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IGNITING AN OIL STRATUM FOR IN SITU COMBUSTION

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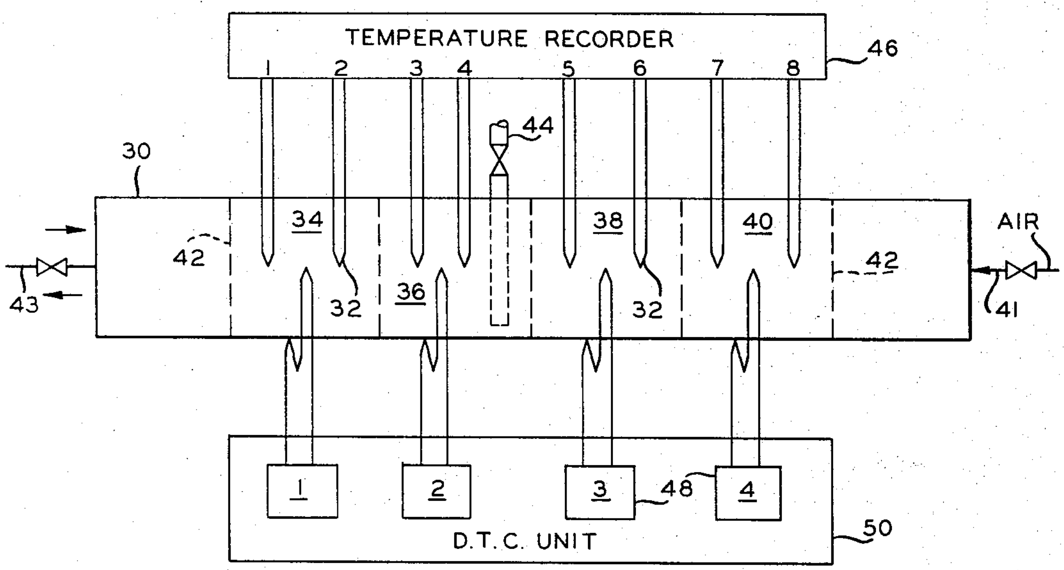

FIG. 2

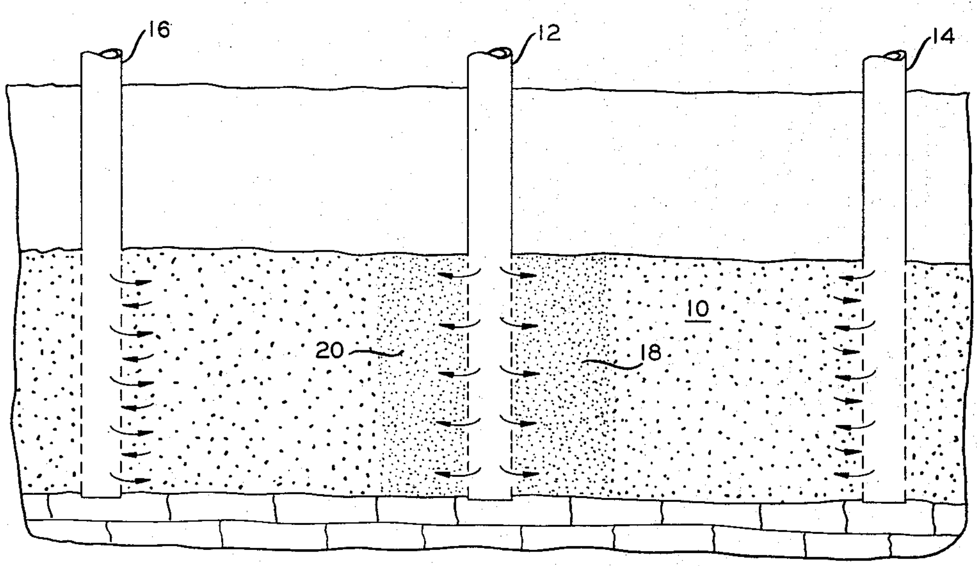

FIG. 1

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IGNITING AN OIL STRATUM FOR IN SITU COMBUSTION

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This invention relates to a process or technique for igniting a permeable oil stratum for initiating in situ combustion therein.

Production of oil from oil strata by both reverse and direct drive in situ combustion has come into use in the petroleum industry. One of the problems encountered in in situ combustion within an oil stratum is that of initiating combustion which can be sustained by an air drive. A desirable procedure in igniting an oil stratum around a production well offset from an injection well wherein reverse drive of the combustion zone from the production well to the injection well is to be used comprises heating the production well bore to at least ignition temperature and feeding air or other O_2-containing, combustion-supporting gas thru the injection well and forcing same to the hot area at the production well. This technique is not always successful and various methods have been proposed for assisting in establishing a sustainable combustion zone moving toward the injection well. One procedure which has been proposed is to inject into the annulus surrounding the production well a low ignition point liquid fuel which ignites spontaneously when contacted with air, particularly, under high pressure. This procedure is designed to establish a combustion zone extending radially from the production well, but this does not always operate as expected because the injected air tends to drive the injected fluid (in the annulus surrounding the production well) into the production well without burning any substantial quantity thereof in the stratum surrounding the production well. Thus, frequently, the intended ignition does not "take off" to establish an inverse drive in situ combustion process.

The present invention is concerned with a process or technique of operation for initiating an inverse burning combustion front in an oil stratum.

Accordingly, it is an object of the invention to provide a process for igniting an oil stratum around a production well and establishing a combustion zone which can be maintained by inverse drive of air or other oxidizing gas. Another object is to provide a process for initiating an inverse burning combustion zone around a central well flanked on either side by offset injection wells. It is also an object of the invention to provide a process for establishing an inverse burning combustion front around a production well, utilizing a spontaneously ignitable, low-ignition point liquid fuel, which does not drive the fuel into the production well. Other objects of the invention will become apparent to one skilled in the art upon consideration of the accompanying disclosure.

A broad aspect of the invention comprises depositing a spontaneously ignitable, low-ignition point liquid fuel in an annulus adjacent a central production or ignition well located between two offset injection wells, thereafter shutting-in the central well and injecting air or other combustion-supporting, O_2-containing gas thru one of the injection wells while producing thru the other so that the injected gas passes into the annulus containing fuel and spontaneously ignites same, injection being continued to establish a substantial combustion zone and ignite the in-place oil, thereafter opening the central well to flow and injecting combustion-supporting gas thru the other injection well so as to initiate combustion in the injected fuel nearest the second injection well and move the resulting

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combustion zone toward the second injection well. Production from both combustion zones is recovered thru the central well which becomes the production well for the following inverse burning drive thru the stratum intermediate the production and injection wells. It is feasible to utilize a ring pattern of wells around a central well or a line of production wells intermediate parallel lines of injection wells. The ring pattern is operated by utilizing substantially diametrically opposite ring wells as initial injection wells to establish the combustion zones on opposite sides of the production well and thereafter injecting thru all of the ring wells whereby the burning zone is moved toward the other injection wells (not used in the original ignition).

Another embodiment of the invention comprises first packing off the central well just below the upper level and also just above the lower level of the stratum in conventional manner around a tubing string and then forcing a liquid solvent for the in-place oil thru the annulus surrounding the central well either from above the upper packer to below the lower packer or vice verse, this being controlled by injecting either thru the annulus or thru the tubing string and producing thru the other flow path. After a substantial annulus has been at least substantially depleted of in-place oil, the selected spontaneously ignitable liquid fuel is injected so as to displace the solvent in the annulus around the central well and deposit in said annulus sufficient fuel to initiate combustion of the in-place oil. After the selected fuel has been deposited in the annulus, operation is conducted as above described, first closing the central well and injecting thru one of the offset wells until a substantial combustion zone has been established and then opening the central well to flow and injecting thru the other offset well also so as to establish another combustion zone in the annulus nearest the second offset well. This technique is useful in strata containing rather heavy viscous oil and assures deposition in the annulus around the central well of sufficient fuel to initiate a combustion zone sustainable by inverse air injection from the offset wells.

A preferred gaseous oxidant is air because of the economics involved but other gaseous oxidants may be utilized such as O_2-enriched air, substantially pure O_2, ozone, gaseous nitrogen oxides, and gases containing combustion-supporting concentrations of these oxidants as well as mixtures of such gases.

Preferred spontaneously ignitable fuels include tung oil and linseed oil. However, other low-ignition point liquids are also suitable for the combustion fuel, such as unsaturated aliphatic hydrocarbons including cracked distillates, cyclic hydrocarbons such as turpentine, tetralin, or decalin, unsaturated aliphatic or cyclic O_2-containing compounds such as crotin-aldehyde, allyl alcohol, furfural, and aliphatic cyclic nitrogen-containing compounds such as ethylenediamine, or aniline or phenylhydrazine. Mixtures of these fuels may also be utilized and the fuel may include an oxidation catalyst such as cobalt naphthenate, manganese resinate and similar well-known oxidation catalysts which do not plug the stratum. Minor amounts of catalyst such as in the range of 0.05 to 1 weight percent of the injected fuel, are used in the operation.

The invention is not limited to the particular fuel or catalyst or oxidant utilized, but resides in the specific manner of operating with these materials. Hence any of the materials available which function in the intended manner are within the scope of the invention.

A more complete understanding of the invention may be had by reference to the accompanying schematic drawing of which FIGURE 1 is a fragmentary elevation in partial section thru a central well and a pair of offset injection wells penetrating an oil stratum and FIGURE 2 is a plan view of laboratory apparatus in which in situ combustion runs were made.

Referring to FIGURE 1 an oil stratum 10 is penetrated by a central well 12 and offset injection wells 14 and 16. The wells may either be cased thru the oil stratum or in a consolidated sand open hole may be used for the combustion process. An annulus 18 surrounding well 12 is substantially saturated with a selected spontaneously ignitable fuel by injecting same thru well 12 in obvious manner.

In operation with the arrangement of FIGURE 1, it is preferred to first inject air or other gaseous oxidant thru well 12 into the surrounding stratum until breakthru of air occurs thru wells 14 and 16. This substantially saturates the stratum with O_2 and hastens the ignition process when injecting air thru the injection wells. After the preliminary air injection is terminated at breakthru, the selected oxidizable liquid fuel is injected thru well 12 so as to substantially saturate an annulus surrounding this well. The amount of injected fuel depends upon the character of the stratum as to porosity, oil saturation, oil characteristics, thickness of the stratum, etc. Ordinarily, a substantial slug of the spontaneously ignitable fuel is injected so as to saturate an annulus from 1′ to several feet thick immediately surrounding well 12. Following the deposition of fuel in annulus 18, well 12 is shut-in and air is injected either thru well 14 or well 16, the one not being used for injection being utilized as a production well. Assuming that air is injected thru well 14 with well 12 shut-in, the injected air and/or air already deposited in the stratum passes into the annulus 18 containing the injected spontaneously ignitable fuel and initiates combustion thereof. Continued supplying of air thru this annulus and the fuel therein expands the combustion zone, raises the temperature in the annulus to the ignition temperature of the in-place oil, thereby igniting same and causing the resulting combustion zone to move inversely to the flow of air toward well 14. When a substantial combustion zone has been established, well 12 is open to flow while continuing injection of air thru well 14 and air is also now injected thru well 16 which has prior to this point been utilized as a production well. Air injected thru well 16 arrives at the annulus around well 12 containing the injected fuel and initiates a combustion zone in the area of 20 in the same manner as occurred on the opposite side of well 12 from air injected thru well 14. Here again, a reverse or inverse burning combustion zone moves away from the central production well toward the injection well. During the movement of the combustion zones toward the injection wells, oil principally in vapor form and upgraded is recovered thru production well 12.

When utilizing a ring pattern of wells around a central well, the ring wells other than 14 and 16 are used as injection wells after establishing of combustion zone 20, thereby advancing the combustion zones 18 and 20 toward the other injection wells, also. It is feasible to initiate combustion in the manner of the invention around each of a series of in-line production wells 12 and inject air thru offset parallel lines of injection wells 14 and 16.

The invention has been demonstrated in the laboratory utilizing a 30″ long, 2¼″ diameter stainless steel tube packed with Ottawa sand containing 1350 barrels per acre foot of Morichal Group II oil. The tube was well insulated and equipped with 4 sectional heaters and thermocouples to provide an essentially adiabatic tube. Eight thermocouple leads connected to an 8-point Brown recorder provided absolute temperature measurements during in situ combustion runs. Additional 4 thermocouple leads were used to maintain a near-adiabatic condition in the tube at all times, using 4 commercially available Acromag differential temperature controllers. The apparatus described and used is illustrated in FIGURE 2 wherein numeral 30 designates the stainless steel tube having 8 thermocouples 32, heating sections 34, 36, 38, and 40 separated by dotted lines 42. Lines 41 and 43 were provided at opposite ends of tube 30 for flow of fluids to and from the sand within the tube. A perforated injection and production conduit 44 extended into the oil sand at about the midsection of the tube 30 for injection of oxidizable fuel and for production of produced fluids. Thermocouples 32 were connected with a temperature recorder 46. Four Acromags 48 in differential temperature controller unit 50 were utilized to maintain near-adiabatic conditions in the tube at all times. The Acromags control the amount of heating in the four heating sections 34, 36, 38, and 40.

Utilizing the apparatus of FIGURE 2, packed with Ottawa sand and containing Morichal Group II oil (as described above), the tube was preheated to 150° F. to correspond to the Morichal field reservoir temperature. Thereafter a slug of catalyzed tung oil (containing 0.1 weight percent of cobalt naphthenate) was injected thru conduit 44 so as to saturate a substantial annulus of the surrounding sand with the fuel. Tube 44 was then closed simulating a shut-in well. Air was then injected thru line 41 while line 43 was open to flow from the sand. An air flux density of about 150 standard cubic feet per hour per square foot of cross section of sand was utilized. This phase of the operation was continued and periodic temperature measurements recorded until the temperature profile thru the tube, as a result of the oxidation reaction, indicated the initiation of a counterflow combustion from about the area the tung oil was injected (around tube 44) toward the air injection (at line 41). At this point, the second phase of the operation was started by injecting air thru line 43 and opening conduit 44 to production. This phase of the operation was continued until the temperature profiles indicates the initiation of the second counterflow or inverse combustion. This second reverse combustion zone moved from adjacent conduit 44 toward air injection line 43.

The table below presents data representing the temperature profile in the tube obtained during the life of the run or test.

TABLE

Time	T_1	T_2	T_3	T_4	T_5	T_6	T_7	T_8	Flux
9:30	134	146	148	148	152	152	150	137	150
10:00	132	143	150	152	154	154	146	133	150
10:30	128	149	166	170	170	156	141	128	150
11:00	123	156	180	188	178	154	136	123	150
11:30	120	169	204	220	185	154	138	118	150
12:00	122	181	225	242	186	150	130	113	150
1:00	135	219	282	307	202	152	132	113	150
1:30	145	248	335	373	212	153	134	120	150
2:00	160	295	413	455	231	160	139	123	150
2:30	175	331	459	498	252	166	143	125	150
3:00	194	358	485	513	275	175	148	125	150
3:30	206	377	498	520	287	183	150	127	150
3:45	200	382	490	509	293	188	153	128	150
4:00	191	372	481	505	297	190	157	130	150
4:30	183	356	473	503	304	197	160	133	150
5:00	175	347	468	507	315	207	167	138	150
5:30	172	343	468	513	330	217	174	142	150
6:30	168	345	480	532	368	245	192	150	150
7:30	168	353	495	555	410	269	204	157	150
8:00	170	359	505	567	434	283	211	160	150

TABLE—Continued

Time	T_1	T_2	T_3	T_4	T_5	T_6	T_7	T_8	Flux
8:30	172	366	516	582	464	300	218	161	150
9:30	177	380	534	611	542	348	240	167	150
10:30	185	394	557	648	639	440	284	185	150
11:00	193	403	568	666	666	487	312	198	150
11:30	195	410	582	682	692	524	335	208	150

NOTE.—At 3:35 injection at both ends was commenced with production thru center.

The invention avoids producing the spontaneously ignitable fuel back into the well thru which it was injected and thus conserves this relatively expensive fuel and avoids burning the same in the production wellbore. It also assures sufficient fuel in the annulus surrounding the production well for ignition of a sustainable counterflow combustion zone.

In some instances, it is desirable to establish adequate gas permeability around the production well by injecting inert gas following the slug of fuel so that air from the injection wells does not bypass the slug and flow around it. After the slug has been dispersed by an inert gas, it may be desirable to fill up the wellbore with water or some other liquid in order to minimize hold up of mobil slug material as it is moved about in the formation by the flowing air. This movement of slug with air movement is actually a favorable phenomenon in this process because it increases the slug saturation per unit volume of stratum and thus assures a favorable condition for reaction to take place.

When the oil surrounding the central production well is highly viscous, it is desirable to flush out the annulus into which the fuel is to be injected so as to provide a void space necessary for containment of the injected fuel. As disclosed above, the annulus is packed off just below and just above the boundaries of the stratum in conventional manner and a solvent for the in-place crude oil such as light oils, kerosene, benzene, etc. is forced thru such as light oils, kerosene, benzene, etc. is forced through to deposition of the low ignition point fuel in the annulus. During this process, if the sand is unconsolidated, the sand grains are free to move and shift from one location to another and consequently compensate for any high permeability streaks or inhomogeneities that naturally exist around the well, which assures more uniform combustion in the annulus when the air supply contacts the oxidizable fuel.

Certain modifications of the invention will become apparent to those skilled in the art and the illustrative details disclosed are not to be construed as imposing unnecessary limitations on the invention.

I claim:

1. A process for initiating in situ combustion in a permeable oil stratum penetrated by a central well and first and second wells offset in substantially opposite directions from said central well, which comprises the steps of:

(1) injecting thru said central well a combustion-supporting volume of a low-temperature oxidizable liquid into an annulus of said stratum adjacent said central well;

(2) thereafter, shutting in said central well and injecting gaseous O_2-containing oxidant thru said first well so as to contact said liquid therewith and ignite and burn same, thereby igniting in-place oil adjacent said annulus and establishing a combustion zone;

(3) continuing the injecting in Step 2 so as to cause said combustion zone to move toward said first well;

(4) during Steps 2 and 3, producing thru said second well;

(5) thereafter, opening said central well to production and injecting gaseous O_2-containing oxidant thru said second well, contacting the oxidizable liquid in said annulus nearest said second well therewith, and burning said liquid thereby igniting in-place oil and establishing a second combustion zone; and

(6) continuing the injecting in Step 5 so as to move said second combustion zone toward said second well while producing fluids from both combustion zones thru said central well.

2. The process of claim 1 wherein said oxidizable liquid is tung oil.

3. The process of claim 2 wherein an oxidation catalyst is admixed with said tung oil.

4. The process of claim 1 wherein said oxidant is air.

5. The process of claim 1 wherein said oxidizable liquid is linseed oil.

6. The process of claim 1 wherein air is the oxidant, tung oil is the oxidizable liquid, and a minor but effective amount of an oxidation catalyst is admixed with the tung oil.

7. The process of claim 6 wherein said catalyst comprises cobalt naphthenate.

8. The process of claim 1 wherein air is the oxidant and air is injected thru said central well prior to Step 1 until air breaks thru into said first and second wells.

9. The process of claim 1 including the steps of:

(7) prior to Step 1, passing a solvent for the in-place oil thru the annulus surrounding said central well; and

(8) displacing solvent and any dissolved oil therein from said annulus by Step 1.

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