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[54] **METHOD FOR ENHANCING THE RECOVERY OF OIL USING STEAM STIMULATION PROCESS**

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[58] **Field of Search** 166/263, 303, 272

[56] **References Cited**

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[57] **ABSTRACT**

In a "huff and puff" type steam stimulation process for enhancing the recovery of oil from an underground formation, amounts of caustic material such as sodium hydroxide are added to the steam in concentrations greater than 500 parts per million, resulting in further enhancement of recovery.

25 Claims, No Drawings

METHOD FOR ENHANCING THE RECOVERY OF OIL USING STEAM STIMULATION PROCESS

BACKGROUND OF THE INVENTION

This invention is directed to enhancing the recovery of petroleum oil from underground reservoirs.

More particularly, the invention is directed to such enhancement utilizing a steam stimulation process in which steam is periodically injected into an underground reservoir through a well communicating thereto.

Steam stimulation processes in which steam is periodically injected into an underground reservoir, then not injected, are well known in the art, and are often referred to as "huff-and-puff" processes. In such processes, steam is injected into a well for a certain period of time. Then, steam injection is temporarily terminated and well fluids including oil (along with water and steam) are produced from the well. Production is later terminated and steam injection is resumed for a further period. Steam injection and production are alternated for as many cycles as desired.

A variation of this type of steam stimulation process includes soaking the steam in the formation following injection thereof. In accordance with this variations, steam is injected, then the formation is allowed to soak with the steam therein, and then well fluids are produced through the well. Further cycles are then performed which include steam injection, soaking if desired, and production.

Steam stimulation of the huff and puff type, as described above, is effective in many instances to enhance the recovery of petroleum oil. This invention is directed to such a process which includes the addition of additives in the steam which further and importantly enhance the production of oil from the well.

SUMMARY OF THE INVENTION

The invention relates to a huff and puff steam stimulation method wherein very small amounts of a caustic material such as sodium hydroxide are included in the injected steam. Inclusion of such additive in the small amounts contemplated by the invention has been found to be quite useful in enhancing the production of oil, both in terms of increasing the initial rate of production and in terms of increasing the total amount of oil recovered.

In accordance with the invention, at least **500** parts per million caustic material is added to steam, and the steam is injected into the underground reservoir through a well. After steam (including the caustic material) has been injected for a certain period of time, steam injection is terminated and production of oil (including at least some water and steam) through the well is commenced. The first stimulation cycle is completed upon termination of production, and this cycle is repeated with as many similar cycles as desired.

Alternatively, following injection of the steam including caustic material, the steam may be allowed to soak into the formation. Then the cycle is completed by producing well fluids following such soaking. This cycle is repeated as many times as desired.

The invention also contemplates the provision of an optimum level of caustic concentration in the injected steam. For many contexts of use, this level has been determined to be about 2000 parts per million of caustic material.

In accordance with other embodiments of the invention, steam having a higher caustic content is injected during the first few cycles. Then the caustic content of the steam is reduced and the steam injection and production cycles are repeated as many times as desired.

Here again, in accordance with these additional embodiments of the invention, optimum levels of caustic content are determined, and in many contexts of use it has been found desirable to employ a steam having a caustic concentration of about 6000 parts per million for the first couple of cycles, and thence employ a steam having a caustic concentration of about 2000 parts per million.

DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

The invention has been summarized above, and will now be explained in terms of certain preferred embodiments which represent the best mode of the invention known to the inventors at the date of this application.

The description of these embodiments of the invention will assume an underground reservoir containing petroleum oil in formations therein, with a well communicating from the earth's surface to said reservoir.

In accordance with a first embodiment of the invention, steam is provided proximate said well. Such steam may be either "dry" steam (substantially 100% vapor) or "wet" steam (mixture of vapor and liquid). A suitable caustic material such as sodium hydroxide is then added to the steam in a convenient manner so that the concentration of the sodium hydroxide in the steam is at least 500 parts per million, based on the weight of water used to make steam.

If the steam is wet steam, NaOH in aqueous solution may be added to the liquid phase of the steam. If the steam is dry steam, a separate aqueous solution of NaOH may be supplied for use therewith.

The steam, containing NaOH, is then injected for a first period of time through the well into the underground formation. At the end of the first period of time, injection of steam is terminated.

Then, for a second period of time, well fluids including oil are produced through the well. Some amounts of water and steam will be produced with the well fluids.

The steam injection period and production period constitute the first cycle of the process in accordance with the invention.

The length of the injection and production periods will depend on the particular properties of the well and the size and nature of the reservoir, etc. As one example, the first period may be that time required for injecting **40,000** barrels of steam, and the second period may be that time required for producing any desired number of barrels of well fluids, or might be based upon any convenient time period, for example twice as long as the time of the injection period.

The cycle including steam injection and production may then be repeated as many times as desired, for example 12.

The NaOH content of the steam injected in this embodiment should be, as mentioned above, at least about 500 parts per million. It is believed that for most contexts of use the point of diminishing returns is reached at about 6000 parts per million and, in fact, greater enhancement of recovery begins to lessen at concentrations much above 6000 parts per million. Applicants have tested concentrations as high as 15,300 parts per million and have found that, under the conditions of

those tests, enhancement of recovery did occur but was not as pronounced as such enhancement at about 2000–6000 parts per million.

In fact, in many contexts of use, applicants have found that the optimum level of NaOH content is about 2000 parts per million, with respect to enhancement of recovery of total oil. It is believed that a somewhat higher concentration of about 6000 parts per million is optimum in the circumstances tested, with respect to initial rate of recovery of oil.

Thus, in accordance with another embodiment of this invention, the concentration of NaOH in the injected steam is decreased from an initial level to about 2000 parts per million, after the first few cycles. Specifically, in accordance with such a preferred embodiment, the NaOH content is maintained at about 6000 parts per million for the first couple of cycles, and then is reduced to about 2000 parts per million for several additional cycles. This procedure will result in many contexts of use, in maximizing both the initial rate of recovery, and the total recovery of oil in place.

In accordance with yet another embodiment of the invention, steam containing caustic is injected for a first period of time, and then the steam injection is terminated. Following termination of the steam injection, production from the well is not immediately commenced. Rather, the steam is allowed to soak in the formation for a period of time. Following a soaking period, then production is commenced and the production is continued for a desired period of time. In accordance with this embodiment, one cycle is represented by the injection period, the soaking period, and the production period.

The first cycle may then be repeated as many times as desired, for example 12.

In accordance with this embodiment of the invention, the caustic concentration of the steam may be similar to that listed in the above discussion in connection with the former embodiments, and may be decreased as explained above after the first few cycles.

Applicants have performed several laboratory experiments to simulate field conditions, and the following examples are taken from these laboratory experiments. These examples, which should not be considered as limiting, illustrate the remarkable enhancement of recovery, both in terms of rate of recovery and total recovery, as compared to traditional steam stimulation processes.

EXAMPLE I

A physical model of a confined quarter five-spot was prepared for laboratory use and equipped with an expansion chamber. A single port was provided for injection and production.

The expansion chamber served to prevent excessive buildup of pressure during the injection period. With the expansion chamber, unconfined fluid movement during the injection period could be accurately simulated.

The model was filled with Ottawa quartz sand, and was saturated with a known amount of oil and water. The oil was crude from the Olig-Potter zone of McKittrick field in California, which has a viscosity of about 17,000 cp at 75°F. The water was filtered water from the Kern River area of California.

Wet steam containing approximately 70% vapor and approximately 30% liquid was provided. This steam was injected into the model for a time period of two minutes. The injection rate was 175.2 cc/minute, corresponding to 1047 barrels/day. The total steam injected during this cycle totaled an equivalent of 39,600 barrels, or about 7.5% of a model pore volume.

The steam injection was then terminated, and production of fluids from the model was commenced. This production was continued for a period of 4 minutes, the fluids produced being cooled through a condenser, and collected in a container for analysis. Then the production period was terminated marking the end of a first cycle. The oil and water were recovered and measured. 11 additional cycles just like the first were then performed, with the amount of oil and water recovered on each cycle being separately collected for measurement.

The production at the end of the 4th, 7th, 10th and 12th cycles was measured. At the end of the twelve cycles, the model was cleaned and the amount of oil remaining in the model was measured from the cleaning fluids. In this experiment and all the others which are enumerated below, the sum of the oil produced and the amount calculated as residual oil was required to be within 2% of the original oil in place, or else the results were not considered valid. In each of these examples, such sum was correct to within 2%.

The temperature at various points in the model was also measured during the experiment, such measurements being made at 16 points at the top and bottom of the model, and at six points in the middle of the model.

The initial oil saturation was measured at 91.5%.

The results were chartered and the oil recovery at certain time intervals is reported in Table 1.

EXAMPLE II

Example I was repeated for a second control run, all parameters being the same as mentioned in Example I, except that the initial oil saturation was measured at 89.7%.

Once again, measurements were taken at the end of the 4th, 7th, 10th and 12th cycles, and the results tabulated in Table 1.

The results from both Example I and Example II show that the percent of original oil in place recovered at the end of 12 cycles was approximately 2.7%.

EXAMPLE III

Example I was repeated except that the initial oil saturation was measured at 97.3%, and 500 parts per million sodium hydroxide was added to the injected steam.

Measurements like those in Example I were made, and the results are shown in Table 1.

The results of this experiment show that 2.77% of the original oil in place was recovered at the end of 12 cycles, for a 2% enhancement in production relative to the base case.

EXAMPLE IV

Example I was repeated, except that the initial oil saturation was measured at 91.7%, and sodium hydroxide was added to the steam at a concentration of 2000 parts per million.

Measurements taken at the end of the 4th, 7th, 10th and 12th cycles are indicated in Table 1, the total percent of original oil in place recovered at the end of 12 cycles being 15.3%. This represents a 465% increase relative to the base case.

EXAMPLE V

Example IV was repeated except that the initial oil saturation was measured at 85.1%, and the sodium hydroxide concentration was 4000 parts per million.

In this example, as seen from Table 1, the percent of original oil in place recovered at the end of the 12th cycle was 13.7. This represents a 410% improvement relative to the base case.

EXAMPLE VI

Example IV was repeated except that the initial oil saturation was measured at 87.6%, and the sodium hydroxide concentration was 6000 parts per million. As seen from Table 1, 12.2% of the original oil in place was recovered at the end of the 12 cycles. This represents a 350% enhancement relative to the base case.

EXAMPLE VII

Example IV was repeated except that the initial oil saturation was measured at 87.0%, and the sodium hydroxide concentration was 6000 parts per million for the first 2 cycles, and 2000 parts per million for the last 10 cycles.

17.1% of the original oil in place was recovered at the end of the 12 cycles, which represents a 530% improvement relative to the base case.

Further, the rates of recovery at the end of 7 cycles and 10 cycles were significantly higher than for the other experiments.

EXAMPLE VIII

Example IV was repeated except that the initial oil saturation was measured at 89.5%, and the sodium hydroxide concentration was 15,300 parts per million.

As seen from Table 1, 9.4% of the original oil in place had been recovered at the end of the 12 cycles, representing a 250% increase in production relative to the base case.

TABLE 1

Example No.	NaOH Concentration ppm	Initial Oil Saturation %	Percent of OOIP Recovered at: 24 min	42 min	60 min	72 min	Final Percentage Increase in Production Relative to Base Case
I	0.0	91.5	0.26	0.90	2.20	2.70	—
II	0.0	89.7	0.33	0.86	1.80	2.69	—
III	500	97.3	0.42	1.41	2.27	2.77	2
IV	2,000	91.7	8.8	11.5	13.6	15.3	465
V	4,000	85.1	7.3	10.7	12.9	13.7	410
VI	6,000	87.6	9.8	11.4	11.9	12.2	350
VII	6,000/2,000	87.0	11.4	14.5	16.2	17.1	530
VIII	15,300	89.5	3.3	5.7	8.5	9.4	250

As seen from the results tabulated in Table 1, the best results in these laboratory studies were obtained by using 6000 parts per million sodium hydroxide for the first two cycles of the steam stimulation process, and 2000 parts per million for the latter 10 cycles. However, dramatic improvements were shown in each of Examples IV, V, VI, VII, and VIII. The improvement in Example VIII, wherein the sodium hydroxide concentration was 15,300 parts per million was less dramatic than in the other examples. This fact, coupled with the extent of the additional sodium hydroxide required to achieve the concentration level of Example VIII indicates that the optimum sodium hydroxide concentration level for these examples is less than 15,300 parts per million.

In other contexts of use, caustic levels considerably higher than those indicated above might be employed. For example, it is believed that in some contexts of use, caustic levels as high as about 50,000 parts per million might be advantageously employed. The desired caustic content will depend on the physical and chemical properties of the field crude, and the reservoir material, and can be determined for each context of use by laboratory experiment or field trial.

Optimization of the sodium hydroxide content will vary from case to case but in most instances for situations similar to these examples it is believed that such optimum concentration would be, based upon a laboratory model, from about 2000 to about 6000 parts per million.

Because of the relatively low chemical adsorption and reactivity of the sand used in the laboratory model, it is believed that sodium hydroxide concentration for use in field applications will need to be considerably greater than those used in the laboratory models. Thus, it is believed for field applications of these examples, the optimum concentration of sodium hydroxide would be somewhere between 2000 parts per million and 15,000 parts per million.

Since rather remarkable enhancement of the recovery of the original oil in place was noted at concentrations up to 15,300 parts per million, applicants believe that it would be prudent in most instances to err on the side of too much rather than too little, sodium hydroxide. This bias will of course be weighed against the availability and cost of sodium hydroxide or other suitable caustic material.

The temperature measurements from Examples I–VIII indicated that when the injected concentration of NaOH was 2000 parts per million or greater, the recorded temperatures in the lower portion of the model were higher and more uniform than when lower concentrations of sodium hydroxide were employed.

At the time of this application, it is believed that the preferred caustic material for most contexts of use is sodium hydroxide. Consequently, the above discussion and all of the above examples have been in terms of NaOH. It is applicants' belief, however, that other suitable caustic materials may be alternatively employed, for example potassium hydroxide, sodium carbonate, and mixtures of the same, or mixtures of sodium hydroxide with either or both of these materials.

It is well known that the art is continually seeking better ways to enhance production of oil, and many of these ways have included the use of steam either in steam stimulation processes or steam flooding pro-

cesses. In Attachment A, which is attached hereto and made a part of this application, applicants have enumerated a number of citations which they consider pertinent to some degree or another in connection with this invention.

In the copending application of Shen, Ser. No. 367,571, filed June 6, 1973, and now U.S. Pat. No. 3,853,178, methods for improving recovery are disclosed in connection with steam flooding processes performed in the context of an injection well and a producing well, wherein small amounts of sodium hydroxide may be added to the steam. In that application, the amounts of NaOH are, in general, even smaller than those added in this invention.

Although the invention has been described in terms of particular preferred embodiments and examples, it will be apparent to those of skill in the art that various changes may be made in the processes described without departing from the scope of the invention.

What is claimed is:

1. A method for enhancing the recovery of oil from an underground reservoir having a well communicating thereto, comprising:
- providing a source of steam for said well;
- adding caustic material to said steam so that the concentration of said caustic material in said steam is in excess of 500 parts per million;
- injecting said steam containing said caustic material into said reservoir through said well for a first period of time;
- terminating the injection of said steam, and thence commencing the production of well fluids from said well;
- continuing the production of well fluids for a second period of time, said first period and said second period defining a steam stimulation cycle;
- terminating said production period; and,
- repeating said steam stimulation cycle several times.

2. The method of claim **1**, wherein said concentration of caustic material is in excess of 2000 parts per million.

3. A method for enhancing the recovery of oil from an underground reservoir having a well communicating thereto, comprising:
- providing a source of steam for said well;
- adding caustic material to said steam so that the concentration of said caustic material in said steam is between about 2000 parts per million and about 15,000 parts per million;
- injecting said steam containing said caustic material into said reservoir through said well for a first period of time;
- terminating the injection of said steam, and thence commencing the production of well fluids from said well;
- continuing the production of well fluids for a second period of time, said first period and said second period defining a steam stimulation cycle;
- terminating said production period; and,
- repeating said steam stimulation cycle several times.

4. The method of claim **3**, wherein the length of said second period is approximately twice the length of said first period.

5. The method of claim **3**, wherein the steam injected during said first period of each cycle is equal to approximately 7.5% of the pore volume of said reservoir.

6. The method of claim **3**, wherein twelve steam stimulation cycles are employed.

7. The method of claim **3**, wherein said caustic material is sodium hydroxide.

8. The method of claim **7**, wherein said sodium hydroxide concentration is about 6000 parts per million.

9. A method for enhancing the recovery of oil from an underground reservoir having a well communicating thereto, comprising:
- providing a source of steam for said well;
- adding caustic material to said steam so that the concentration of said caustic material in said steam is at least approximately 6000 parts per million;
- injecting said steam containing said caustic material into said reservoir through said well for a first period of time;
- terminating the injection of said steam, and thence commencing the production of well fluids from said well;
- continuing the production of well fluids for a second period of time, said first period and said second period defining a steam stimulation cycle;
- terminating said production period;
- repeating said steam stimulation cycle at least one more time;
- providing additional steam for said well;
- adding caustic material to said steam so that the concentration of said caustic material in said steam is approximately one-third that employed during the first steam stimulation cycle;
- injecting said steam containing caustic material into said reservoir through said well for a period of time similar to said first period of time;
- terminating the injection of said steam, and thence commencing the production of well fluids from said well;
- continuing the production of well fluids for a further period of time similar to said second period of time, said further injection and production periods defining a further steam stimulation cycle;
- terminating said production period; and,
- repeating said further steam stimulation cycle several times.

10. The method of claim **9**, wherein the length of said second period is approximately twice the length of said first period.

11. The method of claim **9**, wherein the steam injected during said first period of each cycle is equal to approximately 7.5% of the pore volume of said reservoir.

12. The method of claim **9**, wherein twelve steam stimulation cycles are employed.

13. The method of claim **9**, wherein said caustic material is sodium hydroxide.

14. A method for enhancing the recovery of oil from an underground formation having a well communicating thereto, comrising:
- providing a source of steam for said well;
- adding caustic material to said steam so that the concentration of said caustic material in said steam is in excess of 500 parts per million;
- injecting said steam containing caustic material into said reservoir through said well, for a first period of time;
- terminating the injection of said steam, and thence allowing the steam to soak into the formation for a second period of time;
- thence commencing production of well fluids from said well, and continuing such production for a third period of time;

said first, second and third periods of time defining a steam stimulation cycle;

thence terminating production from said well; and,

repeating said steam stimulation cycle several times.

15. The method of claim **14,** wherein said concentration of caustic material is in excess of 2000 parts per million.

16. The method of claim **14,** wherein

the concentration of said caustic material in said steam is between about 2000 parts per million and about 15,000 parts per million.

17. The method of claim **16,** wherein the length of said third period is approximately twice the length of said first period.

18. The method of claim **16,** wherein the steam injected during said first period of each cycle is equal to approximately 7.5% of the pore volume of said reservoir.

19. The method of claim **16,** wherein twelve steam stimulation cycles are employed.

20. The method of claim **16,** wherein said caustic material is sodium hydroxide.

21. The method of claim **20,** wherein said sodium hydroxide concentration is approximately 6000 parts per million.

22. The method of claim **21,** wherein said sodium hydroxide concentration is reduced to about 2000 parts per million after the first few cycles.

23. The method of claim **22,** wherein the length of said third period is approximately twice the length of said first period.

24. The method of claim **22,** wherein the steam injected during said first period of each cycle is equal to approximately 7.5% of the pore volume of said reservoir.

25. The method of claim **22,** wherein twelve steam stimulation cycles are employed.

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