Oct. 25, 1966 L. K. STRANGE ET AL 3,280,911

WELL LINER WITH PERMEABLE JOINT

Filed Dec. 12, 1963 2 Sheets-Sheet 1

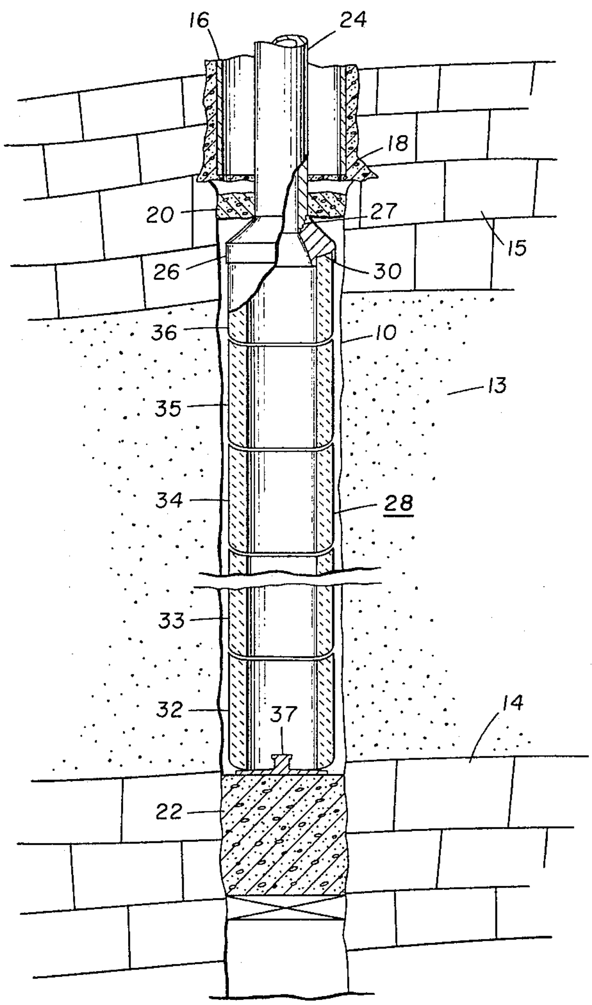


FIG. 1

FIG. 2

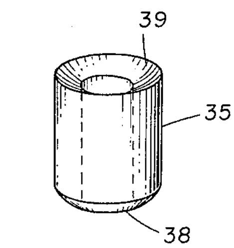


FIG. 3

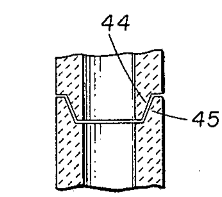


FIG. 4

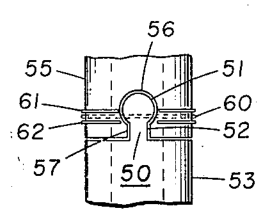


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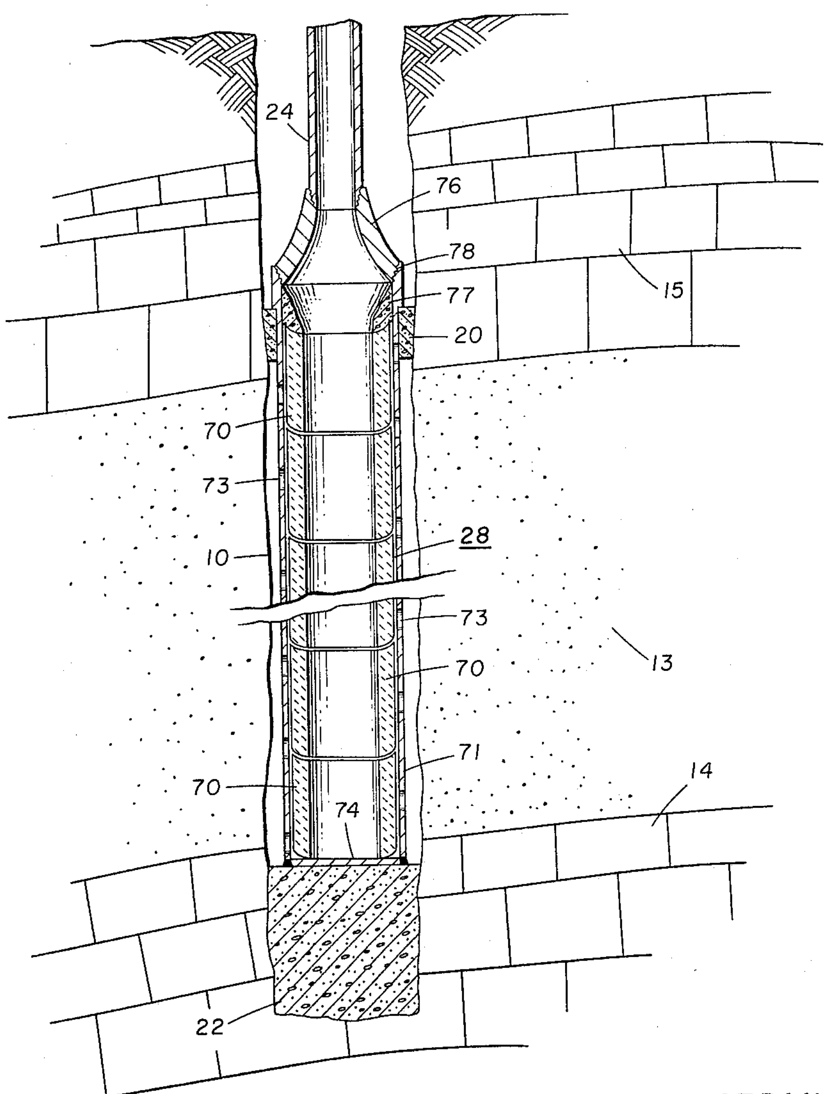
FIG. 5

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WELL LINER WITH PERMEABLE JOINT

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11 Claims. (Cl. 166—228)

This invention relates to a method and an apparatus for completing a well subject to the flow of hot, oxidizing fluids. More particularly, it relates to a liner and a method of completing oil wells with this liner when the wells are associated with high temperature, secondary recovery projects.

Oil exists in subterranean formations in accumulations called reservoirs. Wells are drilled into the formation to tap these reservoirs and produce the oil by using the reservoir energy. Many times a large part of the oil cannot be produced from the formation utilizing solely the reservoir energy.

To increase the amount of oil produced from the formation, various methods have been used. One group of these methods utilizes thermal recovery techniques.

One of these thermal recovery techniques is the in-situ combustion process. In this process, a combustion supporting gas such as air or oxygen is injected into the subterranean formation through one or more injection wells. Then, as the name implies, there is burning in situs, or in the formation, of either an injected fuel or the hydrocarbons native to the formation using the injected combustion supporting gas. Hydrocarbons having lowered viscosity are produced from one or more surrounding production wells. Most in-situ combustion processes are variations on two basic techniques. The first is straightforward combustion in which the zone of combustion or combustion front moves through the formation from the injection well to the production well, the hydrocarbons flowing before it. The second is inverse combustion in which the combustion front moves from the production well to the injection well, the hydrocarbons flowing through the combustion front.

With both in-situ combustion techniques there is encountered the problem of high temperature corrosion of any well liner and other well equipment used, because of the hot, oxidizing fluids. The temperature can be especially severe in an injection well, running as high as 1600° to 2000° F. Even at best, the temperatures will range from 800° to 1200° F. Where the injection well is completed in a relatively thick section, oil may drain by gravity into the injection well. In such cases, this high temperature may be sustained for an extended period of time. Under the extended high temperature conditions and in the presence of the hot oxidizing fluids, the conventional metal liner disintegrates, permitting sloughing of sand into the well, which reduces air injectivity.

The temperature and amount of oxidizing fluids will not be as great in the production well. However, the corrosion is intensified by the erosion of the liner and other well equipment by produced fluids containing particulate matter such as sand grains.

Attempts to alleviate these difficulties have resulted in the use of plastic liners, glass liners, stainless steel tubing, and even titanium tubing. The use of none of these materials has been eminently successful. These materials are brittle and rather inflexible. Further, the wells are often crooked. One of the problems encountered in attempting to set in place a liner made of one of these materials is sticking of the liner in the crooked well. Where the liner will not sustain much tensile stress, the problem can be severe.

It is an object of this invention to provide a well liner capable of withstanding high temperatures. It is a further



object of this invention to provide for a well a heat resistant liner which is capable of being set in place regardless of the degree of straightness of the well. For a more complete understanding of the invention and further objects, reference may be had to the description and figures which follow.

In accordance with the invention, there is provided a liner which is adapted for use in a well where oxidizing atmospheres at temperatures above 800° F. are encountered and which comprises a plurality of stacked, articulated conduit sections of a refractory material which conformably abut each to the other. These articulated conduit sections should preferably be permeable, i.e., the walls of each section should be permeable to the flow of fluids therethrough. In any case, the conformable abutment, which will be referred to as a joint, between sections is permeable to the flow of fluid, this fluid either being injected or produced. However, the joint is impermeable to the influx of solid particles such as sand. The conduit sections will generally by cylindrical, although other shapes may be employed. The invention also provides a well comprising the liner.

FIGURE 1 is a view in cross section of one embodiment of the invention.

FIGURE 2 is an isometric drawing of a conduit section having a protruding spherical end and a recessed spherical end.

FIGURE 3 is a cross-sectional view of two adjacent conduit sections in a lap-type abutting relationship, referred to as a lap-type joint.

FIGURE 4 is an elevation view of two conduit sections conformably abutting in a keyhole-type relationship, referred to as a keyhole joint.

FIGURE 5 is a cross-sectional view of a preferred embodiment of the invention.

Referring to FIGURE 1, well **10** penetrates subsurface formations **13**, **14**, and **15**. Formation **13** is a permeable formation in which in-situ combustion will be carried out and the flow of hot, oxidizing fluids will be encountered. Formations **14** and **15** are impermeable formations adjacent formation **13**. Casing **16** is cemented in place and provided with conventional cement foot **18**. Casing **16** terminates short of formation **13**. Heat resistant plugs, or packers, **20** and **22** form a seal against the impermeable formations **14** and **15**. Packer **20** also forms a seal with conduit **24** penetrating therethrough and connecting with liner **28**.

Liner **28** is comprised of multiple sections such as **32**, **33**, **34**, **35**, and **36** which are relatively short, articulated sections of thick wall refractory tubes. These sections may be as short as six inches or less. They may be as long as four feet or longer. They may be stacked to any desired height to form a liner throughout the producing subterranean formation. The sections can be constructed of any refractory material. For example, fused alumina, silicon carbide, fused quartz aggregate, and the refractory cements can be employed for this construction. Table 1 below shows specifications which are useful in connection with the manufacture of the articulated conduit sections.

*Table 1*

| | |
|---|---|
| Operating temperature | 2500° F. |
| Outside diameter (O.D.) | 4″ to 4½″. |
| Wall thickness | ½″ approx. |
| Length | 1′ to 2′. |
| Stacking height | 150′. |
| Preferred type joint | spherical. |

As stated, the walls of each section should preferably be permeable. The permeability may be as low as about 10 millidarcies and as high as about 600 millidarcies or higher. Sections having even greater permeability are desirable if they have adequate compressive strengths and do not allow finely divided solids such as sand or silt to pass through.

In a specific example, the fused alumina sections had a permeability of about 10 millidarcies and a porosity of approximately 28 percent. In longitudinal compressive tests, an 8-inch section supported a compressive load of 41,000 pounds before breaking. This corresponds to a compressive strength of 5700 p.s.i.a. A 12-inch long section was dropped onto a concrete floor from heights up to 4 feet with only chipping when the end struck the floor squarely. Thirty feet of 18-inch sections of 4¼" O.D. x 3¼" I.D. fused alumina liner weighed only 150 pounds.

Each section terminates in a protruding end and a recessed end. Each section is rough cast so the protruding and recessed ends, while conformably fitting together, provide a rough fit. This fit or joint provides adequate fluid permeability, yet restricts the flow of particulate matter such as sand grains.

For example, with air being injected at a flow rate of 6.28 M c.f. per day per joint of 4¼" O.D. x 3¼" I.D. conduit at a pressure of 200 p.s.i.g., the estimated pressure drop through a typical rough cast joint is less than 1 p.s.i. for a joint providing an average opening on the order of 0.01 inch. Yet, because of the tortuous path through which the fluid must flow, sand grains of much smaller dimensions than the average opening are filtered out.

At least three types of ends will fit yet provide adequate flexure to avoid emplacement problems and, once in place, control the influx of sand into the well.

FIGURE 2 illustrates the preferred embodiment wherein the section terminates in a spherical end. Section **35** is rough cast having one protruding end **38** and one recessed end **39**. Both the protruding end **38** and the recessed end **39** have approximately the same spherical radius of curvature. Thus, they conform when adjacent sections are stacked together as shown in FIGURE 1.

FIGURE 3 is a cross-sectional view of two sections conformably abutting in lap-type relationship. With this configuration, an inner protrusion **44** is adapted to fit conformably into a recessed cylindrical opening **45** of the adjacent section.

FIGURE 4 shows adjacent sections joined with a keyhole-type joint. Therein, diametrically opposed protruding keyhole ends **50** are provided with an enlargement **51** at the extremity of neck **52** on one end of section **53**. At the other end of section **53** there is provided a conformable end illustrated at the bottom of section **55**. There, an enlarged opening **56** adapted to fit enlargement **51** is provided at one end of notch **57** adapted to fit conformably with neck **52** of section **53**. A retaining ring **60** (shown in dotted lines) may be clipped around the joints between rings **61** and **62** to prevent lateral movement. Ring **60** need not be resistant to high temperature since its function is necessary only during the setting operation. While the keyhole-type joint is more elaborate and more expensive than the spherical or lap-type abutment, it has some advantages in that it can sustain slight tension.

When the liner **28** of articulated sections is arranged as illustrated in FIGURE 1, fluids flowing into the formation from the well, such as air injected during an in-situ combustion process, must flow through the liner. Alternatively, as in a production well when hot hydrocarbons, gases, and oxygen are flowing into the well from the formation, they are constrained to flow through liner **28** into its interior where they pass to the surface by conduit **24**. In this way, the majority of well equipment is isolated from the hot, corrosive fluids.

Conduit **24** should be constructed to heat and corrosion resistant material, such as titanium or stainless steel, when used in the production well. Alternatively, it may be conventional tubing having a heat and corrosion resistant



internal coating, such as a ceramic lining. It may be conventional tubing in the injection well.

Conduit **24** may be connected to liner **28** by cap **26**. Cap **26** should be constructed of heat and corrosion resistant metallic alloys, such as those of stainless steel and titanium. Cap **26** is provided with an annular recess **30** adapted to fit conformably the top end of the section **36**, and with threads **27** adapted to screw onto conduit **24**. Cap **26** should be somewhat removed from the turbulent, high temperature zone adjacent formation **13**, as shown in FIGURE 1. Obviously, other connecting means can be employed.

In placing liner **28** into a well, it is necessary to thread individually the sections of the liner over either a wire line operated or tubing operated mandrel where the wellbore is known to be crooked. The flexibility of liner **28**, with its articulated sections which abut one another to form joint means which permit relative lateral movement of these sections, is a particular advantage of the invention and enables it to be inserted into crooked wellbores. The mandrel and liner **28** are lowered into position onto plug **22** and adjacent formation **13** by conventional wire line equipment or tubing, whichever the operator chooses. The mandrel releases bottom support **37** and liner **28**. The mandrel is withdrawn before cap **26** and conduit **24** are put into position and heat resistant packer **20** set in place to isolate liner **28**.

In a preferred embodiment of the invention, the articulated sections of refractory material are assembled within a preperforated, expendable metal conduit which facilitates emplacement when the well is known to be relatively straight. FIGURE 5 is a cross-sectional view of this preferred embodiment wherein the heat resistant liner has been emplaced in the preperforated metal liner. Therein, the articulated conduit sections as exemplified by section **70** have been inserted into preperforated metal liner **71**. This preperforated metal liner **71** is a conventional mild steel liner having preperforations such as shown at **73**. Metal liner **71** is expendable and is used only in setting the heat resistant or refractory liner **28**. Metal liner **71** will have closure **74** at its bottom end to support sections **70** of liner **28**. Closure **74** rests on heat resistant packer **22** which may be, for example, a plug of high temperature cement. Metal liner **71** is connected to conduit **24** in communication with surface equipment. Where the diameter of the conduit **24**, which may be, for example, tubing, is different from the diameter of liner **71**, as will generally be the case, an appropriate "cross-over" connection **76** will be used to connect the two. Obviously, threaded or welded connections can be used conjunctively or alternatively. The top articulated section **70** may be sealed to liner **71** by high temperature cement **77** or other suitable material. With such a seal, heat resistant packer **20** may be set below threads **78**. Alternatively, heat resistant packer **20** may be set above threads **78** as shown in FIGURE 1. In either construction, packer **20** will force fluids to flow in the interior of conduit **24** and through liner **28**.

The insertion of heat resistant liner **28** within metal liner **71** obviously presents no problems in lengths of less than one joint of metal liner. Where it must be longer and thus not readily handled by the rig available, the liner is assembled for emplacement as follows. The first joint of preperforated liner **71** having inserted within it a section of liner **28** is partially lowered into wellbore **10** and held in place. A second joint of preperforated metal liner **71** having inserted inside it another section of liner **28** is positioned directly above the first. By way of example only, a piece of strap steel welded across the bottom end of the second joint will hold the second section of internal liner **28** satisfactorily during such positioning. Because liner **28** is not too heavy, it can be held manually while the strap steel is cut from across the open end of the second length of metal liner **71**. The second length of liner **28** is then lowered onto the first length, and the second length of metal liner 71 is lowered onto and welded to the first length of liner 71. In this manner, any desired length liner can be assembled and lowered into the wellbore.

The invention has been described with particularly with respect to recovery of oil from subsurface reservoirs. It can of course be used in analogous circumstances such as recovering shale oil from oil shale and hydrocarbons from tar sands. Other modifications of the invention will readily occur to one skilled in the art. It is intended to cover such modifications and uses as fall within the scope of the appended claims.

What is claimed is:

1. A well liner adapted for use in oxidizing atmospheres at temperatures above 800° F. which comprises stacked, articulated conduit sections of a refractory material, said sections having protruding and recessed ends and conformably abutting one to another to form joint means providing flexibility in permitting lateral movement of said sections individually and maintaining said sections in fluid permeable, sand impermeable relationship.

2. The well liner of claim 1 wherein said refractory material is fused alumina.

3. A well liner adapted for use in oxidizing atmospheres at temperatures above 800° F. which comprises stacked, permeable, articulated, cylindrical conduit sections of a refractory material, said sections having protruding and recessed ends and conformably abutting one to another to form joint means providing flexibility in permitting lateral movement of said sections individually and maintaining said sections in fluid permeable, sand impermeable relationship.

4. The well liner of claim 3 wherein said sections each have a protruding spherical end and a recessed spherical end.

5. The well liner of claim 3 wherein said sections each have a protruding keyhole end and a recessed keyhole end.

6. A well liner adapted for use in oxidizing atmospheres at temperatures above 800° F. which comprises permeable, articulated, cylindrical conduit sections of a refractory material stacked within a preperforated, expendable metal conduit closed at its bottom end, said sections having protruding and recessed ends and conformably abutting one to another to form joint means providing



flexibility in permitting lateral movement of said sections individually and maintaining said sections in fluid permeable, sand impermeable relationship.

7. The well liner of claim 6 wherein said sections each have a protruding lap-type end and a recessed lap-type end.

8. A well adapted for use in recovering hydrocarbons from a subsurface formation by thermal methods wherein flow of hot, oxidizing fluids will be encountered, which comprises a wellbore penetrating the formation; a liner comprised of stacked, articulated, cylindrical conduit sections of refractory material, said sections having protruding and recessed ends and conformably abutting one to another to form joint means providing flexibility in permitting lateral movement of said sections individually and maintaining said sections in fluid permeable, sand impermeable relationship disposed within the borehole; conduit means connected to said liner and communicating with the surface; and sealing plugs located within the borehole near the top and bottom of the formation supporting said liner and isolating the interior of said conduit, said liner, and said formation from the remainder of the wellbore and well in such manner that any fluid flow between surface and subsurface formation will be via said isolated interior, and through said liner.

9. The well of claim 8 wherein a heat resistant metallic cap connects said liner to said conduit.

10. The well liner of claim 1 wherein said refractory material is refractory cement.

11. The well liner of claim 1 wherein said refractory material is fused quartz.

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# UNITED STATES PATENT OFFICE
# CERTIFICATE OF CORRECTION

Patent No. 3,280,911 October 25, 1966

Lloyd K. Strange et al.

It is hereby certified that error appears in the above numbered patent requiring correction and that the said Letters Patent should read as corrected below.

Column 2, line 20, for "by" read -- be --; column 3, line 22, for "6.28 M c.f." read -- 6.8 mcf. --; line 72, for "to" read -- of --; column 5, line 5, for "particularly" read -- particularity --.

Signed and sealed this 22nd day of August 1967.

(SEAL)
Attest:

ERNEST W. SWIDER
Attesting Officer

EDWARD J. BRENNER
Commissioner of Patents