing system, it has been found advantageous to regulate the flow of compressed air from supply line 48 by a pressure regulating valve 50 that attenuates disturbances in the system that result from the compressor starting and stopping. Compressed air then passes through a heat exchanger 52 wherein fuel-gas

may flow concurrently as in line 54. The purpose of such heat exchange is to bring the gas and air to substantially a uniform temperature before measuring the difference in flow rates in the gas supply line and the compressed air supply lines connected to mixing vessel 34. For this purpose, the flow of compressed air in line 56 from the heat exchanger is detected at orifice unit 58 located near where that line enters chamber 34. At the same time, fuel gas is led by line 60 through another orifice unit 62. Lines 57 and 61, that respectively feed air and gas to mixing chamber 34, are relatively short to reduce pressure drop from the measuring point to the mixing zone, but are also limited in diameter to over about one inch. To maintain pressures in both lines relatively constant up to vessel 34, the pressure in each of the air and gas lines is measured by pressure taps 64 and 66 at orifice units 58 and 62, respectively. Pressures at taps 64 and 66 then control the inlet pressures to heat exchanger 52 by their corresponding valves 68 and 70, respectively in compressed air line 48 and fuel gas line 49. The size of distribution lines 31 and 33 for the individual heaters is also limited to about one inch diameter and preferably does not exceed about two inches.

With the pressures maintained substantially constant by controlling the openings of valves 68 and 70, the fuel-air ratio is controlled automatically to substantially a constant value, independent of inlet pressure variations and the out flow conditions from mixing zone 34. The difference in pressures at the upstream sides of orifice units 58 and 62 is measured through taps 72 and 74, respectively, in compressed air and fuel lines. A differential pressure measuring unit 76 is adjusted to maintain this fuel-air ratio at a difference of from about $8\frac{1}{2}$ to 10 parts of air to each part of gas. Variations in pressures in line 79 are created by flow from nozzle 78 and such variations adjust the opening of control valve 80 to maintain the preselected gas-air ratio. In the present embodiment, it will be seen that the fuel-gas air mixing system is conveniently operated by a pneumatic control system wherein the instrument air supply indicated as reservoir 84, is supplied through a pair of pressure-reducing valves 86 and 88, tapped into the regulated compressed air supply line 56. Desirably, a filter element 90 is interposed in the pressure-reducing line to the instrument air supply to remove dust and condensate from the air line.

From the foregoing description, it will be noted that a gas-air mixing and flow system of limited capacity or dimensions can be operated to maintain constant not only the pressures, but also the flow rates and the gas-air ratios to each burner of a multiple burner installation. And with such a mixing and flow system of limited dimensions, constructed and operated in accordance with the present invention, explosion of the surface equipment can be prevented. Said control system will respond with speed sufficient to compensate for rapid variations in any of the producing wells heated by said system without affecting the safety of mixing gas and air of the earth's surface and without upsetting the pressure conditions in adjacent wells in the entire control system.

Variations and modifications may be made in the details of the system without departing from the invention, and all such modifications and changes coming within the scope of the appended claims are intended to be included therein.

What is claimed is:

1. Apparatus for controlling the flow of a combustible mixture of gas and air to a plurality of bore-hole combustion heaters which comprises a mixing chamber positioned at the earth's surface having a diameter selected so that the maximum velocity of flame travel in said air-gas mixture is limited to a value less than that required for detonation of said mixture, a source of compressed air, means for supplying compressed air from said source to said mixing chamber, means for regulating flow of

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compressed air based on said heaters' requirements from said supply means to said chamber, a source of gas under pressure, means for supplying gas from said source to said mixing chamber, heat exchange means for equalizing the temperatures of said gas and air flowing from said respective supply means to said mixing chamber, means for measuring the air-gas ratio after passing through said heat exchange means, means for regulating said gas flow from said gas supply means before entering said heat exchange means in response to a change in the measured ratio of gas to air flowing to said mixing chamber, means for supplying said gas and air mixture from said chamber to a plurality of borehole heaters, and means for individually controlling flow of said mixture from said mixing chamber to each of said plurality of borehole heaters at rates independently predeterminable for each of said borehole heaters.

2. Apparatus for maintaining substantially constant the flow of a combustible mixture of gas and air to each of a plurality of borehole combustion heaters which comprises an elongated pipe section having a diameter not greater than about four times that of the larger of a pair of inlet supply lines interconnected thereto, said elongated pipe section forming a mixing chamber for fluids supplied through said inlet lines, a source of compressed air connected to said mixing chamber through one of said lines and a source of gas under pressure connected to the other of said inlet lines, means for establishing a predetermined flow of compressed air from said source to said mixing chamber through said one line, means for measuring the ratio of gas to air flowing in said inlet lines before entering said mixing chamber, means responsive to variations in said flow ratio for controlling the flow of gas in said other inlet line to maintain said flow ratio to said mixing chamber substantially constant, means for supplying said gas-air mixture from said mixing chamber to a plurality of borehole combustion heaters, including a line having a diameter substantially equal to the diameter of said gas and air inlet lines, and means for individually controlling the flow of said mixture from said mixing chamber to each of a plurality of borehole heaters, said individual control means being responsive to a change in pressure in said well bore to maintain the output of each of said borehole heaters substantially constant independently of the pressures in other borehole heaters supplied from said mixing chamber.

3. Apparatus for maintaining the supply of a combustible fuel gas and air mixture substantially constant to each of a plurality of well bore heaters independent of the combined demand of the remainder of said heaters which comprises a source of compressed air, a source of compressed fuel gas, an elongated mixing chamber located on the surface of the earth with a diameter selected so that the rate of flame propagation of the said fuel gas and air mixture through the said mixing chamber is less than the explosive velocity of said fuel gas and air mixture, means for independently connecting said sources of fuel gas and air with the said mixing chamber, means for equalizing the temperature of the said fuel gas and air prior to arrival at the said mixing chamber, means for measuring the flow of said air after said temperature equalization to said mixing chamber, means for adjusting the flow of said fuel gas to said mixing chamber according to a predetermined mixture ratio with said measured air, means for connecting said mixing chamber with said well bore heaters, and means in each of said heaters for cumulatively regulating the flow of said air to said mixing

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chamber and for regulating the flow of said fuel gas and air mixture from said mixing chamber to said individual heaters based on a predeterminable pressure setting in each of said heaters' regulating means.

4. Apparatus for maintaining the supply of a combustible fuel gas and air mixture substantially constant to each of a plurality of well bore heaters independent of the combined demand of the remainder of said heaters which comprises individual pressure control means for each heater for regulating flow of a gas-air mixture from a mixing tank to said heater, a mixing tank for flowing fuel gas and air together to form a combustible mixture at the earth's surface, means connecting said mixing tank and said heater, a pair of inlet lines connected to said mixing tank, flow measuring means positioned in each of said lines adjacent said mixing tank, means sensing differences in the flow at said measuring means, means modifying the flow conditions in one of said lines in accordance with sensed changes in said flow, a heat exchanger and means for flowing compressed gas and compressed air through said heat exchanger prior to flow through said flow measuring means but before flow through said flow modifying means to permit maintenance of said flow and pressure conditions of said combustible mixture to said plurality of well bore heaters.

5. The method of controlling the flow of a combustible gas-air mixture from the earth's surface to at least one borehole heater comprising regulating the flow of air from an air supply line to a known value based on said heater's requirements, flowing said air in heat exchange relationship to a fuel gas supply line, measuring the differences in flow after said heat exchange relationship in said air supply line and said fuel gas supply line, adjusting the flow of fuel gas in said fuel gas supply line to achieve a predetermined ratio between the flow in said air supply line and in said fuel gas supply line, mixing said fuel gas and said air in said predetermined ratio at the earth's surface as a combustible mixture in an elongated narrow chamber having a diameter no more than four times the diameter of the larger of said air supply line or said gas supply line and then controlling the flow of said mixture to at least one borehole heater at a pressure sufficient to exceed the borehole fluid pressure at said heater.

6. The method of controlling the flow of a combustible gas-air mixture from the earth's surface to at least one borehole heater which comprises regulating the flow of air to a known value based on said heater's requirements, passing said air in heat exchange relationship with a supply of field gas, measuring the difference in flow after said heat exchange relationship of said air and said gas, controlling the flow of said gas to achieve a predetermined combustible ratio between said air and said gas, mixing said air and said gas at the earth's surface as a combustible mixture in a chamber having a diameter selected so that the rate of flame propagation in said combustible mixture is less than the explosive velocity of said mixture, and then flowing said mixture to at least one borehole heater at a preset pressure.

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