March 4, 1958 K. M. WATSON 2,825,408

OIL RECOVERY BY SUBSURFACE THERMAL PROCESSING

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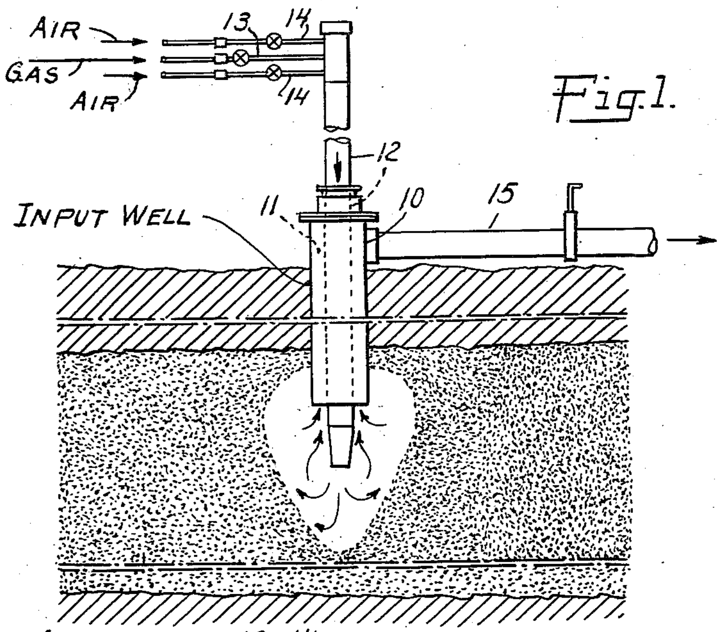


Fig.1.

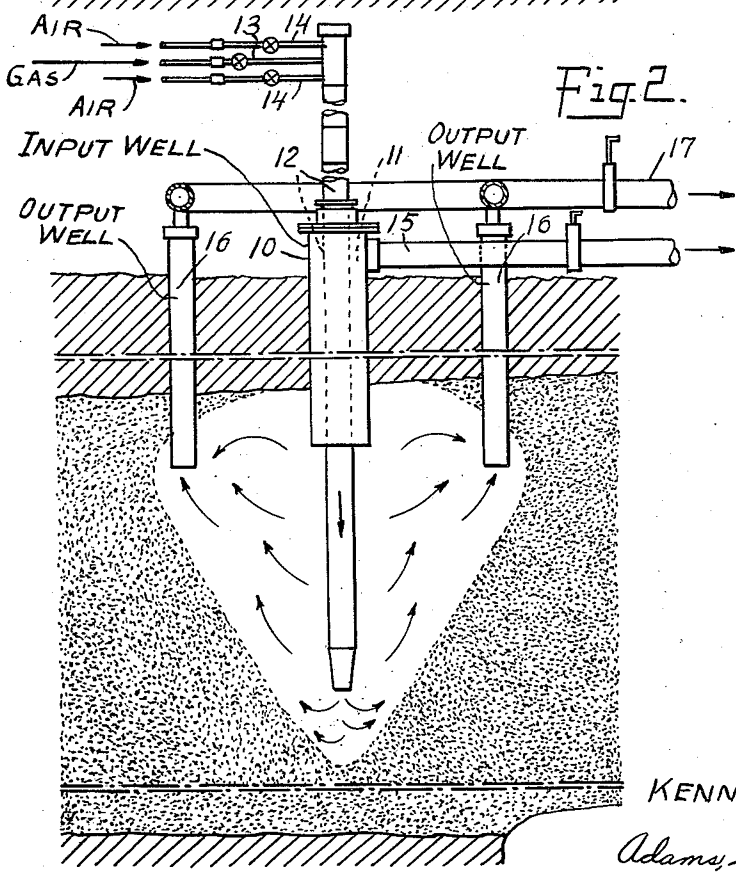


Fig.2.

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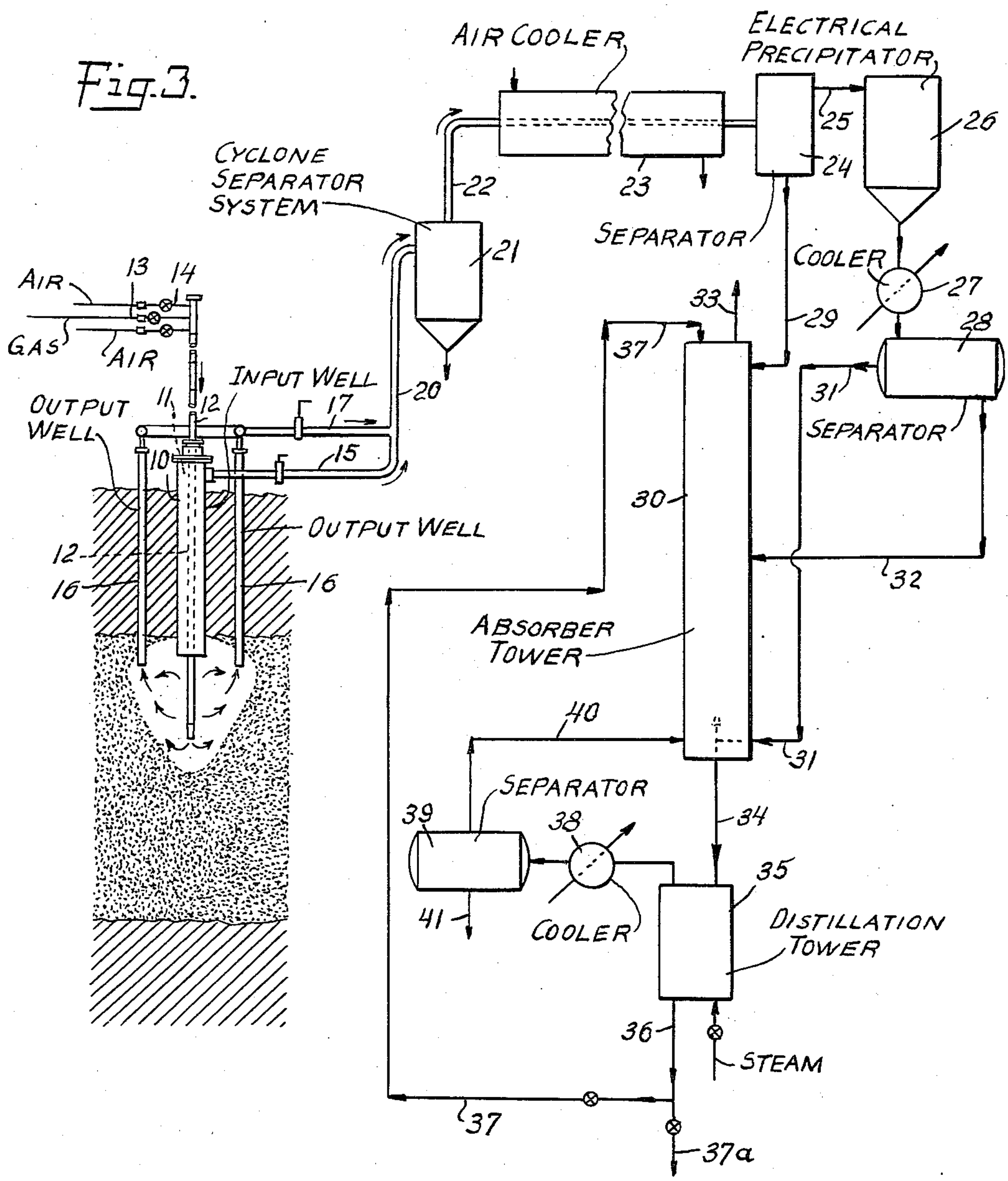
Fig. 3.

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United States Patent Office

2,825,408

Patented Mar. 4, 1958

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2,825,408

# OIL RECOVERY BY SUBSURFACE THERMAL PROCESSING

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Application March 9, 1953, Serial No. 341,113

5 Claims. (Cl. 166—11)

This inventiton relates to the recovery of oil from subsurface formations of unconsolidated oil-containing sands, e. g. tar sands, by subsurface thermal processing.

In the region surrounding the Athabasca River in Alberta, Canada, there exist very large deposits of tar sands. The significance of these deposits as potential source of world oil is apparent from these data: The deposits, it has been estimated, contain about 200 billion barrels of oil. The oil present on Athabasca tar sand has a gravity of between 8 and 12° API and is present to the extent of 14 to 18 weight percent.

The recovery problem however presents a number of difficulties, both from the technical and economic standpoint. Proposals have been made to mine the sands and recover oil from the mined sand aggregates by various operations requiring mechanical preparation followed by washing or heating methods. The cost of these operations, were they to be performed on a large scale, would be excessive both in terms of capital investment and operating expenses. Although the recovery problem in the Athabasca region is aggravated by the climate and by transportation difficulties, similar considerations apply to the recovery of oil from the similar tar sands occurring in the Western region of the United States.

My invention provides a readily applied in situ system for recovery of oil from tar sands by thermal means. It comprises drilling an input bore from the surface through the overburden to the subsurface sands and then is essentially characterized by the establishment of a zone of heated circulating sand, vapors and gases through the erosive action of hot inert gases injected through an input pipe lowered through the input bore into the formation. In effect, a "fluidized" or turbulent region of moving sand is set up by the action of the hot input gases in melting the tar, vaporizing and cracking the hydrocarbons and in eroding the sand structure in combination with the simultaneous release of vapors and gases from the upper portion of the heated region. During the initiation of the operation, the release of vapors and gases is advantageously effected through the input bore, for example by means of an annulus surrounding the input pipe and connections. As the process proceeds and the area of heated moving sand is enlarged, one or more output wells advantageously are drilled in a manner permitting release of vapors and gases through them. My invention further is essentially characterized by progressively enlarging the eroded and heated region of moving sand by vertical movement of the input pipe within the formation.

My invention will be further described by reference to the accompanying drawings of which Fig. 1 is a simplified schematic sketch of an input well with injection equipment at an early stage of the operation, showing part of the subsurface structure in section.

Fig. 2 is a similar view at a later stage of the operation illustrating utilization of output wells for release of vapors and gases.

Fig. 3 is similar to Fig. 2 but also shows an arrangement of recovery equipment for separating oil, condensible hydrocarbon gases and non-condensible gases in simplified diagrammatic flow plan form.

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As shown in the drawings, an input well **10** is drilled through the overburden into the formation and is cased to provide an annular section **11** surrounding input pipe **12**. As shown, fuel gas and air are conducted by separate gas and air lines **13** and **14** respectively to a burner pipe which comprises the last section of the input pipe **12**. Alternatively, the mixture of air and fuel gas can be burned above the surface of the ground to provide a mixture of hot inert flue gases for injection by the input pipe **12** into the formation.

In the operation, an injection gas stream at a temperature higher than the cracking temperature is desired and hence is most conveniently provided by combustion of a fuel gas with air either at the surface or below the surface at the point of injection into the formation. I have found however that it is important to control the combustion in a manner avoiding the presence of excess oxygen so that an inert input gas stream is provided. The pressure of the input gas stream is limited by the overburden. In the absence of cap rock sealing the formation approximately one pound of pressure can be tolerated for each foot of overburden thickness. In the tar sands typically occurring in Canada and the United States there is about 50 to 700 feet of overburden. Because of the limitation placed on the pressure of the injection gases by the thickness of overburden, it is advantageous to drill the input well to the foot of the formation in order to initiate the operation and then to conduct the progressive extension of the hot eroded zone by raising the input pipe or burner gradually up through the formation to the overburden.

As shown in Figs. 1 and 2, the injection of hot inert gases and simultaneous release of vapors and gases through the annulus **11** surrounding input pipe **12** results in melting of the tar, vaporization and cracking of the hydrocarbons and destruction of the sand structure by erosion. The vapors and gases are released from annulus **11** into pipe **15** which may be one of a series of gathering pipes leading to an oil separation and gas recovery system. The non-condensible gas recovered may be recycled, if this is desired, but if it is substantially inert, it should be blended with the combustion gas mixture after combustion rather than beforehand if satisfactory combustion control is to be expected. The release of vapors and gas directly from the input or eroded region, rather than by attempted passage through the formation to a spaced output well as in conventional gas pressuring operations, in the course of the injection process is essential if an enlarging eroded region of hot circulating or fluidized sand is to be created. As the operation proceeds and the temperature level in the input region is raised to about the cracking temperature, i. e. about 700° to 1200° F., the progressive erosion of the subsurface structure is gradually extended by lowering the input pipe gradually deeper into the formation, or conversely by gradually raising the input pipe up through the structure if the well has been originally drilled to the foot of the formation. In this way, the serious problem of formation impermeability is overcome, and the heat introduced by the hot inert gases can reach the oil in successive increments by continuous convection while the products of vaporization and cracking are carried away by gas flow. The effect of the traveling action of the input pipe is to produce a continuously enlarging erosion zone within the formation in roughly conical form. As shown in Figs. 2 and 3, output wells **16** which are representative of a number of wells drilled about the perimeter of the eroded zone are desirably cased and connected to valved recovery lines **17** connecting with the oil separation and gas recovery system.

The amount of heat necessary for a given formation may be calculated from determinations of the heat capacity of the sand and the heats of vaporization and reaction of the tar contained in the sand. Ordinarily, an input gas stream at about 1800° to 1900° F. is desirable, but as temperature equilibrium is approached, the gas temperature may be gradually reduced to about 1150° to 1200° F. It should be maintained above about 1000° F. Approximately a month or more may be required to approach temperature equilibrium. The progress of the subsurface operation can be followed by gas analysis or by drilling window wells and inserting thermocouples or other analytical equipment at formation level. Advantageously, a pattern of input and output wells is planned that will efficiently cover an entire field or selected area of a large field.

The method of recovery of vapors and gases produced in the process for subsequent separation of oil and recycle of non-condensible gases, if desired, is illustrated in diagrammatic form in Fig. 3. In the initial stages of the operation, the vapors and gases produced are recovered through an annulus in the input well but as the subsurface cone is formed and enlarges during processing, recovery is effected through a plurality of perimeter wells around the subsurface cone.

The hot stream of vapors and gases advantageously is first passed by means of line **20** through one or more cyclone separators **21** wherein sand and other solid particles are removed from the gas stream. The gas stream then may be passed by means of line **22** through air cooler **23** and thence into separating drum **24**. It may be desirable to supplement the air cooler with a water-cooled exchanger system although the conditions may be controlled in separator **24** by means of reflux to provide additional cooling. Separator **24** also is advantageously equipped with metal fabric demisting wires to eliminate fog. Nevertheless it usually will be found desirable to pass the uncondensed stream, by means of connection **25**, through an electrical precipitation system **26**, followed by cooler **27** into a secondary separator **28**.

The condensate separated in separator **24** may be introduced by means of connection **29** to an upper portion of absorber tower **30** wherein it is contacted countercurrently with the treated gas stream off separator **28** which is introduced at the foot of absorber **30** by means of line **31**. The condensed mist collected in separator **28** may be introduced into an intermediate section of absorber **30** by connection **32**. Uncondensed gaseous components are vented from absorber **30** by means of line **33**, to be utilized in part as recycle gas if desired, or to be otherwise disposed of. The oil stream from the bottom of absorber **30** is passed by connection **34** to distillation tower **35**. Heat may be introduced to the tower by conventional means such as a steam or bottoms reboiler. A stripped heavy oil fraction is removed as bottoms by means of line **36** from which a portion is returned through line **37** as absorber oil to the top of absorber tower **30**. The overhead from tower **35** is passed through condenser **38** to separating drum **39**. Uncondensed gas may be returned to absorber **30** by means of connection **40**. The distillate collected in separator **39** is removed by means of line **41** to storage or shipping.

In the following example, the illustrative data derived by small scale testing of my invention are provided.

The size distribution of the sand present in a sample of Athabasca tar sand was determined by extracting the oil with benzene and then running a sieve analysis on the remaining sand. It was found that the sieve analysis of the original sand could be closely approximated by a mixture of Wausau graded sand. This mixture was made with nine parts of No. 1/2 grade and one part of No. 2/0 grade sand. The physical characteristics of the Athabasca crude were approximated by blending 57 weight percent of a vacuum still bottoms with 43 weight percent of a straight run residuum. The gravity of this blend was 14.3° API. The synthetic tar sand used in these tests was made with 86 weight percent of the graded sand mixture and 14 percent of the blended heavy hydrocarbons.

The first series of tests was run in an insulated section of four-inch pipe, four feet long. This section of pipe, which had a flange opening at the top, was mounted in a vertical position within a tripod frame. In this test eleven pounds of the synthetic tar sand were tamped into the pipe. This tar sand section was 40" in depth. The flanged cover for this pipe had two openings; one for admitting the burner and the other to provide an exit for the flue gases along with the liberated hydrocarbon vapors. The burner used in this test could be pushed down through the bed through a seal. Also located on the flange cover was a thermowell made of ¼" stainless tubing which extended to the bottom of the sand bed. In order to ignite the top surface of the tar sand the flange cover was propped up to leave a two-inch gap between the flange faces. The burner was then lighted, using acetylene and air as the fuel. After the thermocouple in the upper portion of the sand bed indicated that at least two inches of the bed was over 1100° F., the flange cover was bolted down. The acetylene was turned off and only air at the rate of 45 cu. ft. per hour was fed to the lance type burner. Temperature readings indicated that the sand bed was ignited and combustion could be sustained by air alone. The lance was then pushed down through the bed at the rate of about one inch per minute. The temperature readings made, indicated that the bed temperatures were above 1200° F., which was the limit of the available recorder. The hydrocarbons were driven off as a dense brown smoke which could not be condensed. Indications were that the hydrocarbons on the sand that were not burned were being very highly cracked. When the sand in the pipe section was examined after it had cooled overnight it was found to be for the most part, burned clean. About one quarter of the sand had been blown out of the pipe.

In the second test, the section of the pipe was packed with synthetic tar sand in the same manner as in the first test. The object of this second test was to determine whether or not it was possible to ignite the bottom of the sand section and burn up through the tar sand; taking the vaporized oil and products of combustion out the top. In this test a connection was provided to the bottom of the pipe section.

When cold, the tamped synthetic tar sands in the pipe had sufficient permeability to allow about 100 cu. ft. per hour to pass through the 40" sand section with a 27½ p. s. i. pressure drop. The bottom of the pipe section was heated externally by an acetylene torch until the thermocouple in the bottom of the sand indicated a 1200° F. plus temperature. At that temperature the heating was discontinued and air was started into the bed at about 110 cu. ft. per hour. Within fifteen minutes the pressure drop on the bed increased so that only about 35 cu. ft. per hour of air could pass through the bed with a total pressure drop of 90 p. s. i. across the sand section. As time went on the air rate diminished so that at the end of one hour the flow through the bed was practically nil. This blocking of the sand to the passage of the air was due to oil which was being released from the hot sand at the bottom of pipe condensing on cold tar sand higher in the pipe. Temperature surveys made during the course of the air blowing indicated that ignition of the tar sands had not been established.

Because of the difficulties attendant with carrying out these thermal tests on a small scale in a section of pipe, it was decided to repeat this series of tests on a larger scale. In the larger scale tests a new burner was utilized in which the gaseous fuel and the air were introduced through three stainless steel tubes ⅛" in inside diameter.

One was used to bring the gas to the combustion zone while two were used to introduce the air into the combustion zone. In order to promote proper burning within the combustion zone the gas and air must be introduced into the combustion zone so that they produce a rotary mixing current. This was done by taking the three tubes, the gas line being sandwiched between the two air lines, and giving them a three-quarter corkscrew twist as they entered the combustion zone. The combustion zone of the burner consisted of a six-inch length of zirconia oxide refractory. The inside diameter of this refractory was ¾" and the outside diameter was one inch. The refractory was slipped into a seven-inch length of standard one inch stainless steel pipe. The one inch stainless steel pipe in turn was slipped into another section of 1¼-inch standard stainless steel pipe. The 1/32" annular space between the outside of the one-inch pipe and the inside of 1¼-inch pipe served as a passage for the inert gas, nitrogen or flue gas which was blended into the combustion gases in order to lower the temperature of the gases emerging from the burner. This inert gas used for blending also served to cool the burner thus enabling it to withstand hours of operation without apparent damage.

The larger scale tests were run with the synthetic tar sands contained in 100# grease drums. These drums are 15" in diameter and 20" in depth. Two fire bricks were placed on the bottom of the drum prior to packing it with the synthetic tar sand mixture. It was intended that these bricks would protect the drum bottom from the hot gases emerging from the burner. The drum was then loaded with 205# of synthetic tar sand which was tamped very firmly. After the drum was loaded, a cover made of ¼" steel plate was welded to the top of the drum. A cylindrical baffle 7" in diameter and 4" deep was welded into the lid of the drum. This was to prevent gases from by-passing travel through the sand by going across the top of sand below the cover plate.

A two-inch coupling was welded to the center of this cover plate. A two-inch T was connected to this coupling. The burner was introduced into the drum through the top of this T. There was an O-ring seal around the burner pipe, making it possible to move the burner down into the sand bed during the course of the test. The side of the T was the exit for the produced gases. Also located on the cover plate of the drum were four collecting lines for the produced gas. These consisted of four ½-inch couplings, located on a 10" diameter circle, welded to the plate. The four collecting lines were connected to a common line with which was also connected the line from the two-inch T. The produced gas passed into a cyclone sand trap in order to remove the sand blown out of the drum and then into a water cooled condenser. A block valve was installed on the line which connected the side of the T located above the center of the cover plate to the four collecting lines on the cover plate. This block valve was left open while the burner was being forced into the sand bed in order to allow sand to be blown out but as soon as the burner was forced to the bottom of the bed this valve was blocked, thus causing all the hot gases to pass through the sand before emerging through the collecting lines. The sand bed temperatures in the drum quantity runs were determined by thermocouples inserted in thermowells which pass the entire depth of the bed. These thermowells were introduced into the drum through T's located on the four collector lines. The uncondensed gas, along with the smoke produced by the heating went into a Cottrell precipitator. This precipitator consisted of a 24" section of 2" copper tubing which was insulated by means of Teflon from a fine wire electrode suspended axially through it. The center electrode was maintained at a potential of 13,000 volts D. C. This Cottrell proved to be very effective in condensing the smoke fog given off by the sand mass when it was heated. The 100# grease drum of synthetic tar sand was placed in a 30 gallon open top oil drum and then the open annular space filled in with loose insulation for these tests.

In a test on the drum sized sample, the burner was adjusted to give flue gases with a temperature of 1300° F. with no oxygen present. This was done by feeding the theoretical mixture of gas, in this case hydrogen, and air plus sufficient nitrogen to bring the temperature down to 1300° F. These qualities were measured by means of rotometers. The total of flue gases at standard conditions was 210 cu. ft. per hour. After heating 12½ hours at this rate, this run was interrupted and the oil recovered in the sand trap was weighed and found to total 9#. Practically no oil was recovered from the system beyond this trap. Since examination of this oil showed that it was essentially as viscous as the material mixed with the sand, the test was resumed and the inert gas temperature was raised to 1500° with a total volume of 300 cu. ft. per hour. This heating period totaled 13 hours. The additional oil recovered weighed 17# but did not show any appreciable viscosity reduction. The total oil recovered was 26# out of the 30# originally mixed with the sand. This recovered oil was extracted with benzene and found to contain 8% sand. No water was recovered with this oil. The total oil recovered with 80% of the original charge. Original gravity as 14.3° API; final gravity 8.0° API.

Because the oil recovered in the previous test was essentially unaltered, it was decided to make another test at a higher temperature. For this run the drum was packed with tar sand as in the previous test. The burner was adjusted to give a flue gas temperature of about 1850° F. with a volume of about 380 cu. ft. per hour. This test lasted 12 hours. The back pressure on the burner inlet pipe was 3 to 5# per square inch during this test. The oil recovered by the condensers and Cottrell weighed 11# with water content of 20.0%, having a gravity of 26° API compared to the 14.3° API of the starting oil.

I claim:

1. A process for the recovery of oil from a subsurface formation of unconsolidated oil-containing sands which comprises providing an input bore to the said subsurface sands, inserting an input pipe in the said bore to extend to the said subsurface sands, injecting hot inert gases through the said input pipe into the said subsurface sands to raise the temperature thereof to a hydrocarbon vaporizing and cracking temperature of about 700 to 1200° F. thereby establishing a zone of eroded and heated circulating sands, vapors and gases within said subsurface sands providing an exit for said released vapors and gases to the earth's surface, enlarging the said eroded and heated zone by the progressive vertical movement of the said input pipe within the subsurface sands and thereafter recovering oil produced by the process from the released and withdrawn vapors and gases.

2. The process of claim 1 in which the point of injection is initially near the upper surface of the formation and is moved progressively downwardly into the formation in the course of the process.

3. The process of claim 1 in which the point of injection is initially near the lower surface of the formation and is progressively moved upwardly through the formation in the course of the operation.

4. A process for the recovery of oil from a subsurface formation of unconsolidated oil-containing sands which comprises providing an input bore and an output bore to the said subsurface sands, inserting an input pipe in the said input bore to extend to the said subsurface sands, injecting hot inert gases through the said input pipe into the said subsurface sands to raise the temperature thereof to a hydrocarbon vaporizing and cracking temperature of about 700 to 1200° F. thereby establishing a zone of eroded and heated circulating sands, vapors and gases within said subsurface sands providing an exit for said released vapors and gases through the output bore pro-

vided in the region of the heated circulating sands, enlarging the said eroded and heated zone by the progressive vertical movement of the said input pipe within the subsurface sands and thereafter recovering oil produced by the process from the released and withdrawn vapors and gases.

5. A process for the recovery of oil from a subsurface formation of unconsolidated oil-containing sands which comprises providing an input bore and an output bore to the said subsurface sands, inserting an input pipe in the said input bore to extend to the said subsurface sands thereby forming an annulus between said input pipe and said input bore, injecting hot inert gases through the said input pipe into the said subsurface sands to raise the temperature thereof to a hydrocarbon vaporizing and cracking temperature of about 700 to 1200° F. thereby establishing a zone of eroded and heated circulating sands, vapors and gases within said subsurface sands, enlarging the said eroded and heated zone by the progressive vertical movement of the said input pipe within the subsurface sands, providing an exit for said released vapors and gases to the earth's surface in the initial stage of the operation through the annulus in the input bore, providing subsequently as the heated zone becomes enlarged and exit for said released vapors and gases through the output bore provided in the region of heated circulating sands and thereafter recovering oil produced by the process from the released and withdrawn vapors and gases.

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