United States Patent

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[54] **WELL COMPLETION METHOD**
17 Claims, 9 Drawing Figs.

[52] **U.S. Cl.** **166/276,** 166/278, 166/288, 166/294
[51] **Int. Cl.** **E21b 43/04**
[50] **Field of Search** 166/285, 288, 292, 294, 302, 303, 276, 278

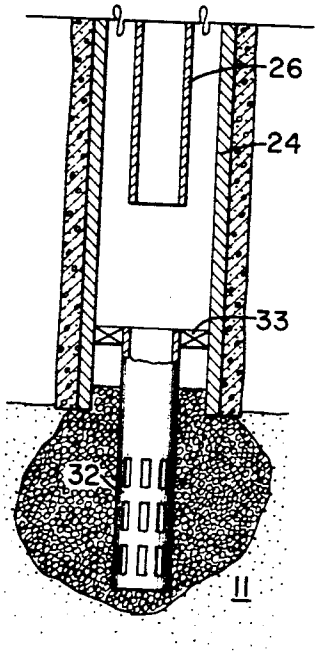
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ABSTRACT: A method of completing wells in unconsolidated formations by forming a temporary consolidated zone in the formation. The consolidated zone provides a relatively rigid framework which facilitates drilling operations and location of production equipment. With the production equipment located, the consolidated zone is returned to its original unconsolidated condition.



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SHEET 1 OF 2

FIG. 1

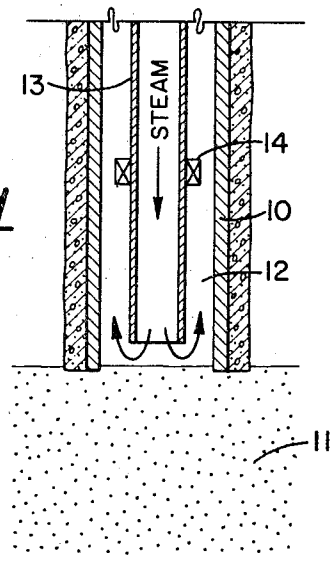


FIG. 2

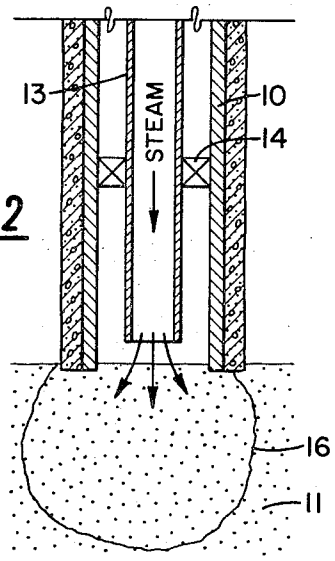


FIG. 3

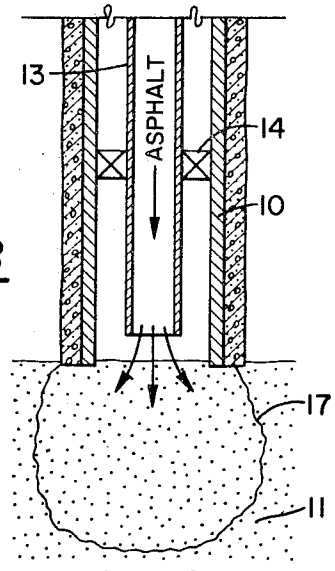


FIG. 4

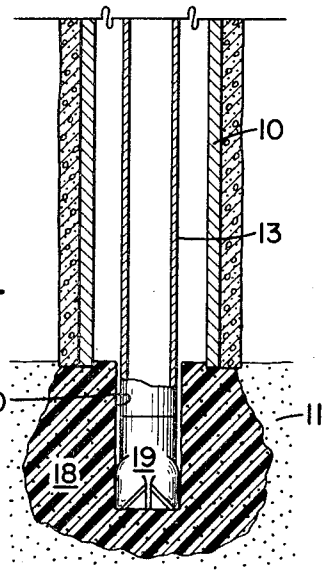
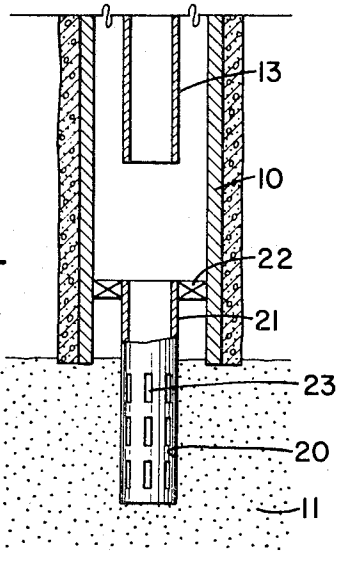


FIG. 5



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FIG. 6

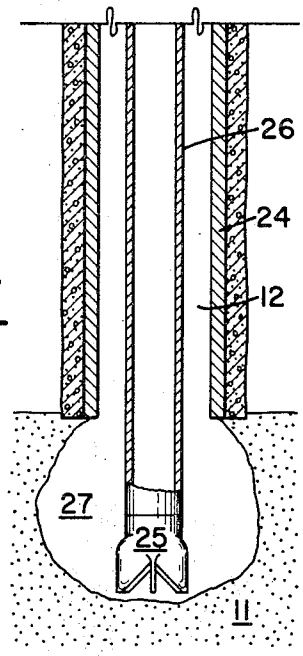


FIG. 7

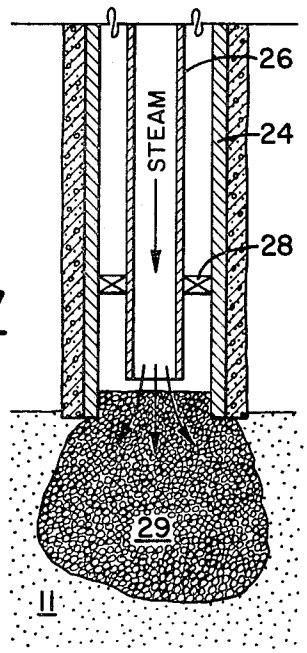


FIG. 8

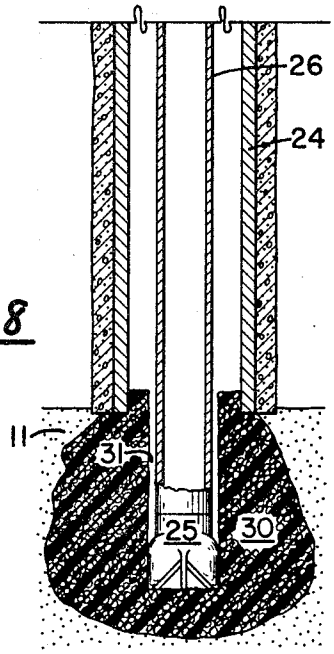
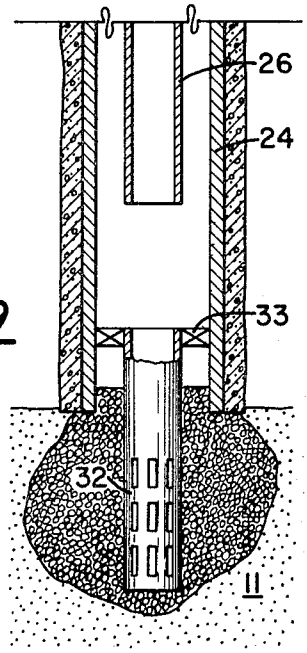


FIG. 9



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WELL COMPLETION METHOD

BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention relates generally to well completions and more specifically to well completions in unconsolidated formations.

2. Description of the Prior Art

In completing oil, gas, and injection wells in unconsolidated formations, consideration must be given to sand control problems likely to arise during operation of the well. Conventionally, sand control has been effected by the use of mechanical bridging devices such as production liners placed opposite the producing interval of the formation. Sand consolidation by thermosetting plastics has also been proposed but this technique inherently results in some reduction in permeability and therefore is not applicable in all types of formations.

For the purpose of this disclosure, the term unconsolidated formation describes a subterranean stratum composed of poorly cemented plastics or sand particles. The incompetent porous media, lacking a matrix to bind the particles into a rigid framework, exhibits a strong tendency to slough or cave into the open hole. This tendency is particularly pronounced when using rotary drilling techniques to advance a borehole through the formation. The circulating drilling fluids wash out large cavities which, because of the incompetent nature of the wall, tend to slough or cave in even after drilling has ceased.

It is considered poor practice to locate the production liner through a cavity for several reasons—the caving of upper unsupported formations can result in pipe failure; sloughing sand and shale can cause the well to "sand-up"; the high vertical permeability in the immediate vicinity of the liner can result in premature coning of water or gas.

A conventional approach to alleviate many of the problems associated with unconsolidated formations is to complete the well by a technique known as gravel packing. Aggregate material such as gravel is packed in the washed-out section providing a support for the incompetent well. A typical gravel pack completion comprises a perforated liner disposed opposite the pay interval and packed in particularly-sized gravel. The gravel pack, in addition to supporting the cavity wall, provides a sand exclusion zone for bridging sand particles entrained in produced fluids. One of the main sources of difficulties in performing the gravel pack completion is the placement of the liner at the proper location in the packed zone. A variety of liner placement techniques have been developed, the more common of which are the wash-down method, reverse-circulation method, and crossover method. These methods are difficult to perform requiring special equipment and special manipulative skills. Thus it will be appreciated that the gravel pack completion is expensive and is therefore employed only after it is definitely established that a sand problem exists.

SUMMARY OF THE INVENTION

The present invention provides a method for completing wells either initially or by way of workover, in unconsolidated formations. This invention finds particular application in locating a production liner or other support medium in the open hole, but can also be used to aid in gravel packing operations.

Basically, the present invention contemplates the following manipulative steps: forming a consolidated zone in the unconsolidated formation; advancing a borehole into the consolidated zone; placing a support medium in the borehole capable of conducting fluids; and returning the consolidated zone to the unconsolidated condition whereupon the formation particles pack around the outer periphery of the support medium.

The step of forming a consolidated zone can be achieved by injecting a molten consolidating material into the formation and causing the material to setup thereby providing a relatively rigid framework for the ensuing drilling step. The borehole wall, resulting from the drilling step, is characterized as competent and of uniform diameter. The step of placing a support medium in the borehole can be effected by placing a producing tube, commonly referred to as a liner, in the borehole, or by packing the borehole with an aggregate material such as gravel. The final step of returning the consolidated zone to the unconsolidated condition can be accomplished by removing the consolidating material from the consolidated zone. Once the consolidating material is removed, the formation particles in the immediate vicinity of the borehole settle, packing tightly around the outer periphery of the support medium. Thus completion of a well by the method of the present invention results in the placement of a liner or other support medium in a packed interval without resort to presently known gravel packing techniques.

In the preferred embodiments of the invention, the consolidating material is a thermosensitive material which exhibits the property of plasticity. The material is injected into the formation in the molten state and permitted to cool below its melting point thereby forming a relatively rigid matrix which binds the formation particles into a cohesive mass. Bituminous material such as natural or petroleum asphalt is ideally suited for the application contemplated. Asphalt is an aromatic substance closely related to the hydrocarbon fluids indigenous to the formation and therefore should be compatible therewith. Furthermore asphalt is available in a variety of grades having a wide range of properties. By selecting the proper grade, asphalt can be tailored to meet the requirements of a particular well. It should be noted however that the present invention is sufficiently broad to include other materials such as thermoplastics and petroleum waxes which exhibit the required properties.

DESCRIPTION OF THE DRAWINGS

FIGS. **1—5** are diagrammatic views illustrating in sequential order the completion of a well in an unconsolidated formation; and

FIGS. **6—9** are diagrammatic views illustrating the novel completion method used in connection with gravel pack operations.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

With reference to FIG. **1**, an oil string **10** is shown set at the top of an unconsolidated formation **11**. In locating the oil string **10** as depicted, a wellbore **12** is drilled to the top of the formation **11** by conventional equipment and techniques. The oil string **10** is run to the top of the formation **11** and cemented in place. The drilling mud is then replaced with completion fluid such as oil-base mud or salt water, preparatory for commencing completion operations. The completion method according to the present invention will be described separately in connection with (1) locating a production liner through the producing interval of the formation and (2) gravel packing in-place a production liner through the producing interval.

With the oil string **10** set and with the drilling fluid replaced with completion fluid, a conventional technique for completing the well in the unconsolidated formation **11** involves drilling through the producing interval and suspending a production liner in the oil string **10**, portions of the liner extending into and substantially through the producing interval. However, it has been found that when drilling the unconsolidated formation **11**, a large washed-out cavity is formed so that the liner, when located, has peripheral portions opposite the washed-out section, creating the adverse conditions discussed above. Also the tendency of the incompetent formation to cave in and slough during running in operations impedes the proper placement of the liner. From an operational point of view, it is desirable that the liner be located close to the formation face so as to preclude sloughing when the well is placed in operation.

In order to avoid the adverse condition described above, the present invention in the preferred embodiment contemplates the injection of a consolidating material into the formation to cement the discrete sand particles into a competent body. Thus when the formation **11** is penetrated by a drill string, a rigid-walled wellbore is formed. The relatively rigid framework provided by the consolidating material facilitates the drilling of the formation and the placement of the production liner. Finally, the consolidating material is removed permitting the sand grains to pack tightly around the production liner and reestablishing fluid communication between the wellbore and the undisturbed portions of the formation **11**. The packing of the sand grains around the liner sets up a "sand bridge" much in the manner of a gravel pack, providing a sand exclusion zone through which produced fluids pass.

A preferred consolidating material for use in this invention is a thermoplastic characterized as having the property of firmness or hardness at the normal subsurface temperature of the formation **11** and the property of high mobility fluidity at temperatures substantially above the normal formation temperature. A wide variety of materials meet this basic requirement. In order that the thermoplastic material be sufficiently hard at the normal subsurface temperature, the material should be selected to have a melting point in the range from about 20° F. to about 50° F. above normal subsurface temperature. The selection of the proper material will depend upon the particular conditions of each well. Natural and petroleum asphalts are ideally suited for the application in oil and gas wells because of their penetration qualities, low melting points, and rheological properties. Asphalt is an aromatic substance closely related to the hydrocarbon fluids indigenous to the formation **11** and therefore should not damage the formation. Certain asphalts, termed asphalt cement, exhibit a plasticlike quality being firm or hard at low temperatures and highly mobile at high temperatures. Asphalt fuses at a temperature in the range from about 100° F. to about 200° F. and can readily be used in formations having normal subsurface temperatures in the range from about 80° F. to about 180° F. It is available in a number of grades having a wide range of properties which make it a versatile consolidating material.

In accordance with the preferred mode for performing this invention, then, asphalt heated to a temperature above its melting point is injected into formation **11** and is permitted to cool forming a consolidated zone **18** (see FIG. 4). In order to maintain the asphalt in the molten state, it is preferred that the wellbore and subsurface equipment be heated to an elevated temperature prior to asphalt injection. Accordingly, hot fluid such as steam is circulated down the tubing **13** and up the tubing casing annulus (see FIG. 1). The steam increases the temperature of the subsurface equipment to a value substantially above the melting point of the asphalt, preferably in the order of from 50° F. to 300° F. thereabove.

After the downhole equipment is heated, a packer **14** provided on the tubing **13** is set and steam is injected into the formation **11**. Injection is continued until a zone indicated by line **16** is heated to a temperature substantially above the melting point of the asphalt (see FIG. 2). With the subsurface temperature thus increased, the hot asphalt is pumped down the tubing **13** and injected into the formation **11**. The mobility and penetration property of the asphalt at the elevated temperature (preferably in the range from about 50° F. to about 300° F. above the melting point of the asphalt) permit substantial invasion of the asphalt into the formation **11**, the outer limits of the invasion indicated by line **17** (see FIG. 3). After the asphalt is placed, the packer **14** is released and completion fluid is circulated to accelerate the cooling of the injected asphalt. The temperature of the injected asphalt is reduced to a value below its melting point forming a consolidated zone **18** (see FIG. 4). The asphalt in the consolidated zone **18** sets up thereby cementing the sand grains together forming a relatively rigid framework which can readily be drilled out. A drill bit **19** is then run on the tubing **13** for drilling through the consolidated zone **18**. As shown in FIG. 4, the advancement of the drill bit **19** through the consolidated zone **18** leaves in its wake a competent, self-sustaining borehole **20**. The drill bit **19** is then pulled and a production liner **21** is run and located as shown in FIG. 5. The production liner **21** is conventional, having a packer **22**, if desired, for hanging the liner and being provided with perforations such as vertical slots **23**. The size of the bit **19** and the liner **21** are selected so that the clearance between the wall of the borehole **20** and the outer periphery of the liner **21** is as small as possible. While the liner **21** provides the support medium in this embodiment, other techniques are available. For example, aggregate material can be packed in the borehole **20** thereby providing support for the borehole wall.

The final step in the completion operation is the removal of the consolidating material from the immediate vicinity of the borehole **20**. Prior to setting the liner **21**, a hot fluid such as steam, water, or completion fluid is circulated past the exposed formation face and/or injected into the formation **11**. An asphalt solvent or diluting substance such as diesel oil or other suitable aromatic solvent can be incorporated in the fluid to facilitate liquefying the asphalt. When the consolidated zone **18** has been heated to a temperature above the melting point of the asphalt, the liner **21** is set and the well placed on production. The liquid asphalt is flushed into the borehole **20** along with produced fluids. Alternatively, the liquid asphalt can be removed from the immediate vicinity of the borehole **20** by injecting the hot fluids into the formation **11** forcing the asphalt radially outwardly from the borehole **20**. If the alternate procedure is used, it is advisable to incorporate sufficient solvent or diluent in the fluid to prevent the asphalt from taking on a set as it is cooled to the normal formation temperature. Removal of the consolidating material permits the sand grains in the immediate vicinity of the borehole **20** to pack tightly around the outer periphery of the liner **21**.

While the heating steps of this invention can are preferably performed by using steam, it is recognized that other heating means are available, such as electric heaters, hot water or hot completion fluid. Because of its high heat content, steam is the preferred heating medium, particularly for wells designated for steam injection. Steam injection is generally applied in heavy oil reservoirs which are usually characterized by shallow depth, poorly consolidated formations of the type considered herein. The availability of steam at the wellhead makes team an economically attractive heating medium.

In the embodiment of this invention relating to gravel pack completion (FIGS. **6—9**), the manipulative steps of the invention are generally the same as those described above. A portion of the formation **11** in the vicinity of the wellbore **12** is replaced with an aggregate material such as gravel, so that at the beginning of the completion according to this invention the porous media comprises an undisturbed zone and a gravel pack zone. As before, the basic invention comprises the steps of injecting a consolidating material into the porous media; causing the consolidating material to harden thereby forming a consolidated zone; advancing a borehole into the consolidated zone; setting a production liner in the borehole; liquefying the consolidating material; and removing portions of the liquefied consolidating material from the consolidated zone.

With reference to FIGS. **6—9**, the well is drilled to the top of the formation **11** and an oil string **24** set and cemented in place. A bit **25** is run on tubing **26** and, after the drilling fluid is displaced with completion fluid, the formation **11** is penetrated. The circulating completion fluid washes out a large cavity **27** (see FIG. **6**). After the bit **25** is pulled the tubing **26**, providing with a packer **28**, is run preparatory for commencing the gravel pack operations. Gravel is squeezed into the cavity **27** forming a tightly packed zone **29** (see FIG. **7**). With this accomplished, the completion technique described above is followed. Steam displaces the completion fluid and is circulated to heat up the subsurface equipment. The packer **28** is then set and steam is injected into the packed zone **29** in-

creasing the temperature thereof to a value greater than the melting point of the asphalt. Hot molten asphalt is then injected into the packed zone **29** substantially filling the pores thereof. The asphalt is then permitted to cool to a temperature below its melting point whereupon it sets up forming a relatively firm consolidated zone **30** (see FIG. **8**). Completion fluid can be circulated down the tubing **26** and up the tubing-casing annulus to accelerate the cooling of the asphalt. After the asphalt has hardened, a borehole **31** is advanced into the consolidated zone **20**. Because of the rigid framework provided by the asphalt, the wall of the borehole **31** is characterized as competent and of relatively uniform diameter. A production liner **32** is then placed in the borehole **31** (see FIG. **9**). Finally, the asphalt is liquefied by heating the consolidated zone **30** which can be accomplished by circulating steam through the liner **32** prior to setting the liner packer **33** if used. Thus, when the well is placed on production the liquefied and dispersed asphalt will be produced into the borehole **31** along with the produced fluids. Sufficient portions of the asphalt must be removed to reestablish fluid communication between the borehole **31** and undisturbed portions of the formation **11**. Removal of the consolidating material returns gravel in the immediate vicinity of the borehole **31** to the unconsolidated condition. This causes gravel to settle around the outer periphery of the liner **32** forming a tightly-packed interval.

The final heating step can be performed by the use of steam or by other available subsurface heating means such as electric heaters, the injecting of hot water, asphaltic solvent and diluent, etc.

An alternative gravel pack procedure involves the placement of a slurry of gravel and asphaltic material in the cavity **27**. Following the initial heating step described above, the slurry is placed in the cavity **27** and permitted to cool to a temperature below the melting point of the asphalt. The asphalt takes on a set forming the consolidated zone **30**. With this accomplished the gravel pack completion described above is followed.

Thus it has been demonstrated that the present invention provides a completion method which effectively avoids the difficulties previously experienced in completing wells in unconsolidated formations.

I claim:

1. A method of completing a well in an unconsolidated formation comprising the steps of:

a. forming a consolidated zone in said formation;

b. advancing a borehole into said consolidated zone;

c. placing a support medium in said borehole, said support medium being capable of conducting fluids; and

d. returning the consolidated zone to the unconsolidated condition whereupon the formation particles pack around the outer periphery of said support medium.

2. A method of completing wells in a subsurface formation comprising the steps of:

a. injecting a consolidating material into said formation at an injection temperature such to maintain said material in the molten state;

b. causing said material to harden thereby forming a consolidated zone in said formation;

c. advancing a borehole into said consolidated zone;

d. setting a production liner in said borehole;

e. liquefying said consolidating material; and

f. removing portions of said liquefied consolidating material from the consolidated zone to increase fluid communication between the borehole and the undisturbed portion of said formation.

3. The invention as recited in claim **2** wherein said consolidating material is a thermosensitive material exhibiting the property of plasticity, said material being flowable at said injection temperature and hard at the normal subsurface temperature of said formation.

4. The invention as recited in claim **3** wherein said thermosensitive material has a melting point in the range from about 20° F. to about 50° F. above said normal subsurface temperature, and said injection temperature is in the range from about 50° F. to about 300° F. above said melting point temperature, said step of causing said material to harden being effected by cooling said injected material to a temperature below said melting point.

5. The invention as recited in claim **4** wherein the step of liquefied said consolidating material is performed by heating said consolidated zone to a temperature greater than said melting point.

6. The invention as recited in claim **3** wherein said thermosensitive material is asphalt.

7. The invention as recited in claim **2** wherein the step of removing said liquefied consolidating material is performed by producing said well whereby said consolidating material flows into the borehole along with fluids indigenous to said formation.

8. A method of completing a well in a subsurface formation comprising the steps of:

a. heating a zone of said formation to a temperature substantially greater than the normal subsurface temperature of said formation;

b. injecting into said heated zone a thermoplastic consolidating material at an injection temperature such to maintain the material in the molten state;

c. cooling the injected consolidating material sufficiently to impart a set thereto thereby forming a consolidated zone in said formation;

d. advancing a borehole into said consolidated zone;

e. setting a production liner in said borehole;

f. heating said consolidated zone sufficiently to liquefy said consolidating material thereby establishing communication between the borehole and the undisturbed portion of said formation;

g. flushing said liquefy consolidating material out of said consolidated zone.

9. The invention as recited in claim **8** wherein said thermoplastic material is asphaltic material having a melting point in the range of from about 100° F. to about 200° F., said asphalt being adapted for use in formations having a normal subsurface temperature of at least 20° F. less than the selected asphalt and wherein step (a) increases the temperature of said zone to a value greater than said melting point, step (b) is performed at a temperature greater than said melting point, step (c) reduces the temperature of the injected asphalt to a value below said melting point, and step (f) increases the temperature of said consolidated zone to a value greater than said melting point.

10. The invention as recited in claim **9** wherein step (a) is performed by injecting steam into said formation.

11. The invention as recited in claim **10** wherein step (c) is performed by circulating a cooling fluid through said borehole.

12. The invention as recited in claim **11** whereby step (f) is performed by injecting a fluid having a temperature greater than said melting point into said consolidated zone.

13. The invention as recited in claim **12** wherein said fluid contains a material capable of dissolving and diluting said asphalt.

14. The invention as recited in claim **13** wherein step (g) is performed by injecting steam into said formation whereby said liquefied asphalt is displaced radially outwardly from said borehole.

15. The invention as recited in claim **12** wherein step (g) is performed by placing said well on production wherein said liquefied asphalt is produced into said borehole along with fluid indigenous to said formation.

16. A method of completing a well in a subsurface formation comprising the steps of:

a. advancing a borehole into said formation;

b. enlarging said borehole to form a cavity;

c. filling said cavity with a slurry composed of a molten thermoplastic material and an aggregate material;

d. causing said thermoplastic material to harden thereby forming a consolidated zone in said cavity;

e. advancing a borehole into said consolidated zone;
f. setting a production liner in said borehole produced by step (e);
g. liquefying said thermoplastic material; and
h. producing said well whereby portions of said liquefying thermoplastic material are produced along with fluids indigenous to said formation.

17. The invention as recited in claim 16 wherein said thermoplastic material is asphalt.