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Eickmeier

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[54] **METHOD FOR PRODUCING HIGH HYDROGEN SULFIDE CONTENT GAS WELLS**

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[52] **U.S. Cl.** **166/303**

[51] **Int. Cl.** **E21b 43/24**

[58] **Field of Search** 166/302, 303, 57; 299/5, 299/6

[56] **References Cited**

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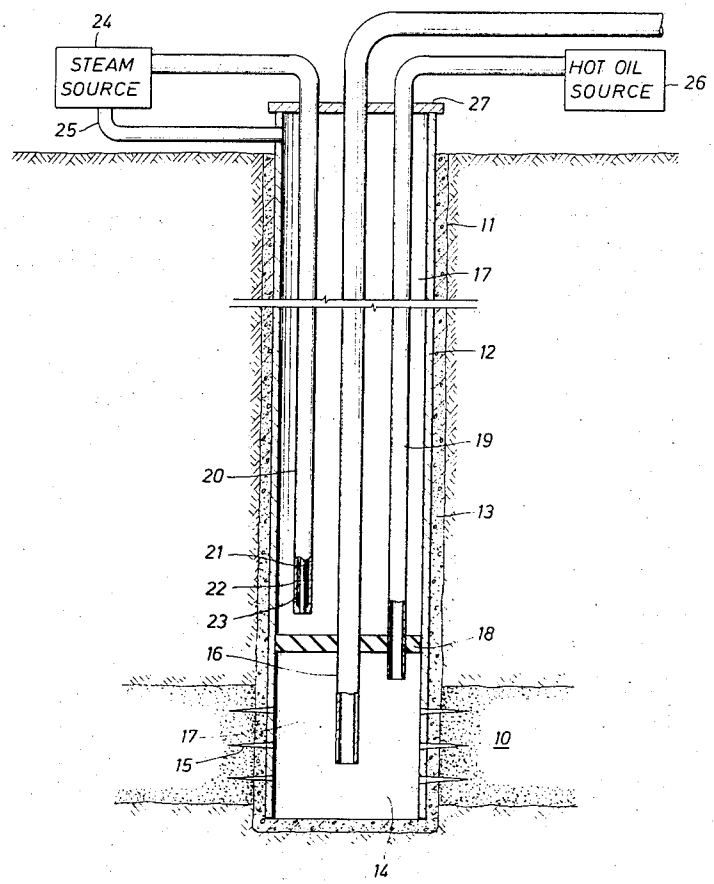
Primary Examiner—Stephen J. Novosad

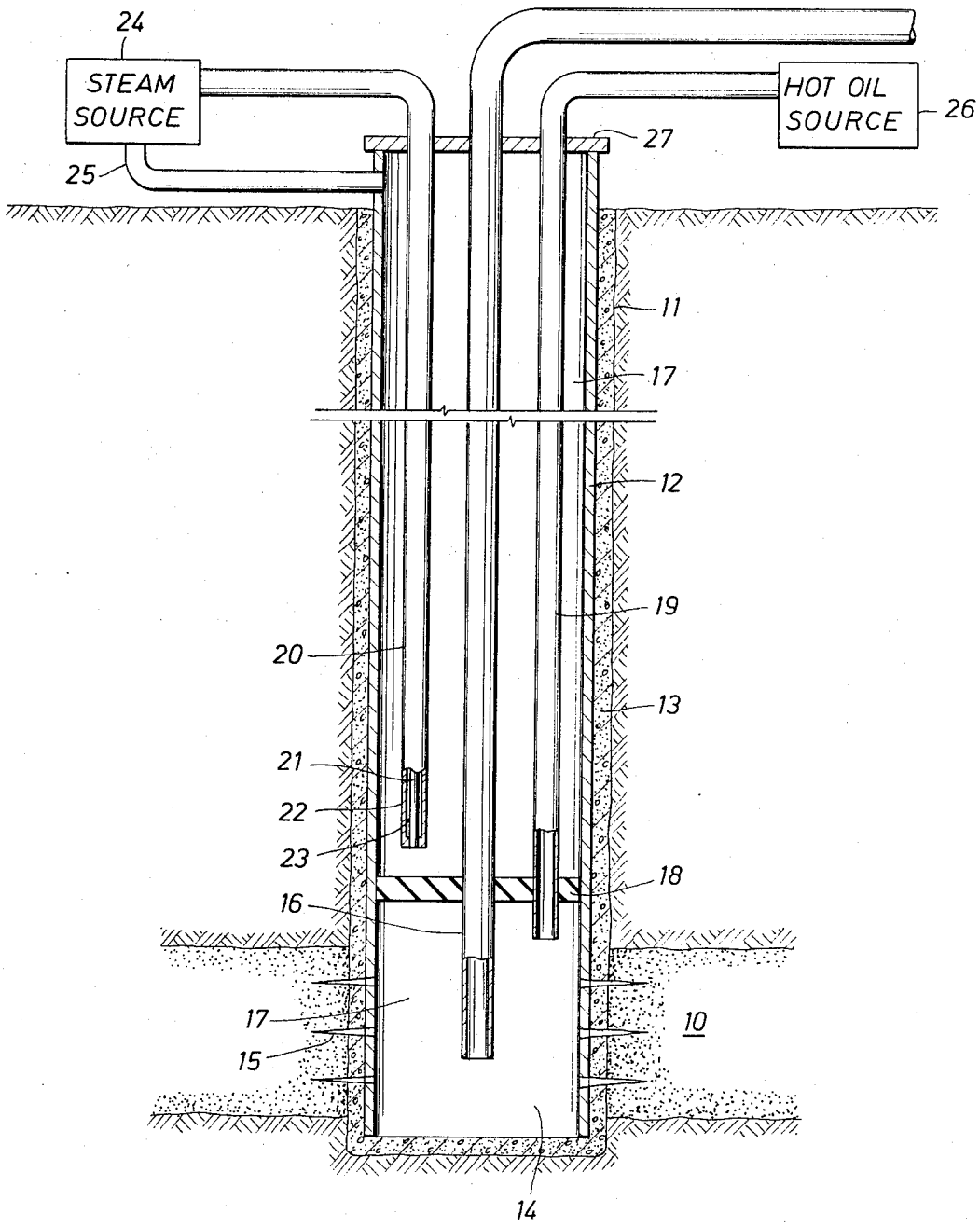
Attorney, Agent, or Firm—Tom M. Moran

[57] **ABSTRACT**

Sulfur precipitation in the production tubing string of wells producing gas with a high hydrogen sulfide content is reduced by circulating a hot fluid down an insulated circulating tubing string and up the casing-production tubing annulus to heat produced fluid in the production tubing string and, simultaneously, injecting a hot oil into produced fluid adjacent the productive interval to dissolve precipitated sulfur and/or otherwise prevent sulfur deposition on the inside of the tubing string as the hot oil mixes with this fluid and is produced up the tubing string.

10 Claims, 1 Drawing Figure




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STEAM SOURCE
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HOT OIL SOURCE
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METHOD FOR PRODUCING HIGH HYDROGEN SULFIDE CONTENT GAS WELLS

BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention relates to a production technique for producing gas from wells and, more particularly, to a technique for producing gas having a high hydrogen sulfide content through wells.

2. Description of the Prior Art

In producing hydrocarbon-hydrogen sulfide mixtures from subsurface reservoirs containing fluid having a hydrogen sulfide (H_2S) content on the order of 70 to 100 per cent, elemental sulfur associated with the fluid tends to deposit in the tubing string which carries fluid from the reservoir to the surface. As surfur-containing, hydrogen sulfide-hydrocarbon fluid flows upwardly through the tubing string the pressure on the fluid decreases due to the reduction of the static head in the fluid column. The temperature also tends to decrease. Under these changed pressure-temperature conditions the solubility of elemental sulfur dissolved in the reservoir fluid decreases markedly and sulfur tends to come out of solution and crystalize on the tubing string causing plugging of the pipe. Plugging by sulfur deposition can become so severe as to cause stoppage of the recovery of fluids from the production well.

It has been suggested, for example see U.S. Pat No. 3,393,733 to C. H. Kuo et al, that such sulfur deposition may be prevented by injecting a hot fluid miscible with the reservoir fluid into the production tubing string near the productive interval. This injected fluid mixes with he reservoir fluids and the combined fluid is produced up the tubing string. The injected miscible liquid dissolves sulfur as it forms in the tubing or by other means prevents sulfur from depositing on the tubing. Injected fluid temperature and rate are determined to satisfy the condition that injected fluid take into solution, or otherwise transport to the surface, all sulfur which precipitates in the tubing.

This prior art production technique has the disadvantage that injected fluid, which is generally more dense than produced fluid, is required in such quantity as to significantly increase the pressure gradient in the tubing string. This imposes an increased back-pressure on the productive formation and results in decreased well deliverability. In addition, the large amount of elemental sulfur contained in the injected fluid must be separated from that fluid at the surface if the sulfur is to be recovered or if the solvent is to be reused. This may require a substantial amount of separating equipment and attendant expense.

SUMMARY OF THE INVENTION

It has now been found that sulfur-containing fluid can be produced from a subsurface formation without plugging of the production tubing from sulfur deposition by flowing the fluid to the surface through a production tubing string while heating the flowing sulfur-containing fluid indirectly by heating the production tubing string and thereby conductively heating the flowing fluid. For example, heat may be supplied to the production tubing string from electric heating coils disposed around the tubing string or by circulating a hot fluid into the well and into contact with the exterior of the production tubing string. The flowing sulfur-containing fluid may be concurrently heated directly by injecting a hot sulfur-solvent into the well and into contact with the produced sulfur-containing fluid.

According to a specific embodiment of the method of invention, a well bore extending from the surface to a formation of interest containing a fluid having a high hydrogen sulfide content is at least partially lined with a large diameter tubular casing and is completed so as to be in fluid communication with the formation. A first string of tubing, a production tubing string, is then extended into the well to a point adjacent the bottom of the productive formation. The casing-production tubing string annulus is packed off with a pack-off means set above the productive formation and a second string of tubing, a hot-oil injection string, is extended into the well bore and through the pack-off means to connect this hot oil injection string in fluid communication with the packed-off interval of the well bore opposite the productive formation. A third string of tubing, an insulated circulating string, is then installed in the casing-production tubing annulus so as to extend throughout a major length of the annulus above the pack-off means.

Hydrogen sulfide rich fluid may than be produced from the productive formation through the production tubing string. Simultaneously, a hot fluid, such as steam having a temperature about 300° F, is circulated down the insulated circulating tubing string and up the casing-production tubing annulus in an amount sufficient to heat the produced fluid in the production tubing string and thereby maintain the temperature of this fluid above a pre-determined minimum temperature, which is preferably above the melting point of sulfur. Concurrently, a fluid in which sulfur is soluble, such as a light substantially sulfur-free crude oil, advantageously can be injected down the injection tubing string into the packed-off interval of the well bore and produced up the production tubing string with the reservoir fluid in an amount sufficient to dissolve precipitated sulfur, or to otherwise prevent sulfur deposition, on the inside of the production tubing string as the hot oil mixes with the produced fluid and is produced up the production tubing string.

When operating according to this method the amount of sulfur solvent injected down the injection tubing string is substantially reduced in comparison to that used in prior art methods. This reduction is achieved because the sulfur carrying capacity of oil and produced fluids is increased at higher temperatures, because the sulfur which is formed at temperatures above the melting point of sulfur may be of such a nature that it will not readily plug the production string, and because the method will result in higher flowing pressures which will result in less sulfur formation in the production string.

The method results in higher flowing pressures in the production string because the reduced solvent injection requirement results in lower density fluid flowing in the tubing string. Heat transfer from the annulus into the production tubing also lowers the density of the flowing fluid and contributes to higher flowing pressures.

At these higher flowing pressures, the cooling associated with flashing of well fluids does not necessarily occur in the tubing string since it is possible to flow the well while maintaining minimum tubing flowing pressure above the bubble point pressure of produced fluids. Because of the lighter fluid column in the tubing

string wells demonstrate greater deliverability and greater ultimate recovery. At the resulting higher production rates the produced fluids contribute more of the total heat required to offset well bore heat losses and thereby reduce the amount of heat required to be injected down the circulating tubing string.

BRIEF DESCRIPTION OF THE DRAWING

The Drawing shows a view, partly in cross-section, of an earth formation penetrated by a well suitably equipped for the practice of this invention.

DESCRIPTION OF PREFERRED EMBODIMENT

Referring to the drawing, we see a subsurface, fluid-containing earth formation **10** penetrated by a well **11.** The well **11** is provided with equipment of a type suitable for the practice of an embodiment of this invention. The well **11** may be completed in a conventional manner. For example, a casing **12** may be run from the surface into the well to a point adjacent the bottom of the formation **10** and fixed in place with a cement **13.** The well bore hole **14** may be opened into communication with the formation **10** by perforating the casing **12** and cement **13** with a number of perforations **15.**

To produce a fluid having a high hydrogen sulfide content from the formation **10** according to this embodiment of the invention, a production tubing string **16** may be run into the bore hole **14** to a point adjacent the productive formation **10.** The annular space **17** between the production tubing string **16** and the casing **12** may then be packed off above the productive interval **10** with a suitable pack-off means such as packer **18.** The packer **18** is preferably of a type adapted for use in dually completed wells and is preferably made from materials which are resistant to H_2S corrosion.

A second string of tubing, a hot oil injection string **9,** may be extended into the well bore and connected in fluid communication with the production tubing string **16** at a point sufficiently deep to provide for the injection of hot oil-solvent into the produced fluid stream before sulfur precipitation occurs. The connection between the hot oil injection string **19** and the production string **16** may be made in any suitable manner. For example, if the packer **18** is of the type used in dual completions, the hot oil injection string **19** may be extended through the packer **18** thus connecting the hot oil injection string **19** in fluid communication with the packed-off interval of the bore hole **14** adjacent the formation **10** and, through the packed-off interval, into fluid communication with the production tubing string **16.**

A third tubing string, advantageously, an insulated circulating string **20** may be installed in the annular space **17** between casing **12** and production tubing string **16** throughout a major length of that annulus **17** above the packer **18.** The circulating string **20** for best results extends into the annulus **17** to a sufficient depth such that by circulating hot fluid down the circulating string **20** and p the annulus **17** the temperature of substantially all produced fluid in the production string **16** is maintained above a desired minimum which is advantageously above the melting point of sulfur.

The circulating string **20** may be insulated in any suitable manner. For example, the circulating string **20** may comprise two concentric tubing strings **21** and **22** with a closed annular space **23** between the strings **21** and **22.** The annular space **23** may be filled with a low pressure gas or with other suitable insulating material. Insulation of circulating tubing string **20** minimizes heat transfer to the borehole **14** and surrounding earth formations as a heated fluid passes down the circulating string **20** from the surface of the earth. The circulating tubing string **20** may be connected in fluid communication with a source of heated fluid such as steam source **24.** This steam source **24** is preferably connected in fluid communication with the bore hole **14** near the earth's surface, as by a conduit224, so that fluid which flows down circulating string **20** may be returned to the steam source by flowing up the annular space **17** and through the conduit **25.**

The injection tubing string **19** may be connected at the surface in communication with a source of a solvent capable of carrying to the surface elemental sulfur which may tend to precipitate in the production tubing string **16.** For example, the injection tubing string may be in communication with a source of hot oil **26.** The casing **12** is preferably closed at the surface with a suitable well head closure assembly **27.**

According to this embodiment of the invention, hydrogen sulfide-rich fluid is produced from the formation **10** through the production tubing string **16.** Simultaneously, a hot fluid such as steam having a temperature about 300° F is circulated from steam source **24** down the insulated circulating string **20** and up the casing-production tubing annulus **17** in an amount sufficient to heat the produced fluid in the production tubing string and, thus, maintain the temperature of this fluid above a pre-determined minimum temperature which is advantageously above the melting point of sulfur. The total amount of heat required at the bottom of the circulating string **20** may be determined by considering heat losses to the equipment in the well **11** and to formations penetrated by the well as fluid moves down the circulating tubing **20** and by considering the desired minimum temperature to be maintained in the produced fluid.

This minimum temperature, which is advantageously in the range of 150° to 250° F, is selected to minimize the amount of sulfur coming out of solution in the well annulus. The required temperature, of course, varies with the properties of the produced fluid. Important considerations in determining the desired minimum temperature are that the sulfur carrying capacity of oil and produced fluids is increased at higher temperatures, and that sulfur formed at temperatures approaching and above the melting point may be of such a nature that it will not readily plug the production string. To maintain the desired minimum the annulus **17** is advantageously maintained at a minimum temperature within the range of about 180° F to about 250° F along its entire length.

To supplement heat circulated down the circulating tubing string **20,** a sulfur solvent, for example light crude oil of about 35° API gravity heated to a temperature in the range of about 250° to 450° F, may be concurrently injected down the injection tubing string **19** from hot oil source **26** and into the packed-off interval of the bore hole **14** adjacent the formation **10.** In many wells the fluid in the formation **10** is a liquid at prevailing conditions of temperature and pressure. The hot oil, therefore, mixes miscibly with this produced fluid and is carried up the production tubing string **16** along with the reservoir fluid. As the mixture of fluids moves up the production tubing string **16,** the pressure and temperature of the flowing fluids may be lowered tend-

ing to cause sulfur to precipitate. The hot oil dissolves or otherwise carries to the surface this sulfur which might otherwise be deposited in the well bore. Therefore, the hot oil is preferably injected down the production tubing string **16** in an amount at least sufficient to dissolve precipitated sulfur or otherwise prevent (as by providing heat to the produced fluid) sulfur deposition on the inside of the production tubing string **16** as the hot oil mixes with the produced fluid and is produced up the production tubing string **16.** However, in order to reduce the increased fluid pressure gradient in the production tubing string **16** caused by the relatively high density hot oil, the amount of hot oil injected should be as low as possible to achieve the desired results. In many wells, injection of hot oil may not be necessary since sufficient heat to prevent sulfur deposition in the production tubing string **16** may be supplied through the circulating tubing string **20.**

By reducing injection of hot oil and by heating fluid in the production tubing string **16,** operating according to the present invention provides a produced fluid column lighter than that obtained in prior art production methods. This results in higher flowing pressures in the tubing **16.** At such higher flowing pressures the considerable cooling associated with the flashing of produced fluid from the liquid to the gas phase may not occur in the tubing string **16.** It may be possible to flow the well **11** while maintaining minimum flowing pressure throughout the production tubing string **16** above the bubble point pressure of the reservoir fluid. This significantly reduces the precipitation of sulfur in the well **11.** Additionally, the well **11** may demonstrate greater deliverability and greater ultimate flowing recovery as a result of the lighter fluid column in the tubing string. Also, injected heat requirements are reduced since reservoir fluids are produced more rapidly and therefore lose less heat to the well **11.**

The embodiment of the invention in which an exclusive property or previlege is claimed are defined as follows:

1. A method for preventing sulfur deposition in the production tubing string of a well producing a sulfur-containing fluid from a subterranean earth formation which comprises:

flowing the sulfur-containing fluid from the earth formation to the surface through the production tubing string; and

simultaneously heating the production tubing string by circulating a heated fluid into the well through an insulated string of pipe and up the casing-production tubing annulus to thereby indirectly heat the flowing sulfur-containing fluid in the production tubing string.

2. The method of claim **1** where the hot fluid is steam.

3. The method of claim **1** where the heated fluid has a temperature sufficient to maintain the temperature of the flowing sulfur-containing fluid above the melting point of sulfur.

4. The method of claim **1** including the step of injecting a hot sulfur-solvent into the flowing sulfur-containing fluid through an injection tubing string connected in fluid communication with the production tubing string at a point below a pack-off means in the said well.

5. The method of claim **4** where the hot sulfur-solvent is a heated light crude oil.

6. The method of claim **4** wherein the hot sulfur-solvent is heated to a temperature in the range of 250° to 450° F.

7. A method of producing a fluid having a high hydrogen sulfide content from a fluid-containing subsurface earth formation through wells without plugging the wells with sulfur precipitate which comprises the steps of:

providing a well bore extending from the earth surface to the subsurface earth formation;

lining at least a part of the well bore with a tubular casing;

completing the well bore in fluid communication with the subsurface earth formation;

extending a production tubing string into the well-bore to a point adajacent the subsurface earth formation whereby an annulus is defined between the tubular casing and the production string of tubing;

packing off the annulus with a pack off means set at a point in the well bore above the subsurface earth formation to prevent fluid flow up the annulus from the subsurface earth formation;

extending an insulated circulating tubing string into the annulus to a point above the pack off means;

producing fluid having a high hydrogen sulfide content up the production tubing string from the subsurface earth formation;

and simultaneously circulating a hot fluid down the insulated circulating string and up the annulus to heat the produced fluid in the production tubing string and thereby retard sulfur precipitation in the production tubing string

8. The method of claim **7** including the steps of:

extending an injection tubing string into the well bore;

connecting the injection tubing string in fluid communication with the production tubing string at a point adjacent the top of the subsurface earth formation; and

injecting a hot sulfur-solvent down the injection tubing string whereby the hot sulfur-solvent mixes with the produced fluid in the production tubing string and is produced up the production tubing string along with the produced fluid to carry to the surface sulfur which may precipitate from the produced fluid in the production tubing string.

9. The method of claim **7** wherein the step of extending an insulated tubing string into the annulus comprises extending concentric tubing strings into the annulus and filling the annular space between these concentric strings with an insulating material.

10. A method for preventing sulfur deposition in the production tubing string of a well producing a sulfur-containing fluid from a subterranean earth formation comprising the steps of;

flowing the sulfur-containing fluid from the production zone to the surface through the production tubing string;

heating the outside of the production tubing string to heat the sulfur-containing fluid flowing through the production tubing string to retard sulfur deposition from the flowing fluid; and

injecting a hot sulfur-solvent into the flowing sulfur-containing fluid through an injection tubing string at a point below a pack-off means in said well.

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PO-1050
(5/69)

UNITED STATES PATENT OFFICE
CERTIFICATE OF CORRECTION

Patent No. 3,796,265 Dated March 12, 1974

Inventor(s) JAMES R. EICKMEIER

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

The Patent should read:

"[30] Foreign Application Priority
August 19, 1971, Canada 120,935"

Signed and sealed this 22nd day of October 1974.

(SEAL)
Attest:

McCOY M. GIBSON JR.
Attesting Officer

C. MARSHALL DANN
Commissioner of Patents