Sept. 24, 1963 M. H. GASKELL ET AL 3,104,702

RECOVERY OF CELLAR OIL

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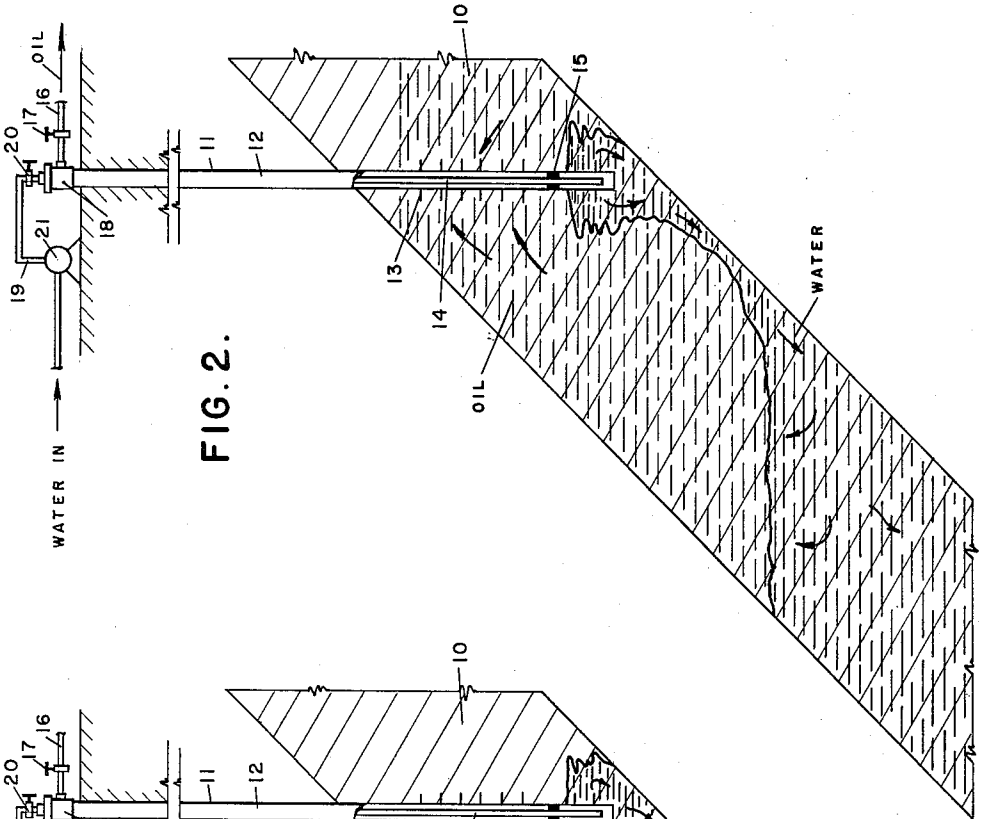


FIG. 2.

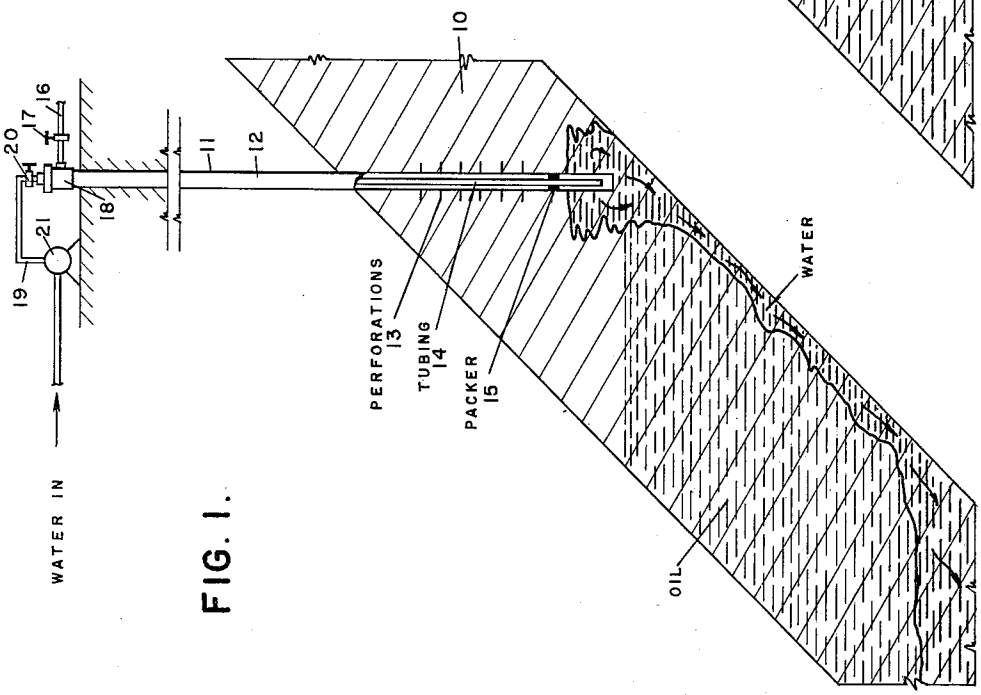


FIG. 1.

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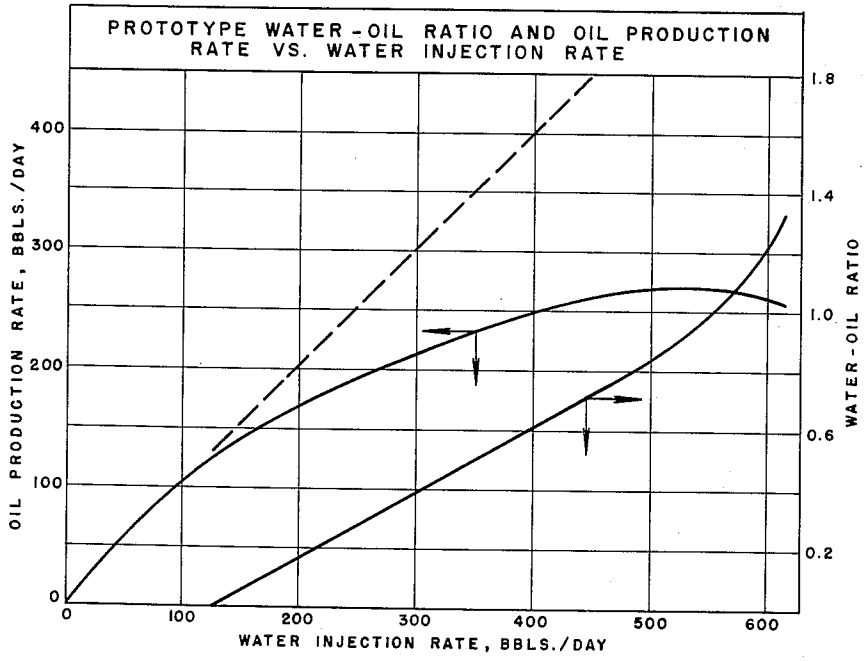


FIG. 3.

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RECOVERY OF CELLAR OIL

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2 Claims. (Cl. 166—9)

This invention concerns recovery of oil located below the structurally lowest well in reservoirs in which a natural water drive is not present.

Small, steeply inclined reservoirs without natural water drives are often found associated with salt domes or other highly faulted structures. Frequently, only one well may be economically justified in these reservoirs and oil is produced from them by an expanding gas-cap drive or by a dissolved gas drive. Although a large fraction of the oil up-structure from the well may be recovered during primary depletion, because of gravity effects, only a small fraction of the down-dip oil can be produced. The down-dip oil is defined as cellar oil in contradistinction to attic oil which is the oil above the structurally highest well in reservoirs where a natural water drive is present.

The method of the invention, the primary object of which is to provide an improved method for recovery of cellar oil, comprises the simultaneous injection of water and production of fluid from a single well in which the lower portion of the productive formation or interval of the well is completed for water injection and the upper portion thereof is completed for production. The fluid production rate is maintained equal to the water injection rate to prevent the oil level from falling below the well or rising into the gas cap.

The above noted object and other objects of the invention will be apparent from a more detailed description of the invention when taken in conjunction with the drawings wherein:

FIG. 1 is a cross-sectional view of the earth's subsurface showing a well penetrating an inclined reservoir and illustrating the mechanics of operation when water is initially injected;

FIG. 2 is a view similar to that shown in FIG. 1 illustrating the mechanics of operation during simultaneous oil production and water injection; and

FIG. 3 is a graph showing plots of oil production rate and water-oil ratio vs. water injection rate.

A series of experiments were conducted with a sand packed lucite model scaled to represent a 30 acre, single well reservoir representative of typical conditions for cellar oil recovery operations to determine if practical water injection and oil production rates could be achieved in certain reservoirs.

The prototype reservoir and the fluids were selected to have the dimensions and physical properties shown in the following Table I.

Table I

Property	Prototype	Model
Length	1,140 feet	36 inches.
Thickness	30 feet	0.95 inch.
Length/thickness	38	38.
Areal extent	29.8 acres	9 sq. ft.
Dip angle	30 degrees	30 degrees.
Porosity	30 percent	37.9 percent.
Permeability	500 md	190 darcies
Oil viscosity	0.384 cp	4.07 cp.
Water viscosity	0.4 cp	4.24 cp.
Oil-to-water viscosity ratio	0.960	0.960.
Density difference	0.346 gm./cc.	0.4407 gm/cc.
Interfacial tension	73 dyne/cm	4.26 dyne/cm.
Connate water	25 percent	9.5 percent.
Residual oil	15 percent	15 percent.
Pore volume	2,083,000 bbl	7650 cc.
Injection rate	1,720 q (bbl/day)	q (cc./sec.).
Time	t/241 months	t seconds.

The model properties also shown in Table I were chosen to satisfy the prototype scaling requirements shown in Table I. The clear lucite model, formed as a rectangular parallelepiped 36 inches long, 36 inches wide, and 0.95 inch thick, was supported at a dip of 30 degree to the horizontal by a wooden frame. With the model in this position, the well was drilled vertically through the geometric center of the sand. The model well bore was scaled to represent a 9-inch well bore and was perforated along the top and bottom third of its length; the middle third was not perforated. The sand packed in the model was a round-grained quartz (Ottawa), 20 to 30 mesh sand. The oil phase was a white mineral oil with a density of 0.812 gm./cc.

The aqueous phase was a solution of sodium nitrate, glycerol, xylene sulfonate spent-caustic product, and polyethylene glycol 300. The sodium nitrate was added to give a density of 1.253 gm./cc., glycerol was added to give a viscosity of 4.24 cp., and xylene sulfonate spent-caustic product and polyethylene glycol 300 were added to lower the interfacial tension to 4.26 dyne/cm.

At the end of each run, the sand nearest the bottom of the model had a high water saturation and a low oil saturation. Above this was a small region of sand with a high oil saturation and a low water saturation. The very top portion of the sand was predominantly saturated with gas, with low saturations of oil and water. The model was under vacuum, as it had to be maintained at subatmospheric pressure at all times to prevent its being deformed.

The model was prepared for the each succeeding experiment without changing its 30-degree angle of dip by first allowing all the mobile liquid to drain from ports located along the bottom. The desired quantity of oil then was injected into these same ports. Carbon dioxide was next injected through the ports and flushed through the oil in order to simulate a gas saturation resulting from solution gas drive, and the pressure was brought to approximately 7 inches Hg absolute. The oil then was allowed to drain to the bottom of the reservoir with the final oil level being in the vicinity of the well bore. At this point the oil-rich zone contained both a connate water saturation and residual gas saturation, and the model was ready for the next experiment.

The process was carried out in the experimental runs by injecting water into the bottom third of the well while oil was produced from the top third. The production rate was controlled with a throttling valve, and the water injection rate was adjusted as closely as possible to the same value with a constant rate pump. When equal injection and production rates had been established, they were continued until the water-oil ratio and the water-front height stabilized. The model was reprepared for each run as described above, and equilibrium production conditions were established at a different injection rate.

In FIGS. 1 and 2 is shown a reservoir **10** penetrated by a well **11** provided with well pipe **12** extending to the earth's surface and perforated as at **13**. A tubing **14** extends through well pipe **12**, and the annulus therebetween is packed off by means of a packer **15** adjacent the lower end of the well. A conduit **16** provided with a valve **17** is connected to a wellhead **18** and fluidly communicates with the annulus. Another conduit **19** provided with a valve **20** is connected to wellhead **18** and fluidly communicates with tubing **14**. A pump **21** is connected to conduit **19**, and in turn fluidly communicates with a source of water supply. As evidenced in FIG. 1, as water is injected into the bottom portion of the well through tubing **14**, a bubble of water forms around the injection perforations. As the injection of water continues, the bubble of water expands upwardly until it

reaches an equilibrium vertical position. At very low rates, the bubble does not reach the top portion of the well, which is the production interval, and consequently only oil is produced. As the injection rate is increased, the bubble of water reaches the production interval, and water begins to be produced. Additional increases in the injection rate increases the water-oil ratio. The oil production rate increases with increasing injection rate at first. However, it eventually reaches a maximum value and decreases thereafter. In FIG. 2, the oil has been displaced upwardly by the water, and as the water is continuously injected, the oil is produced through perforations 13 and the annulus.

The data from the experiments performed are presented in FIG. 3, wherein both the water-oil ratio and the oil production rate are shown as a function of injection rate. For the prototype investigated, the first water was produced at a water injection rate of about 125 bbl./day, and the maximum oil production rate, 275 bbl./day, occurred at an injection rate of 550 bbl./day.

These results show that practical injection and production rates can be achieved in certain reservoirs by the simultaneous injection production technique. Also shown is that there is a critical water injection rate at which water is first produced and an injection rate which results in a maximum oil production rate.

Having fully described the objects, method and operation of our invention, we claim:

1. A method for recovery of cellar oil from an inclined reservoir having no natural water drive and which is penetrated by a well pipe perforated with upper and lower perforations along a portion of its length at a location in said reservoir adjacent the upper level of said cellar oil, said well pipe containing a tubing and means for closing off the annulus between said tubing and said well pipe between the upper and lower perforations in said well pipe comprising the steps of producing fluid from said reservoir through said upper well pipe perforations and said annulus while simultaneously injecting water into said reservoir through said tubing and lower well pipe perforations to maintain oil adjacent said upper perforations, the rates of water injection and fluid production being substantially equal.

2. A method as described in claim 1 in which said fluid consists of both oil and water and said water injection and fluid production rates are selected so as to achieve a maximum oil production rate.

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