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WELL COMPLETION FOR EXTREME TEMPERATURES

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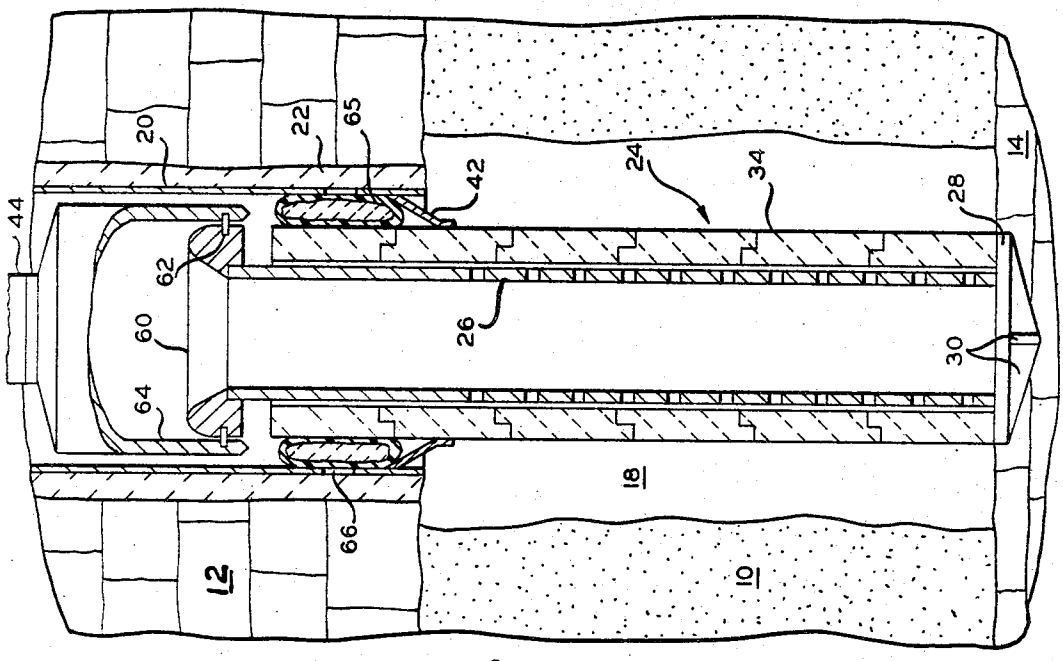


FIG. 2

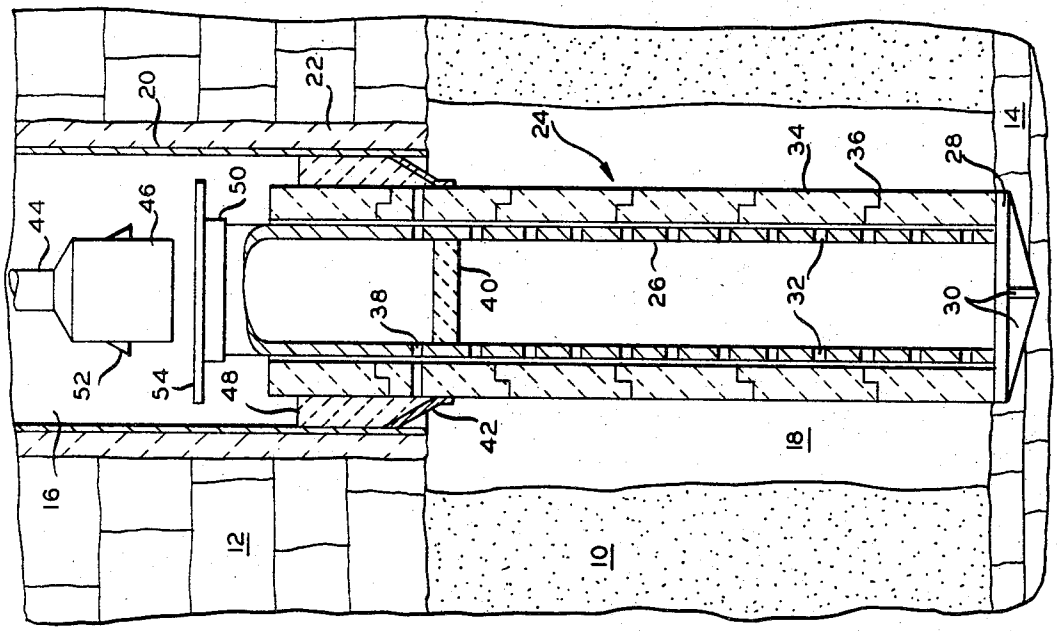


FIG. 1

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WELL COMPLETION FOR EXTREME TEMPERATURES

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ABSTRACT OF THE DISCLOSURE

A well is completed for high temperature service by setting a casing string extending to a level adjacent the top of a producing stratum, cementing the lower end of the casing to the adjacent earth with high temperature refractory cement, forming above ground an assembly of several joints of permeable refractory ceramic pipe end-to-end around an upright perforate metal conduit of smaller diameter than the pipe to form a narrow annulus therewith the joints being cemented together with aforesaid refractory cement, the lowermost joint resting on a support flange fixed to the lower end of the metal conduit, and the assembly being of such length as to reach from the bottom of the well into the lower end of the casing, setting the assembly on the well bottom, and cementing the upper section to the surrounding casing with said cement.

This invention relates to well completion apparatus for high temperature production and to a process for completing a well to be used in such production.

In the production of hydrocarbons from an oil stratum by in situ combustion, wellbore fires occur occasionally and wellbore temperatures reach temperatures in excess of 2000° F. Steel used in normal completions loses its strength at temperatures above about 1400° F. Thus, in wells utilized in an in situ combustion recovery or production operation, there is need for a well completion apparatus arrangement and structure which withstands extremely high temperatures.

This invention is concerned primarily with a downhole arrangement of apparatus and a method for completion of a well with such apparatus which will withstand extremely high temperatures and be effective in producing oil therethru.

Accordingly, a principal object of the invention is to provide an arrangement of apparatus for completing a well for production at high temperatures. Another object is to provide a method for completing a well with an arrangement of apparatus for high temperature production. A further object is to provide an apparatus arrangement and structure and a method of installing same downhole in an oil sand which is effective in the production of oil at high temperatures and in preventing sand invasion of the wellbore. 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 a permeable refractory ceramic liner or conduit within an oil stratum downhole in a well extending upwardly from the bottom of the hole into the lower end of a casing string, said liner being formed of several longitudinal end-to-end sections bonded together with high temperature refractory cement and being cemented to the casing string with a high temperature refractory cement. The lower end of the casing is likewise cemented to the surrounding earth structure with a high temperature refractory cement to withstand fire conditions downhole. A perforated steel liner is positioned within and spaced from the porous

refractory liner or conduit and extends above the upper end of the refractory liner.

The suitable refractory liner used in the structure is available from Variperm Company of Long Beach, Calif. This refractory conduit comes in suitable lengths of about 5' for cementing together into any required length for downhole completion. Variperm is a porous and permeable cement which withstands high temperatures up to at least 3000° F. and is effective in preventing sand invasion of the wellbore.

The method of the invention comprises assembling the required number of joints of the refractory liner on a steel pipe or conduit of greater length than the length of the built-up refractory liner. The joints are cemented together with a special high temperature refractory cement which withstands temperatures up to at least 2500° F. The steel pipe is provided with a plate welded on the bottom end thereof extending radially outside of the pipe as a support means for the built-up ceramic liner. On the bottom of the plate is fixed anchoring means for engaging the bottom of the hole to prevent turning of the assembly during the step of unlatching the setting tool from the upper end of the steel pipe. Squeeze holes are formed in the upper section of the ceramic liner at a level just above the bottom end of the casing for use in cementing the liner to the surrounding casing. The assembly is built up above ground and is lowered into the hole on a suitable setting tool on the lower end of a tubing string. A cement plug is provided within the steel liner or pipe at a level just below the squeeze holes so as to facilitate the cementing of the refractory ceramic liner to the lower end of the casing. This cement plug is preferably installed in the steel liner above ground but may be installed after the assembly is positioned downhole. The cementing-in operation is effected by injecting the predetermined quantity of cement for filling the annulus intermediate the ceramic liner and the casing to a suitable level just below the top of the ceramic liner and the squeeze plug is injected on top of the cement. The cement is then forced downhole with a suitable fluid injected behind the squeeze plug and the fluid is injected until the squeeze plug is driven to the level of the squeeze holes. After the cement has set, the tubing string is rotated to unlatch the setting tool from the upper end of the steel pipe (liner) and the setting tool is withdrawn from the hole.

When assembling the downhole apparatus above ground, a metal petal basket is attached securely to the outside of the ceramic liner just below the squeeze holes to be at the approximate level of the lower end of the casing when the assembly is bottomed in the hole. The petals of the basket are directed upwardly so that, when the cement is squeezed thru the squeeze holes into the surrounding annulus, the outer end of the overlapping petals contact the casing and provide a suitable cement retainer for the cementing-in operation.

The upper end of the steel pipe or liner is provided with means for substantially closing the surrounding annulus to prevent a drill bit from entering the annulus and a drill string with a bit on the lower end thereof is lowered into the wellbore until it enters the steel pipe containing the cementing plug and rotation of the drill string drills out the squeeze plug, the cementing plug, and any cement left in the pipe during the cementing operation. In the event any other equipment used in setting the assembly downhole is left in the steel pipe, this is also drilled out to open the assembly completely for injection and withdrawal of fluids through the permeable cement liner and the perforate steel liner inside thereof.

The preferred high temperature refractory cement utilized in the invention is disclosed and claimed in the co-

pending application of Charles R. Venable, Jr., et al., filed Nov. 29, 1965, Ser. No. 510,403. An illustrative cement composition in accordance wtih the invention in said application consists of 36.49 weight percent calcium aluminate cement, 54.73 weight percent Alundum (fused alumina aggregates of 20 mesh and finer size), and 8.78 weight percent NaCl. The water added to the mix is 2.997 gallons per 100 pounds of mix. This particular cement mix is heat resistant to at least 2500° F., has low porosity, and has low shrinkage under high temperature conditions. These features of the cement render it highly suitable for the cement to be used around the lower end of the casing and in the annulus between the ceramic liner and the casing as well as for sealing the joints of refractory conduit used in building up the refractory liner. Any suitable high temperature refractory cement which has similar qualities may be utilized in this application.

A more complete understanding of the invention may be had by reference to the accompanying schematic drawing of which FIGURES 1 and 2 are sectional elevations through the lower end of a well penetrating an oil sand lying intermediate two shale formations.

Referring to FIGURE 1, an oil sand **10** lies intermediate a shale overburden **12** and a shale substratum **14**. Well **16** penetrates these strata and the sand is underreamed as at **18**. Well **16** is provided with a casing **20** obviously extending to ground level and the usual casing head. The lower end of casing string **20** is cemented in at **22** with a suitable high temperature refractory cement.

The downhole completion equipment assembly **24** comprises a perforate or slotted steel pipe **26** which is joined at the lower end by a plate **28** welded thereto and to this plate is welded triangular shaped fins **30** forming an anchoring means in the well bottom. The length of pipe or steel liner **26** is predetermined so that it extends axially into the lower end of casing **20** a substantial distance. Numeral **32** designates the holes or slots in the steel liner. A series of joints of porous, permeable refractory ceramic or cement conduit **34** are positioned around pipe **26** so that the lowermost joint of ceramic conduit **34** rests on and is supported by plate **28**. Joints **36** in the ceramic liner formed by joints or sections **34** of the ceramic pipe are cemented together with high temperature refractory cement the same as or similar to that utilized at **22**. A sufficient number of joints of ceramic conduit are built up to extend to a level just below the upper end of the steel liner **26**. Squeeze holes **38** and cementing plug **40** are positioned in the assembly **24** for the purpose of cementing the assembly in with respect to the lower end of the casing. A metal petal basket **42**, or other cement retaining device, is firmly fixed to the outer surface of the ceramic liner at a level adjacent the bottom end of the casing so that when cement is forced down tubing string **44** (before disconnecting or unlatching liner setting tool **46**) the annular mass of cement **48** is forced into place, sealing off the annulus outside of the ceramic liner as shown.

The assembly **24** is fabricated above ground by sliding ceramic conduit joints **34** over the upper end of steel liner **26** and cementing the step-down joints with high temperature refractory cement as each is positioned in place around the steel liner. These joints of conduit have an inner diameter of at least ½" and up to 1" larger than the outer diameter of the steel liner so that upon heating to elevated temperatures sufficient expansion room is provided because of the higher coefficient of expansion of the steel liner than that of the permeable cement liner. Cement plug **40** is preferably positioned in the assembly before lowering of the same into the well. After the required number of joints of ceramic conduit have been cemented into position in the assembly, setting sleeve **50** is attached by threading, welding, or other suitable means to the upper end of steel liner **26** and this setting sleeve is provided with conventional means (not shown) cooperative with lugs **52** on setting tool **46** for latching onto the assembly for lowering into the well. Other latching or connecting means, including screw threads may be provided on setting tool **46** and setting sleeve **50** so that after the assembly is set and cemented in and the assembly drilled out, setting tool **46** may be unlocked from sleeve **50** by simply turning the tubing string or drill pipe **44**. During this operation, vanes **30** on the bottom of plate **28** prevent the rotation of the assembly to permit turning of the setting tool with respect to sleeve **50** and the assembly.

An annular plate **54** is attached by any suitable means, such as welding or threading, onto the periphery of setting sleeve **50**. This annular plate closes a substantial portion of the annulus surrounding the upper end of the assembly so that when a rotary drill bit is lowered on the drill string **44** (after removal of setting tool **46**) to drill out the squeeze plug, residual cement, and cementing plug **40**, the drill bit does not enter the annulus but must enter the steel pipe **26**.

Referring to FIGURE 2, corresponding elements are correspondingly numbered to those of FIGURE 1. Assembly **24** is similar to that shown in FIGURE 1 but it is provided with a different setting mechanism including a collar **60** attached to the upper end of sleeve **26**, which is provided with shear pins **62** linked to setting tool **64**. Setting tool **64** is attached to the lower end of tubing or drill string **44**.

In the embodiment illustrated, refractory cement for sealing liner **34** to casing **20** is enclosed in a suitable rupturable bag **65** in the form of an annulus surrounding the assembly just above metal petal basket **42**. Before lowering the assembly into the well, an annular section of casing **66** is milled out so that when the cement-containing bag **65** is broken and removed from the annulus, the cement fills the annulus above metal petal basket **42** and flows into milled out section **66** to join cement **22** behind the casing and form a better seal than would otherwise be provided.

With the cement enclosed within a rupturable bag as illustrated in FIGURE 2, the cementing is effected after releasing setting tool **64** from the assembly by exerting downward pressure on the drill string so as to shear pins **62**. After shearing of pins **62** and before withdrawal of the setting tool from the well, the drill string is lowered into the hole sufficiently to rupture bag **65** and free the cement which then fills the annulus and slot **66** in the casing. It is feasible to include rupturing means on the lower end of setting tool **64** which not only ruptures bag **65** but acts as a spear and hook to remove this bag from the hole, thereby freeing the cement of the bag. The lower end of setting tool **64** also serves as tamping means for tamping the cement into place to form a proper seal.

Bag **65** is preferably formed of plastic such as polyethylene and the cement therein is of the proper consistency for setting up in a reasonable setting time into a hard cement.

While it is preferred to utilize a standard metal petal basket attached to the outside of the ceramic cement pipe or liner for a cement retainer, an alternative method comprises utilizing a rubber petal basket, although this would have to be custom made. A special casing shoe with a lip to retain the cement could also be used in place of installing a cement retainer on the liner. Asbestos fibers installed above and below the squeeze holes would help in obtaining a good seal between the cement liner and the casing.

Since the steel pipe inside the permeable cement liner must be free to expand upon heating, it is essential to avoid getting cement between the steel pipe and the cement liner during the cementing operation. This may be done by coating the outside of the steel pipe or liner with heavy, heat-resistant grease before the joints of cement liner are slipped over the steel liner.

The cement-to-cement seal shown in FIGURE 2 is

much less affected by extreme temperatures than the casing-to-cement seal. The downhole assembly and method of the invention can be applied to open hole or perforated casing completions in addition to the application illustrated in the drawing. In open hole operation, it is essential to set a plug in the open hole at the level at which the bottom of the assembly is to be locked, following this plug-setting by lowering the assembly into the hole and proceeding as described above.

The steel pipe **26** may be fabricated of ordinary carbon steel or of any of the high temperature steels known in the trade. Ordinary carbon steel is adequate in view of the fact that the principal purpose of this pipe is to provide a foundation for the assembly, hence, even though the strength of this pipe is greatly reduced by heating or even melted, it does not interfere with the function of the permeable ceramic cement conduit **34**.

In one installation of the invention, casing **20** was 9⅝" I.D., sleeve liner **34** was 7" O.D., and steel pipe **26** was 5" O.D., leaving about ¼" annulus between the ceramic liner and the steel pipe. Ceramic liner **34** was 20' long and extended about 8' into casing **20**.

The downhole assembly illustrated and disclosed herein may be used as a production well either in a reverse or direct drive in situ combustion process or as an injection well in an inverse drive in situ combustion process wherein the combustion zone moves countercurrent to the flow of air and finally arrives at the injection well.

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.

We claim:

1. Apparatus in a well extending into a permeable oil stratum, useful in a hot fluid drive, comprising in combination:

(1) a casing extending to a level adjacent the upper surface of said stratum;

(2) an annulus of high temperature refractory cement sealing the lowermost section of said casing with the surrounding earth formation;

(3) a permeable refractory liner supported from the bottom of said well within said stratum, extending upwardly and axially into the lower end of said casing to form an annulus of substantial thickness with said casing, said liner comprising several longitudinal end-to-end sections bonded together by high temperature refractory cement; and

(4) a mass of high temperature refractory cement filling and sealing a substantial vertical section of the annulus of (3).

2. The apparatus of claim **1** wherein the liner of (3) comprises ceramic aggregates bonded together by high temperature refractory cement.

3. The apparatus of claim **1** including a coaxial perforate steel liner within the refractory liner of (3) forming a narrow annulus therewith and having a radially and outwardly extending flange on its lower end supporting said refractory liner and resting on the bottom of said well.

4. The apparatus of claim **3** including means on the upper end of said steel liner for closing a substantial portion of the surrounding annulus to prevent a drill bit from entering said annulus when directing a drill bit into said steel liner.

5. A method of completing a well extending into a permeable oil stratum which comprises the steps of:

(1) setting a casing string in said well extending to a level adjacent the top of said stratum;

(2) cementing the lower end of said casing to the surrounding earth formation with a refractory cement capable of withstanding temperatures up to at least 2000° F.;

(3) forming above ground an assembly comprising several joints of permeable refractory ceramic pipe end-to-end around an upright perforate metal conduit of smaller diameter than said pipe to provide a narrow annulus therewith, said joints being cemented end-to-end with refractory cement capable of withstanding temperatures up to at least 2000° F., the lowermost joint resting on a support flange extending outwardly from the lower end of said metal conduit, and the length of assembled ceramic pipe being such that the upper section thereof extends into the lower section of said casing when said assembly is bottomed in said well;

(4) setting the assembly of (3) on bottom in said well; and

(5) cementing said upper section of said ceramic pipe to the surrounding casing with high temperature refractory cement.

6. The method of claim **5** including the steps of:

(6) providing squeeze holes in said pipe and conduit at a level in said upper section of pipe;

(7) attaching cement retaining means around said section below said squeeze holes which engage the adjacent casing;

(8) anchoring a cementing plug within said upper section of pipe and conduit below said squeeze holes;

(9) pumping said cement down a tubing string leading into said assembly and forcing said cement thru said squeeze holes into the surrounding annulus; and

(10) drilling out any cement remaining in said assembly after step (9) and the cementing plug of step (8) to open the well to flow into and out of said stratum.

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