May 19, 1959 C. L. DE PRIESTER ET AL 2,887,160

APPARATUS FOR WELL STIMULATION BY GAS-AIR BURNERS

Filed Aug. 1, 1955 2 Sheets-Sheet 1

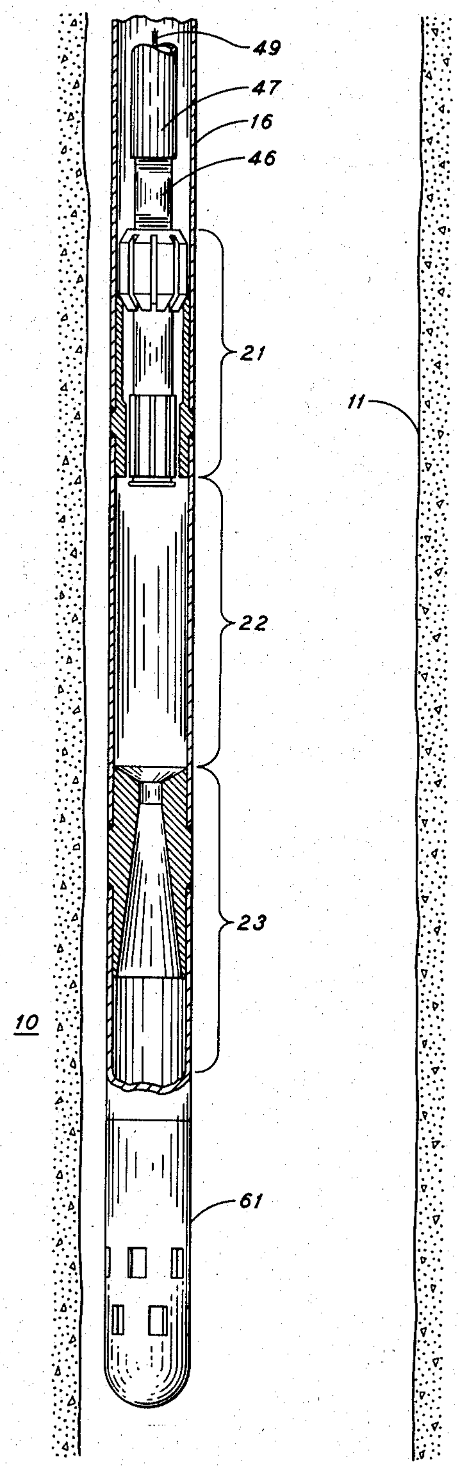

FIG. 1B

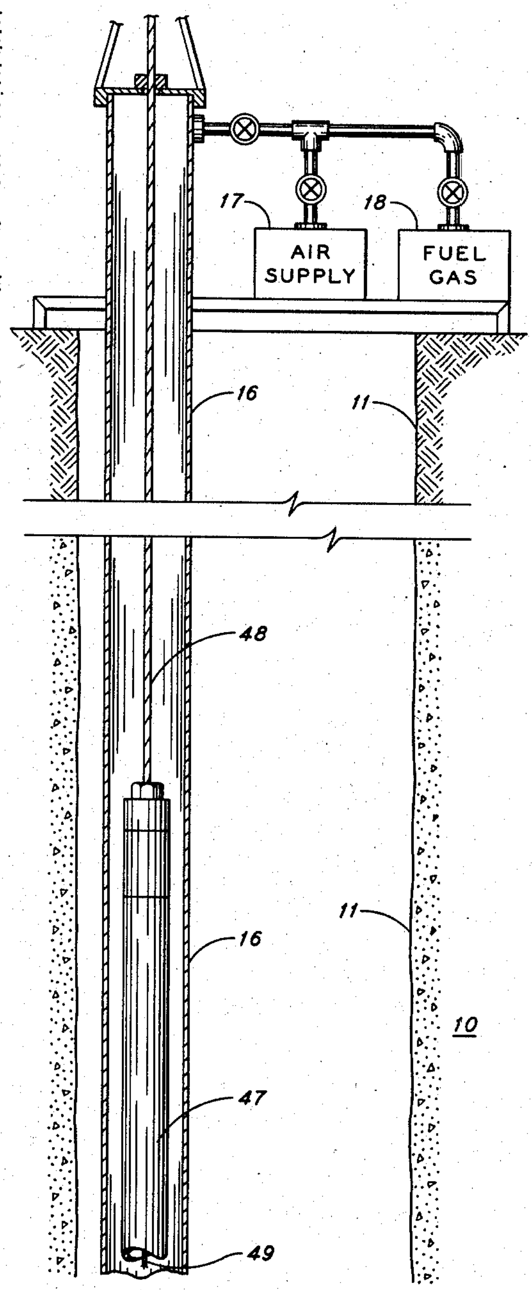

FIG. 1A

INVENTORS
CORAL L. DE PRIESTER
CLARKE N. SIMM

BY O. S. Lord
Walter L. Madden, Jr.
ATTORNEYS

May 19, 1959 C. L. DE PRIESTER ET AL 2,887,160

APPARATUS FOR WELL STIMULATION BY GAS-AIR BURNERS

Filed Aug. 1, 1955 2 Sheets-Sheet 2

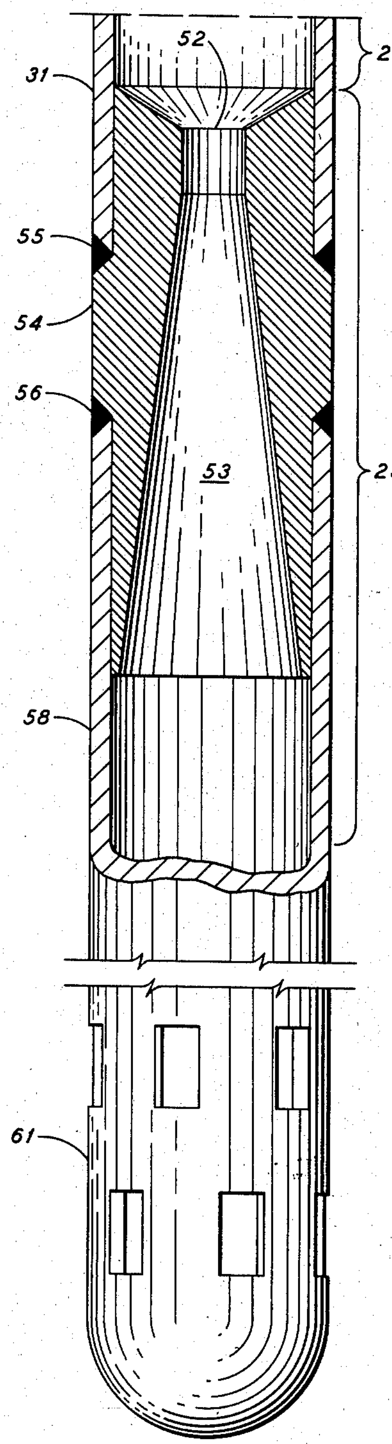

FIG. 2B

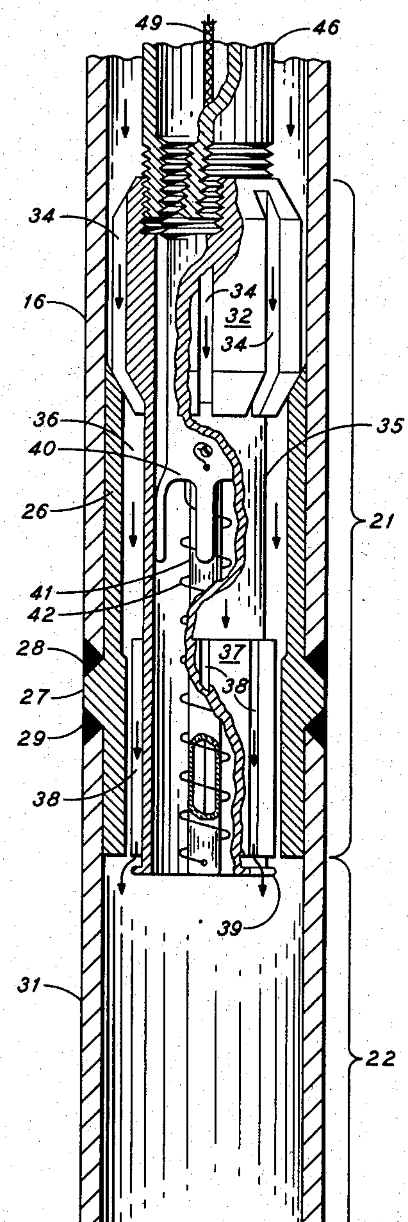

FIG. 2A

INVENTORS
CORAL L. DE PRIESTER
CLARKE N. SIMM

BY O. J. Lord
Walter L. Madden Jr.
ATTORNEYS

United States Patent Office

2,887,160

Patented May 19, 1959

2,887,160

APPARATUS FOR WELL STIMULATION BY GAS-AIR BURNERS

Coral L. De Priester and Clarke N. Simm, Fullerton, Calif., assignors to California Research Corporation, San Francisco, Calif., a corporation of Delaware

Application August 1, 1955, Serial No. 525,505

11 Claims. (Cl. 166—59)

This invention relates in general to methods of and apparatus for stimulating the flow of oil from subterranean formations and relates more particularly to methods of and apparatus for burning a gaseous combustible mixture adjacent a subterranean oil-bearing formation to heat such formation and the surrounding oil.

It is well known that the productivity of most oil wells decreases with time. Such decreases may be caused, for example, by a natural depletion of the reservoir or by plugging or clogging of the formation adjacent the well bore by waxes, paraffins or other material.

One proposed solution to remedy this production decline is to dispose adjacent the formation to be heated a burner device in which a gaseous combustible mixture is burned and the resulting heated combustion products utilized to heat the oil in which the burner is submerged and/or the surrounding formation. The use of such burners appears to offer the most efficient method of well stimulation, owing to the fact that the burner device itself may be located adjacent the formation to be treated and may thus operate without any substantial thermal losses between the surface of the earth and the burner location.

Most of such burners utilize a mixture of a fuel gas and air and are so designed that these two elements of the combustion mixture are fed separately to the burner from the surface of the earth, the usual method of introduction being to use lengths of concentric tubing to maintain the gases separated until combined in the combustion chamber. These prior art devices required the separation of the two components of the combustible mixture to prevent flashback of the combustion flame from the combustion chamber up to the surface of the earth. Some of the prior art devices have employed a single conduit for carrying both elements of the combustible mixture from the earth's surface to the combustion chamber, but so far as we are aware, all such devices have been subject to danger from flashback of the combustion flame from the combustion chamber up the single conduit carrying the combustible mixture. Such flashback is obviously undesirable, both from the standpoint of the stability of the burner installation and the attendant hazard and risk involved in such flashback.

Most of such burners are a unitary structure consisting basically of a combustion chamber and ignition device and admission or inlet passages from the conduit to the combustion chamber. However, the use of such unitary structures has the disadvantage that these burners are subject to plugging, particularly in the admission or inlet passages, by scale or other particles which are present in the tubing or other components of the system, and to remedy such plugging, the entire burner assembly must be removed from the well bore to obtain access to the plugged component, thus materially increasing the cost of the operation and resulting in a considerable amount of unproductive time for the installation. Similarly, failure of the ignition device necessitates removal of the entire burner assembly from the well bore.

We have found that a burner may be designed which incorporates the advantages of a single conduit for carrying both or all of the elements of a combustible mixture from the surface to the burner location while still providing adequate protection against flashback of the burner flame. Our burner design also eliminates the plugging problems discussed above, by utilizing a two-component construction comprising an outer shell containing the combustion chamber itself and a separable inner unit comprising the delivery nozzle and ignition device. The inner unit is inserted in the shell after the shell is in place and may be subsequently withdrawn independently of the shell to remedy any plugging problems which may arise.

Broadly, the present invention contemplates a burner design comprising a single conduit through which both or all of the elements of the combustible mixture are fed from the surface of the earth to the burner. The burner proper consists of two separable components: an outer shell which contains a combustion chamber and a tail pipe member, and which is attached to the mixture-carrying conduit; and an inner unit comprising an ignition device and a nozzle and orifice assembly. The nozzle assembly comprises at least one set of slots extending in the direction of the gas flow and disposed radially about the central axis of the tubing. The nozzle assembly further comprises a redistribution annulus below the upper slots for insuring uniform radial distribution of the mixture issuing from the upper slots. Preferably, a second set of slots and a deflector ring are provided below the redistribution annulus for deflecting the gas-air mixture issuing from the delivery slots towards the walls of the combustion chamber. The upper slots are designed to prevent any large particels of scale or other foreign material from reaching the delivery slots and they also act as a secondary flashback prevention in addition to the delivery slots, as will be discussed more fully hereinbelow. The redistribution annulus provides even radial distribution of the gas-air mixture, and is particularly important in the case of plugging of one or more of the upper slots, where uneven distribution of the gas-air mixture would otherwise result.

The delivery slots provide passage for the gas-air mixture into the combustion chamber, and the dimensions and number of these slots are so chosen to substantially prevent any flashback of the combustion flame through the combustible mixture in the burner tubing and to deliver combustible mixture to the combustion chamber in a manner providing satisfactory flame stability and ease of ignition over a wide range of heat energy outputs. Flashback is substantially prevented by limiting the minor dimension of the rectangular slots to a value less than the "quenching distance," which distance is the maximum distance of separation between parallel surfaces that prevents propagation of a flame front. If parallel plane surfaces are separated by a distance less than the "quenching distance," a flame will not propagate therethrough because the energy released by combustion is absorbed into the confining walls at such a rate that the temperature of the flame front is reduced below the value necessary for propagation. The maximum quenching distance varies inversely with the pressure. By way of example, we have found that with a slot depth of 0.040 inch, flashback is prevented up to pressures of 20 to 30 pounds per square inch absolute. Variations in the other cross-sectional dimension of the slot appear to have little effect on the quenching distance above a certain minimum value. In circular conduits, the quenching diameter is approximately 1.5 times the quenching distance for a given operating pressure, so that there is little effect of variations in the second cross-sectional dimension if it is greater than 1½ or 2 times the least dimension. Similarly, variations in the slot length have little effect on the quenching distance so long as the length is at least 2 to 4 times the quenching distance. Flashback is also prevented by setting the number and width of delivery slots such that the velocity of the mixture is greater than the velocity of flame propagation at the desired operating conditions. This latter expedient may be resorted to when it is not practical to set the minor slot dimension below the quenching distance because of the necessity for maintaining a certain minimum slot dimension to prevent plugging of the slots by scale and other foreign matter from the burner tubing and supply system.

The deflector ring is located below the delivery slots and acts to deflect the gas-air mixture issuing from the delivery slots toward the walls of the combustion chamber to produce an effective turbulence pattern in the gas-air mixture for increased burner stability and capacity. The ignition means for the burner proper extends down through the nozzle assembly and, in one form, the ignition means comprises an electric heating coil disposed inside the nozzle for igniting the combustible mixture flowing into the combustion chamber from the delivery slots. In another method of ignition of the burner of the present invention, suitable chemicals capable of producing an exothermic reaction, such as sodium, phosphorus, red nitric-aniline, pyrotechnic materials, etc., may be dropped down an inner tubing from the surface to land in the combustion chamber and therein produce the required temperature level to initiate combustion of the gaseous mixture. Alternatively, the burner may be ignited by a spark plug or by the flashback method disclosed in the patent application of Clarke N. Simm, Serial No. 414,217.

It is therefore an object of the present invention to provide improved methods of and apparatus for heating a subterranean petroliferous formation to increase the productivity thereof.

It is a further object of the present invention to provide methods of and apparatus for burning a gaseous combustible mixture at a location below the surface of the earth in which the elements of the combustible mixture are fed from the surface to a combustion chamber at the location through a single conduit and a plurality of restricting slots are provided between the conduit and the combustion chamber to prevent flashback of the combustion flame from the combustion chamber to the conduit.

It is a further object of the present invention to provide apparatus for heating a subterranean formation in which the elements of a gaseous combustible mixture are fed from the surface of the earth through a single conduit and a series of delivery slots in said conduit to a combustion chamber, the dimensions of the slots being such as to prevent flashback of the combustion flame from the combustion chamber to the conduit.

It is a further object of the present invention to provide apparatus for heating a subterranean formation in which the elements of a gaseous combustible mixture are fed from the surface of the earth through a single conduit and a series of delivery slots in said conduit to a combustion chamber, the dimensions of the slots providing distribution of the combustible mixture such that the burner has satisfactory flame stability and ignitability.

It is an additional object of this invention to provide a burner assembly for burning a gaseous combustible mixture to heat a subterranean formation in which the burner comprises two separable components, an outer chamber, and an inner unit comprising a nozzle assembly through which the gaseous mixture passes for additional mixing and which may have as an integral part thereof an ignition device for igniting the combustible mixture.

It is a further object of the present invention to provide a burner assembly for burning a gaseous combustible mixture to heat a subterranean formation in which the assembly comprises two components which may be separated when the burner is in position to aid in remedying plugging of the burner or to replace components thereof.

Objects and advantages other than those set forth above will be apparent from the following description when read in connection with the accompanying drawings, in which:

Fig. 1A illustrates the disposition of the upper portion of the apparatus of the present invention in a representative well bore;

Fig. 1B is a continuation of Fig. 1A and represents the disposition of the remainder of the apparatus of the present invention in the representative well bore;

Fig. 2A is an enlarged view of the upper end of the burner proper shown in Fig. 1B; and

Fig. 2B is a continuation of Fig. 2A illustrating on an enlarged scale the lower end of the burner assembly.

Referring to Figs. 1A and 1B by character of reference, numeral **11** designates the wall of a well bore extending from the surface of the earth to a formation **10** to be treated in accordance with the present invention. The treated formation may be of any type containing petroliferous deposits, and there are no known restrictions on the methods of well completion in connection with the use of the present invention. The apparatus of the present invention includes a length of tubing **16** extending from the surface of the earth to the formation to be treated. The elements of the gaseous combustible mixture are fed through conduit **16** to the burner proper. Assuming that the combustible mixture comprises air and a fuel gas, a compressor **17** may be utilized to supply the air to conduit **16** and a second compressor **18** is utilized to supply the fuel gas to conduit **16**. The fuel gas may be obtained, for example, from a supply of field gas which may be available from other wells in the area. It will be understood that the flow rates of the elements are adjustable by suitable means.

The burner proper may be divided into component portions comprising a nozzle and ignition portion **21**, a combustion chamber portion **22** and a diffusion and exhaust portion **23**. As shown more in detail in Fig. 2A, nozzle and ignition portion **21** includes a generally cylindrical nozzle support member **26** which fits inside the lower end of conduit **16**. Support member **26** is provided with a circumferential raised ring **27** having beveled edges thereon, and the upper edge of this ring is welded to the lower end of conduit **16** by a weld **28**. The lower edge of beveled ring **27** has welded thereto a length of tubing **31** of substantially the same diameter as tubing **16** and forming the walls of the combustion chamber. Nozzle support member **26** is also provided with a landing shoulder at the upper end thereof for engaging the lower end of the upper slot portion **32** of the nozzle assembly. This upper portion is provided with slots **34** about the periphery thereof through which the gaseous combustible mixture passes from conduit **16**. We have found that for upper slots **34**, dimensions of 1/16 inch by 1/8 inch are very satisfactory. However, there appears to be no criticality in either the dimensions or the number of these slots, except at the bevel bearing surface where the nozzle is supported in the landing shoulder; at this point, the total open area of the slots should not be less than the total open area of the lower delivery slots.

The nozzle assembly further comprises a cylindrical portion **35** extending from the lower end of the upper slot portion **32** and forming, together with the wall of the nozzle support member **26**, a redistribution annulus **36**. Redistribution annulus **36** in turn leads to a lower slot portion **37** provided with a plurality of longitudinal delivery slots **38**. The gaseous mixture which passes through delivery slots **38** strikes a deflector ring **39** which deflects the combustible mixture toward the walls of the combustion chamber.

The dimensions of delivery slots **38** are chosen with respect to the quenching distance for the particular fuel gas or gases being used in the operation so as to provide maximum protection from flashback. The minimum dimension of the delivery slots is made large enough to prevent plugging by scale and other foreign matter from the tubing, and we have found in practice that a minimum slot depth of 0.040" is very satisfactory. The quenching distance varies approximately inversely with pressure and varies only slightly with fuel composition for combustible mixtures of air and fuel gas composed primarily of methane, ethane, and propane. The following table lists values of quenching distance as a function of pressure for fuel gases composed primarily of methane, ethane, and propane:

Pressure, atmospheres:	Quenching distance, inches
0.2	0.30
0.4	0.14
0.7	0.092
1.0	0.070
2.0	0.050
3.0	0.040

The quenching distance for hydrogen is 0.025 inch at 1 atmosphere and varies inversely with pressure for pressures less than 1 atmosphere. For operating conditions, such as at high pressure, where the quenching distance is less than 0.040, flashback can be prevented by setting the width and number of the delivery slots such that the velocity of the gaseous combustible mixture in the slots exceeds the burning velocity of the mixture, within the limitation that nozzle slot design must provide satisfactory burner operation.

Burner operating characteristics are markedly affected by the number and dimensions of the delivery slots, and certain practical considerations, not directly affecting burner operation, also affect slot design. For satisfactory flame stability a certain order of restriction is necessary between the supply conduit and the combustion zone. The amount of restriction necessary depends on the size of the flame zone and the desired capacity range of the burner. Practically, slot design can be related to combustion chamber diameter because both variables are functions of desired capacity, as will be discussed hereinafter. The total cross-sectional area of the delivery slots should not be so small that the pressure drop through the slots is excessive. Numerous burners of this type have been built according to the disclosures herein, and have been operated under wide ranges of conditions. It is understood that specifications of actual dimensions of burners disclosed herein merely represent points within ranges of satisfactory operation, and do not restrict the scope of our invention. We have found that delivery slot depth of 0.040 inch gives satisfactory performance in burners with combustion chambers having inside diameters of 1.05 inch and 1.61 inch. The 1.05-inch I.D. burner operates satisfactorily with four delivery slots of .040 inch depth and either of 5/64-inch or 3/32-inch width. The 1.61-inch I.D. burner operates satisfactorily with either eight delivery slots of .040-inch depth and 3/32-inch width, or with 16 slots of .040-inch depth and 3/32-inch width. The choice of the particular slot dimensions utilized depends on operating condition but there is wide overlap of satisfactory capacity for the various designs.

The igniter portion of the burner in the particular embodiment illustrated comprises a ceramic mounting **41** on which is mounted an electric heating coil **42** to ignite the gaseous combustible mixture issuing into the combustion chamber from delivery slots **38**. Ceramic mounting **41** may be secured by a suitable ceramic cement to a cross-over or coupling member **46**. The upper end of coil **42** is surrounded by a metallic shroud **40** which serves to center the igniter mechanism and to conduct heat away from coil **42**. Shroud **40** may be welded to cross-over **46**. The nozzle assembly, comprising the upper portion **32** containing slots **34**, cylinder **35** forming the redistribution annulus, the lower slot portion **37** containing delivery slots **38** and deflector ring **39**, and the ignition mechanism, is a separate unit from the nozzle support member **26** and conduits **16** and **31**, and may be run in and out of the hole independently of these latter elements. The nozzle and igniter assembly is connected through a cross-over or coupling member **46** to a sinker bar member **47** (Figs. 1A and 1B) which is in turn connected to a cable **48** for raising and lowering the nozzle and ignition assembly. An electric cable **49** passes through cable **48**, sinker bar **47** and cross-over **46** to supply current to heating unit **42** of the igniting mechanism.

Combustion chamber **22**, formed by the wall of conduit **31**, is terminated at the lower end thereof with an orifice **52** of reduced diameter. Orifice **52** leads to a diffuser section formed by a conical opening **53** in a diffuser cone piece **54**. Cone piece **54** has a circumferential bevelel ring, the upper end of which is welded to the lower end of conduit **31** by a weld **55**. An additional length of conduit **58** is welded to the lower edge of the raised ring of diffuser cone **54** by a weld **56** to form a tail pipe for the combustion products issuing from diffuser opening **53**. In the particular embodiment illustrated in the drawings, the burner mechanism is terminated at its lower end by a slotted bull nose **61**. Bull nose **61** is closed at the lower end thereof to prevent entry of foreign matter in the burner assembly during lowering thereof into the well bore, and the slots in bull nose **61** provide an outlet for the combustion products to contact the formation and/or fluid to be heated. Owing to the temperature encountered in the operation of the burner, it is recommended that suitable heat and corrosion resistant materials be used for construction of the nozzle, nozzle support, combustion chamber, exhaust orifice, and tail pipe. We have found stainless steels and high nickel content alloys to be very satisfactory.

In operation of the present invention, conduit **16** with nozzle support **26**, conduit **31**, diffuser cone **54**, tail pipe **58** and bull nose **61** attached thereto is first run into the well bore and located at the desired position relative to the formation to be treated. As indicated in Figs. 1A and 1B, the diameter of the burner assembly relative to the diameter of the well bore is such as to permit the use of the burner simultaneously with a conventional pump tubing string to permit simultaneous heating of and productioin from the treated formation. After running conduit **16** and the attached elements to the desired position, the nozzle and igniter assembly is then lowered in conduit **16** by cable **48** until the lower end of upper slot portion **32** engages the landing shoulder on nozzle support **26**.

Air supply **17** and fuel gas supply **18** may then be activated to supply the elements of the combustible mixture into conduit **16**, and these elements are mixed in passing down conduit **16** to the burner assembly. The combustible mixture passes through upper slots **34** which, as mentioned earlier, act to prevent larger particles of foreign matter such as scale from entering delivery slots **38**. The combustible mixture issuing from slots **34** enters the redistribution annulus formed between the walls of cylinder **35** and nozzle support **26** to provide even distribution of the gaseous combustible mixture. This redistribution is particularly important if one or more of upper slots **34** become plugged. The combustible mixture then passes through delivery slots **38** and strikes deflector ring **39** to deflect the mixture toward the walls of combustion chamber **22**.

If the delivery slots or other elements of the burner become plugged prior to or during injection, or during subsequent combustion, such plugging may be remedied by raising cable **48** to lift the nozzle and igniter assembly clear of the burner shell, and the plugging material may be washed out of the shell down through the burner without withdrawing either the nozzle assembly or the burner shell from the well bore.

To ignite the gaseous mixture, heating element **42** is energized through cable **49** to heat electric heater coil

42 to a temperature sufficient to ignite the mixture. The resulting flame of combustion is confined within combustion chamber 22 by exhaust orifice 52, and orifice 52 also functions to increase the stability of the burner operation by attenuating or eliminating shock waves which originate in the fluid surrounding the burner assembly. The size of orifice 52 should preferably be related to the combustion chamber size to produce a reasonable pressure drop across the orifice at the expected throughput. For example, we investigated orifice diameters ranging from 0.25-inch to 0.75-inch for a combustion chamber having an inside diameter of 1.61 inches and a length of 7 inches and found this range quite satisfactory. The lower limitation on the orifice diameter appears to be controlled by the creation of excessive pressure drop across the orifice and the risk of plugging of the orifice by sand or other foreign matter. The upper limit of the orifice diameter is controlled primarily by the requirement for burner stability. In this connection, in experiments with combustion chambers of 1.61-inch diameter 7-inch length, we found that when no orifice was provided in the combustion chamber, the combustion flame was blown out of the end of the combustion chamber at input rates in excess of 145,000 B.t.u./hr.; whereas when an orifice of 0.5 inch was provided in the combustion chamber, the flame was stable at inputs exceeding 350,000 B.t.u./hr. The tailpipe 58 also adds stability to the burner operation, and in this connection, we have experimented with tailpipes whose ratio of length to inside diameter ranged from 4 to 20 and found this entire range satisfactory.

The capacity of the burner is determined by the diameter and length of the combustion chamber and other factors. We have operated burners with 1.05-inch combustion chamber diameter at rates from 12,500 B.t.u./hr. to 140,000 B.t.u./hr. and have operated burners with 1.61-inch combustion chamber diameter from 12,500 B.t.u./hr. to 350,000 B.t.u./hr. at pressures from atmospheric up to 160 p.s.i.g. Satisfactory operation over at least a part of the above-quoted ranges has been observed with variation of the ratio of combustion chamber length to combustion chamber diameter over the range from 0.6 to 7.0, but the best operation apparently results when this ratio is in the range of 4 to 5. It will be understood that the ranges quoted for burner capacity, combustion chamber dimensions and tailpipe dimensions are not to be considered limitations of the method or apparatus, but rather as ranges that have been experimentally investigated and found satisfactory.

Although but a few illustrative embodiments of the present invention have been described, it will be apparent to those skilled in the art that various changes and modifications may be made therein without departing from the spirit of the invention or the scope of the appended claims.

We claim:

1. Apparatus for burning a mixture of a fuel gas and an oxygen-containing gas to stimulate the production of oil from a subterranean formation penetrated by a well bore comprising a length of tubing extending in said well bore from the earth's surface to said formation for carrying said mixture, a combustion chamber secured to the lower end of said tubing, a delivery nozzle assembly containing a plurality of restricting passages of reduced cross-sectional area positioned in said tubing between the lower end of said tubing and said combustion chamber, said restricting passages forming the only communication between said tubing and said combustion chamber to prevent flashback of the combustion flame from said combustion chamber to said tubing, means extending through said tubing and connected to said delivery nozzle for inserting and removing said delivery nozzle assembly from said tubing independently of said tubing and said combustion chamber, and ignition means for igniting said mixture in said combustion chamber.

2. Apparatus for burning a mixture of a fuel gas and an oxygen-containing gas to stimulate the production of

oil from a subterranean formation penetrated by a well bore comprising a length of tubing extending in said well bore from the earth's surface to said formation for carrying said mixture, a combustion chamber secured to the lower end of said tubing, a delivery nozzle assembly containing a plurality of restricting slots of reduced cross-sectional area positioned in said tubing between the lower end of said tubing and said combustion chamber, said restricting passages forming the only communication between said tubing and said combustion chamber to prevent flashback of the combustion flame from said combustion chamber to said tubing, means extending through said tubing and connected to said delivery nozzle for inserting and removing said delivery nozzle assembly from said tubing independently of said tubing and said combustion chamber, and ignition means for igniting said mixture in said combustion chamber.

3. Apparatus for burning a mixture of a fuel gas and an oxygen-containing gas to stimulate the production of oil from a subterranean formation penetrated by a well bore comprising a length of tubing extending in said well bore from the earth's surface to said formation for carrying said mixture, a combustion chamber secured to the lower end of said tubing, a landing shoulder in the lower end of said tubing, a delivery nozzle containing a plurality of restricting passages of reduced cross-sectional area positioned in said tubing on said landing shoulder between the lower end of said tubing and said combustion chamber, said restricting passages forming the only communication between said tubing and said combustion chamber to prevent flashback of the combustion flame from said combustion chamber to said tubing, means extending through said tubing and connected to said delivery nozzle for inserting and removing said delivery nozzle from said tubing independently of said tubing and said combustion chamber, and ignition means for igniting said mixture in said combustion chamber.

4. Apparatus for burning a mixture of a fuel gas and an oxygen-containing gas to stimulate the production of oil from a subterranean formation penetrated by a well bore comprising a length of tubing extending in said well bore from the earth's surface to said formation for carrying said mixture, a combustion chamber secured to the lower end of said tubing, a delivery nozzle containing a plurality of restricting slots of reduced cross-sectional area positioned in said tubing between the lower end of said tubing and said combustion chamber, said restricting passages forming the only communication between said tubing and said combustion chamber to prevent flashback of the combustion flame from said combustion chamber to said tubing, means extending through said tubing and connected to said delivery nozzle for inserting and removing said delivery nozzle from said tubing independently of said tubing and said combustion chamber, a deflector ring secured to the lower end of said delivery nozzle for deflecting said mixture toward the walls of said combustion chamber, and ignition means for igniting said mixture issuing into said combustion chamber.

5. Apparatus for burning a mixture of a fuel gas and an oxygen-containing gas to stimulate the production of oil from a subterranean formation penetrated by a well bore comprising a length of tubing extending in said well bore from the earth's surface to said formation for carrying said mixture, a combustion chamber secured to the lower end of said tubing, a delivery nozzle containing a plurality of restricting slots of reduced cross-sectional area positioned in said tubing between the lower end of said tubing and said combustion chamber, said restricting passages forming the only communication between said tubing and said combustion chamber to prevent flashback of the combustion flame from said combustion chamber to said tubing, means extending through said tubing and connected to said delivery nozzle for inserting and removing said delivery nozzle from said tubing independently of said tubing and said combustion chamber,

and an electrical heating coil disposed in the lower end of said delivery nozzle assembly for igniting said mixture in said combustion chamber.

6. Apparatus for burning a mixture of a fuel gas and an oxygen-containing gas to stimulate the production of oil from a subterranean formation penetrated by a well bore comprising a length of tubing extending in said well bore from the earth's surface to said formation for carrying said mixture, a combustion chamber secured to the lower end of said tubing, a delivery nozzle containing a first set of restricting passages of reduced cross-sectional area and a second set of restricting passages of reduced cross-sectional area positioned in said tubing between the lower end of said tubing and said combustion chamber, said restricting passages forming the only communication between said tubing and said combustion chamber to prevent the entry of foreign matter in said combustion chamber and to prevent flashback of the combustion flame from said combustion chamber to said tubing, means extending through said tubing and connected to said delivery nozzle for inserting and removing said delivery nozzle from said tubing independently of said tubing and said combustion chamber, and ignition means for igniting said mixture in said combustion chamber.

7. Apparatus for burning a mixture of a fuel gas and an oxygen-containing gas to stimulate the production of oil from a subterranean formation penetrated by a well bore comprising a length of tubing extending in said well bore from the earth's surface to said formation for carrying said mixture, a combustion chamber secured to the lower end of said tubing, a delivery nozzle positioned in said tubing between the lower end of said tubing and said combustion chamber, said delivery nozzle comprising an upper set of slots of reduced cross-sectional area for preventing the entry of foreign matter into said combustion chamber and a lower set of slots of reduced cross-sectional area for preventing flashback of the combustion flame from said combustion chamber to said tubing, and ignition means for igniting said mixture in said combustion chamber.

8. Apparatus for burning a mixture of a fuel gas and an oxygen-containing gas to stimulate the production of oil from a subterranean formation penetrated by a well bore comprising a length of tubing extending in said well bore from the earth's surface to said formation for carrying said mixture, a combustion chamber secured to the lower end of said tubing, a delivery nozzle containing a plurality of restricting slots of reduced cross-sectional area positioned in said tubing between the lower end of said tubing and said combustion chamber, said restricting passages forming the only communication between said tubing and said combustion chamber to prevent flashback of the combustion flame from said combustion chamber to said tubing, means extending through said tubing and connected to said delivery nozzle for inserting and removing, said delivery nozzle from said tubing independently of said tubing and said combustion chamber, a deflector ring secured to the lower end of said delivery nozzle for deflecting said mixture toward the walls of said combustion chamber, and an electrical heating coil disposed in the lower end of said delivery nozzle assembly for igniting said mixture issuing into said combustion chamber.

9. Apparatus for burning a mixture of a fuel gas and an oxygen-containing gas to stimulate the production of oil from a subterranean formation penetrated by a well bore comprising a length of tubing extending in said well bore from the earth's surface to said formation for carrying said mixture, a combustion chamber secured to the lower end of said tubing, a delivery nozzle containing a plurality of restricting slots of reduced cross-sectional area positioned in said tubing between the lower end of said tubing and said combustion chamber, said restricting passages forming the only communication between said tubing and said combustion chamber to prevent flashback of the combustion flame from said combustion chamber to said tubing, means extending through said tubing and connected to said delivery nozzle for inserting and removing said delivery nozzle from said tubing independently of said tubing and said combustion chamber, ignition means for igniting said mixture issuing into said combustion chamber, and a slotted exhaust member secured to the lower end of said combustion chamber for directing the heated combustion gases against said formation.

10. Apparatus for burning a mixture of a fuel gas and an oxygen-containing gas to stimulate the production of oil from a subterranean formation penetrated by a well bore comprising a length of tubing extending in said well bore from the earth's surface to said formation for carrying said mixture, a combustion chamber secured to the lower end of said tubing, a delivery nozzle containing a plurality of restricting slots of reduced cross-sectional area positioned in said tubing between the lower end of said tubing and said combustion chamber, said restricting passages forming the only communication between said tubing and said combustion chamber to prevent flashback of the combustion flame from said combustion chamber to said tubing, means extending through said tubing and connected to said delivery nozzle for inserting and removing said delivery nozzle from said tubing independently of said tubing and said combustion chamber, a deflector ring secured to the lower end of said delivery nozzle for deflecting said mixture toward the walls of said combustion chamber, ignition means for igniting said mixture issuing into said combustion chamber, and a slotted exhaust member secured to the lower end of said combustion chamber for directing the heated combustion gases against said formation.

11. Apparatus for burning a mixture of a fuel gas and an oxygen-containing gas to stimulate the production of oil from a subterranean formation penetrated by a well bore comprising a length of tubing extending into said well bore from the earth's surface to said formation for carrying said mixture, a combustion chamber secured to the lower end of said tubing, a delivery nozzle positioned in said tubing between the lower end of said tubing and said combustion chamber, said delivery nozzle including an upper set of slots of reduced cross-sectional area for preventing the entry of foreign matter into said combustion chamber, a redistribution annulus below said upper set of slots for producing uniform distribution of said mixture, and a lower set of slots of reduced cross-sectional area below said redistribution annulus for preventing flashback of a combustion flame from said combustion chamber to said tubing, and ignition means for igniting said mixture in said combustion chamber.

References Cited in the file of this patent

UNITED STATES PATENTS

1,282,955	Scholz	Oct. 29, 1918
1,678,592	Garner et al.	July 24, 1928
2,001,739	MacGregor	May 21, 1935
2,474,313	Hess	June 28, 1949
2,506,853	Berg et al.	May 9, 1950
2,584,606	Merriam et al.	Feb. 5, 1952
2,668,592	Piros et al.	Feb. 9, 1954