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METHOD FOR STORAGE OF PETROLEUM IN NATURAL UNDERGROUND RESERVOIRS

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Fig. 1.

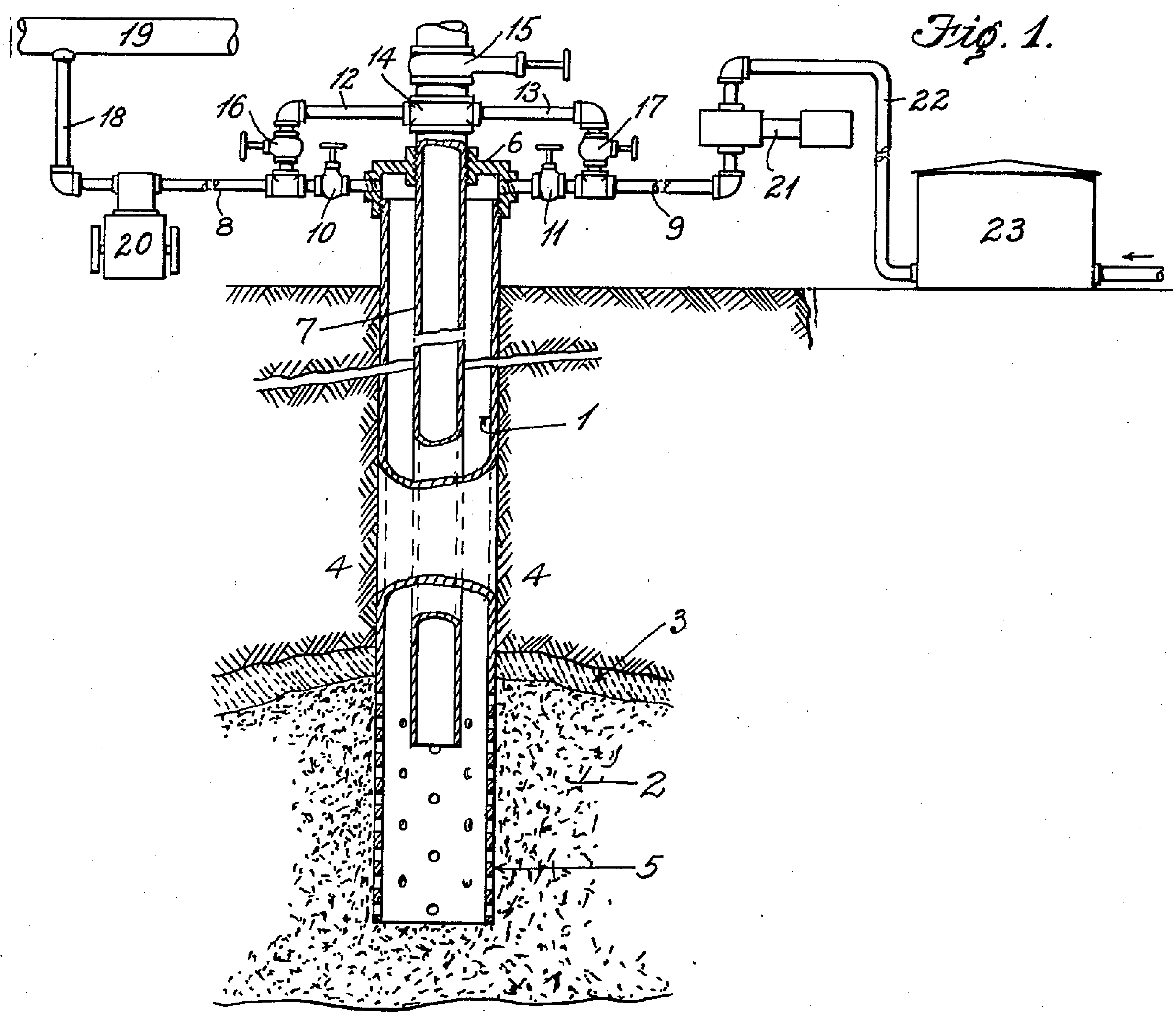
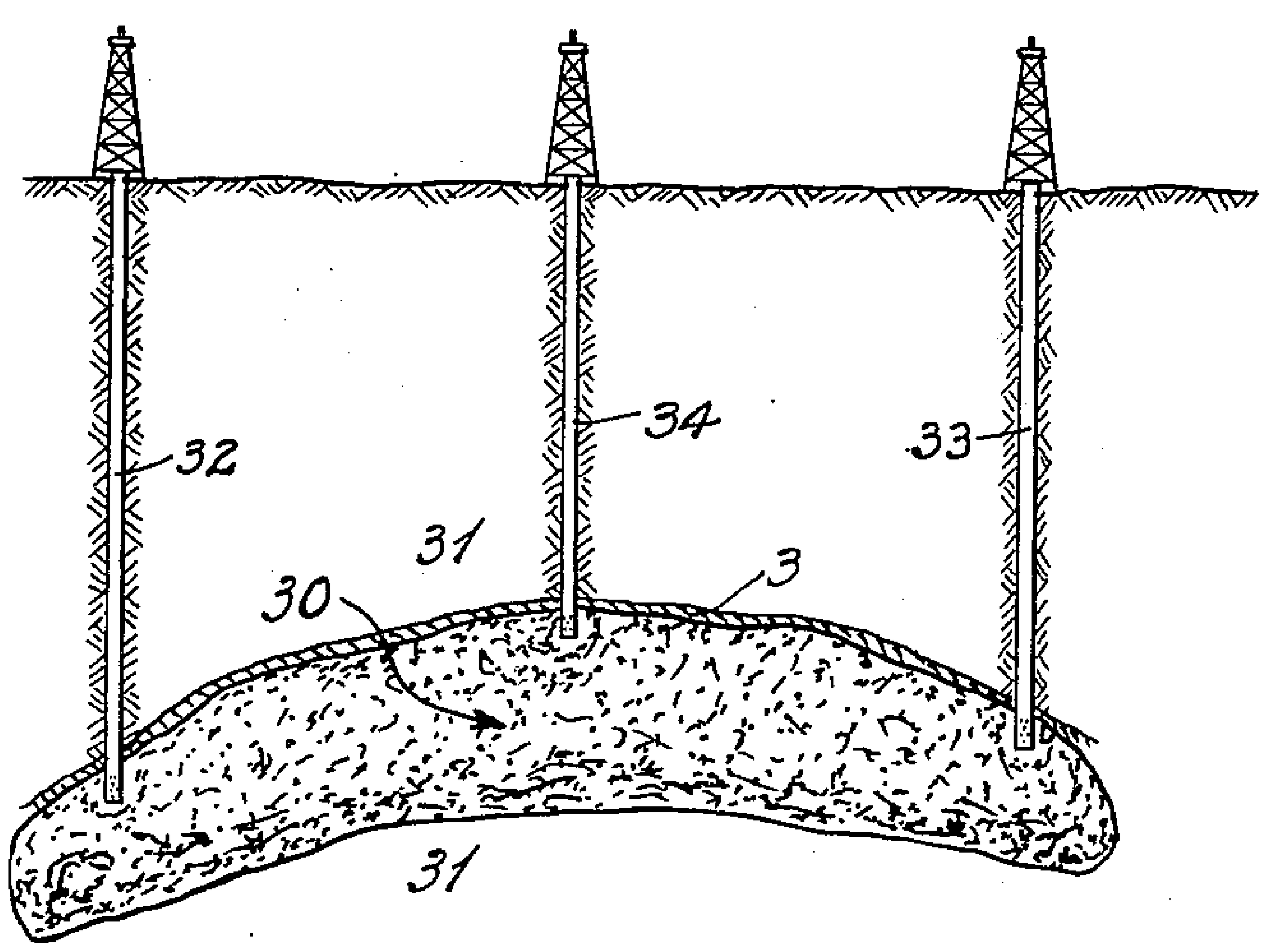


Fig. 2.



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METHOD FOR STORAGE OF PETROLEUM IN NATURAL UNDERGROUND RESERVOIRS

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11 Claims. (Cl. 166—21)

This invention relates to the storage of crude oils or of other oils in depleted or partially depleted natural underground reservoirs.

The storage of crude oil involves the use of steel tanks or concrete reservoirs. When the crude oil contains any material amount of light or volatile oils, the only safe storage, because of fire hazards, is steel tanks with appropriate roofs to minimize evaporation losses. These concrete reservoirs and steel tanks are very costly.

It is an object of this invention to eliminate the expenditure required for the construction of tanks for storage of oils, and at the same time prevent evaporation losses, and eliminate fire hazards. This is accomplished by the use of natural subterranean reservoirs, such as depleted or partially depleted oil pools, in such a manner as will insure the economical recovery of the stored oil from the reservoir.

It is a further object to recover a portion of the residual oil which always remains in the sands of the so-called depleted natural underground reservoirs.

Petroleum in its natural state exists in underground reservoirs, or oil pools, associated with natural gas, and, in the majority of cases, in contact with water either at the edge or bottom of the producing formations. These fluids are contained in the interstices or pore spaces in the rock or sand strata under a pressure. This pressure, termed reservoir pressure, is the resultant of the gas pressure, the rock pressure and the hydraulic pressure, if there is such. Previous to the time when the first well is drilled in such a reservoir or pool, the pressure conditions are at an equilibrium. When a well is drilled and placed on production, a region of lower pressure results at the point where the well bore taps the pool. This causes a pressure gradient from the areas of high pressure toward the well, so that a fluid flow into the well takes place.

The major source of energy in the propelling of the oil from the interstices in the reservoir to the well is the natural gas which is, to a certain extent, dissolved in the oil under the existing pressures, and to a certain degree may exist in a gaseous state.

When the gas pressure is diminished to such a point that it is insufficient to cause the migration of the oil to the well bore and its elevation up the well to the ground level, the reservoir may be said to be depleted or at least partially depleted. It is then usual to introduce a pump into this well and lift the oil mechanically. As an alternative gas may be employed. Although the gas from the formation is insufficient to lift the oil, some residual gas present in the formation usually escapes with the oil when it is pumped or lifted. After a period the oil production by means of the pump or gas lift falls below an economical limit and the reservoir may be said to be exhausted. However, there is considerable oil remaining in the formation. While estimates of the recovery of the oil from oil sands vary, it is safe to say that as an average the maximum recovery of oil from formations containing the oil is but 25% of the total oil originally present. Consequently approximately 75% of the original oil remain in the sands which are thus saturated with oil. This oil is always heavier and more viscous than the oil originally present, because the more volatile fractions and the gas have been removed. The resultant depleted or partially depleted formation may then be spoken of as a sand saturated with oil substantially free from volatile fractions and gas.

We have found that, after the reservoir or pool is partially or economically exhausted of its petroleum and natural gas content, it may be used as a storage reservoir for crude petroleum or fluid petroleum products by the simulation of the former natural conditions. This simulation of the former natural conditions will consist of introducing the oil under pressure into the well or wells of the reservoir or pool either alone, or simultaneously or alternately with substantial quantities of a gas. Many ways are available for such introduction. This gas may be introduced through the same well bore. The oil may be introduced into certain wells and the gas into other adjacent ones, and, after a period, the operation may be reversed so that the oil enters through the bore holes which previously were used for the introduction of gas, and vice versa. This introduction of oil and gas causes the formation of a mixture of oil and gas under pressure in said reservoir, which pressure aids in the subsequent recovery of the mixture.

The partially depleted underground reservoirs are preferably those which are naturally sealed against the loss of both oil and gas pressure. If an unsealed natural reservoir should be selected, the oil and gas introduced under pressure into such a reservoir would migrate away and be lost. The selection of a reservoir to be used for the storage should be based either on tests to determine whether said reservoir maintains the fluid pressure, i. e. whether or not said pressure is dissipated into the surrounding strata, or on geological data of said reservoir and of the surrounding strata to determine whether said reservoir is surrounded by formations which will prevent the dissipation of the oil and/or gas introduced for storage. As a matter of economy, it is of course desirable to have legal control of the entire reservoir to prevent migration of the gas and oil introduced to parts of the reservoir controlled by others.

Thus, the invention may be stated as residing in the feature of storing liquids, crude oil or of other oils in wholly or partly depleted natural subterranean oil reservoirs or pools, preferably sealed against losses of both oil and gas, this storage of oil being made either alone or in conjunction with the introduction and storage of natural or other gas in substantial quantities for the purpose of aiding the subsequent recovery of the stored oil. The introduction of oil into the oil strata is most conveniently effected through existing oil wells, and where the introduction occurs together with substantial quantities of gas, it may be commingled therewith at the surface or at the bottom of the well, or in the oil stratum itself.

This invention further resides in the introduction of oil into a depleted or partially depleted formation. The oil is advantageously of a lower specific gravity than that of the residual oil remaining in the partially depleted oil pool, for the purpose of increasing the fluidity of the residual oil in the partially depleted strata, so that a greater portion of the oil can be ultimately recovered.

Referring to the drawing which discloses certain embodiments of the invention by way of illustration, and which will aid the understanding of the invention:

Fig. 1 is a diagrammatic vertical section of a well, showing the penetrated natural underground reservoir and showing the connections at the surface of the ground to the sources of oil and gas to be introduced and stored in said natural underground reservoir; and

Fig. 2 is a diagrammatic vertical section of a natural underground reservoir or pool, showing three wells which have been drilled into said reservoir, and which may be variously used for the introduction and subsequent recovery of oil or oil and gas to be stored.

Fig. 1 shows a means for the storage of oil and of gas through a single well. As shown in this figure, the casing 1 penetrates the partially depleted natural reservoir 2 in which the storage of the oil and gas is to be made. This reservoir is preferably properly sealed. Usually, such a reservoir will have an impervious covering, such as for instance shale or cap rock covering 3 to prevent the dissipation of the existing and/or introduced oils and gas into the surrounding formations 4. The lower portion of the casing 1, located in the stratum 2, is perforated as at 5. The upper end of the casing 1 is provided with a closure head 6, through which a tubing pipe 7 passes into the casing 1, said tubing 7 reaching to a point in the neighborhood of the perforations 5. Two pipes 8 and 9 are connected to the upper part of said casing, said pipes carrying valves 10 and 11 respectively. The branch pipes 12 and 13 are connected to a cross fitting 14 provided on the tubing 7. A valve 15 is positioned in tubing 7 above said cross fitting. Valves 16 and 17 are placed in the branch pipes 12 and 13 respectively. Pipe 8 is connected by means of a pipe 18 to a source of gas, such as a gas line 19. A compressor 20 is placed in the pipe 8. Pipe 9 is connected to the discharge end of a pump 21, the suction end of which is connected by means of a pipe 22 to a source of the oil to be stored in the reservoir 2. This may be an oil tank 23 or an oil-conveying line.

Fig. 2 shows one form of a partially depleted natural reservoir or oil pool 30 also preferably sealed to prevent the dissipation of the residual and/or stored oil and gas into the surrounding formations 31. A plurality of wells are assumed to be drilled into said natural subterranean reservoir 30; three such wells 32, 33 and 34 being represented. Well 34 is shown as drilled into the high point of the reservoir, while wells 32 and 33 are shown as drilled further down the slope of the inclined formation.

In the case where only one well is used for the introduction of the oil and gas into a depleted natural reservoir, such as indicated in Fig. 1, the oil and the gas may be mixed at the surface and be introduced into the formation in a mixed state, or they may be mixed at the bottom of the well, or again they may be introduced alternately into the same well so that the oil and the gas to be stored will comingle while passing through the sands of the natural reservoir.

If the gas and oil to be stored are to be mixed at the surface, valves 10 and 11 are closed and valves 16 and 17 are opened. The oil is forced under pressure from tank 23 and pipe 22 through pipes 9 and 13, by means of the pump 21, into the cross fitting 14. At the same time, the compressor 20 forces the gas under the same pressure, from the gas source 19, through pipes 18, 8 and 12, into the same cross fitting 14, where the oil and gas are mixed, a part of the gas being dissolved in the oil under the existing pressure. The oil and gas thus comingled then pass through the tubing 7 and are forced through the perforations 5 into the natural subterranean reservoir 2 to be stored therein.

If the oil and gas are to be mixed at the bottom of the well, either in a mixing device attached to the lower end of the tubing 7 or while passing through the perforations 5 of the casing 1, the oil then may be pumped into the well through the tubing 7 while the compressed gas is being forced in through the casing. Valves 11 and 16 are then closed, while valves 10 and 17 are opened, it being understood that in all cases valve 15 is closed during introduction of oil and/or gas. The oil is then pumped by the pump 21 through the pipe 22, 9 and 13 and tubing 7 into the bottom of the well, where it is mixed with the compressed gas forced by the compressor 20, through the pipes 18 and 8 and the casing 1. The thus comingled oil and gas are then forced through the perforations 5 into the natural subterranean reservoir 2 by means of the pressure exerted by the pump 21 and compressor 20. It is to be observed that this method employs the hydrostatic head of the oil column in 7 to assist the action of pump 21 and that gas in introduced into the formation under a very high pressure, i. e. that of the head of oil in 7 plus the pump pressure. This assists in the dissolving of gas in the oil.

If it is desired to force the oil and gas alternately into the well, the oil is first forced by the pump either through the casing or through the tubing, or through both the casing and the tubing by opening or closing the respective valves 11 and 17. After a predetermined period of time the pump is stopped, valves 11 and 17 are closed, and gas is injected under the necessary pressure from the gas source 19 by means of the compressor 20. This introduction may also be made either through the casing or through the tubing, or again through both, by the manipulation of the corresponding valves. The mixing of the oil and of the gas will occur while the two are travelling through the interstices of the natural underground reservoir 2.

In the case as indicated in Fig. 2, where a plurality of wells drilled into the same natural underground reservoir are to be used for the introduction of oil and of substantial quantities of gas for the purpose of storage, the oil and gas may be introduced into the natural subterranean reservoir 30 through one or more wells 34. Additional quantities of gas may be introduced into the same strata through the wells 32 and 33 at the lower portions of the reservoir. This will cause a better mixing of the gas and oil in the sand since the gas, having a smaller specific gravity will tend to rise to the top of the dome, while the oil and the mixture of oil and gas will tend to occupy the lower portions thereof. It is quite obvious that the oil alone may be pumped into the reservoir 30 through the well 34 and compressed gas introduced through the wells 32 and 33, since the tendency of the two fluids to move due to the difference in specific gravities will cause an intimate mixing of the gas and oil.

It is also within the scope of the invention to introduce oil or a mixture of gas and oil, through the wells 32 and 33, while gas in substantial quantities is introduced through well 34 so that a gas pocket is produced above the oil and in the upper portion of the reservoir. This pocket of gas above the oil in the strata will eventually aid in the recovery of the oil which has been introduced therein or which has remained in the partially depleted reservoir previous to the storage of additional quantities of gas and oil, since the conditions which will be found in such a structure will be similar to the conditions found in structures where the gas under pressure is found in a pocket above the oil and thus drives the latter to the point of lowest pressure, i. e. to the well or wells on production from said oil structure such as wells 32 and 33.

It is obvious that different field conditions and the different objects desired to be obtained will cause the use of one or the other of the above enumerated methods, or other methods, of introducing oil and gas for storage into the partially depleted subterranean reservoirs as will be understood by those skilled in the art. Thus, for example, if it is desired to obtain a good solution of the gas in the oil, the two will be introduced into the sand in a mixed condition or, if a plurality of wells are used, the oil will be forced into the upper portion of the reservoir while the gas will be injected under pressure into the lower portion thereof so that the two will be thoroughly intermixed while passing therethrough due to the difference in specific gravities and due to the pressure exerted on them at the wells. On the other hand if storage is the sole purpose, the oil may be introduced alone to be later recovered from the wells by gas-lift, gas-drive and/or pumping. In this case, it is preferable to use only a few wells located adjacent to each other to that the oil will be found localized and uncontaminated, thus facilitating the ultimate recovery. It is also obvious that the type of formation of the natural underground reservoir will limit, at least as to rate, the total amount of storage capacity and of ultimate recovery of the stored oil and gas.

It is obvious that the pressures required for the introduction of oil and gas into the underground reservoirs will vary with the type and underground configuration of said reservoirs and with the degree or stage to which this storage has progressed. Loose or porous formations will require a smaller pressure for the introduction of oil and gas, while tight or compact formations will require much higher pressures. At the start of the storage operations, the back-pressure is low while at later stages of said operations, when a sufficient amount of oil and gas has been introduced under pressure into the formation, a considerable back-pressure is developed requiring much higher pressure for oil and gas introduction. It is thus obvious that with the progress of the storage operation, greater and greater pressures will be required.

It was found that it is often advisable to introduce an oil of a lower specific gravity than the one naturally contained in the natural underground reservoir being used for storage. The low specific gravity, i. e. the light oil, has a lower viscosity and travels easier through the interstices of the reservoir. The light oil introduced into the formation will also dilute the residual heavier oil remaining in the partially depleted natural underground reservoir, thus lowering the specific gravity of the latter and increasing the ultimate total recovery of oil from said formation. The introduced oil and gas, both due to their lower viscosities and their large amount, materially reduce the viscosity of the originally contained oil. In the passage of the introduced oil and gas through the formation, an intimate mixture and solution of the original oil and the introduced oil and gas occurs. This results in a mixture of reduced viscosity and lower specific gravity, both aiding in the recovery of the oil and gas. Beneficial results may be obtained by heating the oil or gas, or both of them, prior to forcing them under pressure into the formation. This is advisable if the oil in the formation is of such high specific gravity and of such asphaltic or paraffin content as to close the pores. This will assist in the dilution of the oil and the introduction and subsequent recovery of oil and gas since the hot oil and gas will act to aid in the mixing of the introduced oil and of the original oil and will assist in the clearing of the closed pores. It is preferable to avoid storing gasoline and similar very light liquid hydrocarbons in formations containing asphalt base oils. These light oils tend to precipitate asphalts thus clogging the pores of the sand. An added advantage of this method of storing gas and oil resides in the fact that, while dry gas is introduced into the formation, the so-called "wet" gas, i. e. one containing light hydrocarbon fractions, is obtained therefrom during the subsequent recovery of the oil and of the gas.

It was also found that the storage of oil with substantial quantities of gas aids the ultimate recovery of the oil since the injected gas reduces the amount of energy required later for the removal of said oil from the reservoir used for storage. However, it was also noticed that an extraordinarily low gas-oil ratio, i. e. the volume of gas expended for the raising of a unit volume of oil, is obtained. This is due to the fact that an ideal, and not accidental, reservoir is created, which has an intimately mixed solution of gas and oil. Of course, the precautions which should be taken with any well placed on production, such as the maintenance of a low gas-oil ratio and the starting of recirculation of gas for gas-lift as soon as heading begins, should also be taken in the case of wells placed on production from such replenished natural underground storage reservoirs.

Since the natural reservoir prior to replenishment was saturated with oil, none of the introduced oil is lost due to wetting of the sands. It is possible not only to recover the oil introduced into the formation but also obtain some of the residual oil due to the re-energization of the reservoir by the introduced oil and gas.

It is to be understood that the specific disclosures herein made are merely illustrative of the generic invention and are not to be considered as in any way limiting, since many variations may be made by those skilled in the art within the scope of the invention which we claim.

We claim:

1. A method of storing oil and gas in and the recovery of oil and gas from a partially depleted natural subterranean oil reservoir having a plurality of wells drilled thereinto, which comprises introducing oil and natural gas into said reservoir for the purpose of storing the same and without removal of oil and gas, causing the oil and gas to accumulate in said reservoir under pressure in simulation of an original oil field, and subsequently recovering oil from the subterranean reservoir.

2. A method of recovering oil from a partially depleted natural underground reservoir containing oil, which comprises introducing gas and a normally liquid oil of a specific gravity lighter than that of the residual oil remaining unrecovered in the reservoir, causing the oil and gas to accumulate therein under pressure, allowing the introduced oil to mingle with the residual oil for a considerable period of time, and subsequently recovering the mixed oils and gas.

3. A method of recovering oil from a partially depleted natural underground reservoir containing residual oil without sufficient gas to remove said residual oil, which comprises introducing under pressure a gas and a crude oil of a specific gravity lighter than that of the residual oil remaining unrecovered in the reservoir, said pressure being sufficient to cause the passage of the introduced oil and gas through the pores of the reservoir, accumulating the introduced oil and gas under pressure in the reservoir in simulation of an original petroleum bearing zone, storing the introduced oil and gas in the reservoir for a prolonged period of time to cause commingling of the introduced oil with the residual oil, and subsequently recovering the mixed oils.

4. A method of oil storage comprising introducing large quantities of petroleum oil into natural underground reservoirs, accumulating the oil in said reservoirs, and storing the oil therein in liquid form.

5. A method for storing liquids comprising introducing a liquid which is liquid under normal conditions and a gas soluble in said liquid into a natural underground reservoir and accumulating and storing the liquid therein in liquid form.

6. A method comprising storing oil by introducing crude petroleum and a gas soluble therein into a natural underground reservoir, and accumulating said gas and oil in said reservoir under pressure without withdrawal of gas and oil whereby the oil is stored in said reservoir as a liquid in contact with said gas.

7. A method comprising introducing a normally liquid petroleum and natural gas under pressure into a natural underground reservoir without removal of said gas and oil, and accumulating and storing the gas and oil in said reservoir under pressure for a prolonged period of time.

8. A method for storing oils comprising the step of introducing crude petroleum into a depleted natural underground reservoir, accumulating the oil in said reservoir, allowing the oil to remain therein for a considerable period of time, and subsequently recovering the oil.

9. A method of storing and recovering petroleum comprising introducing petroleum and natural gas into a natural underground reservoir, accumulating the petroleum and gas therein in commingled relation under pressure in simulation of a natural petroleum field, and subsequently recovering the petroleum and gas from the reservoir.

10. A method of conserving, storing and recovering petroleum comprising recovering crude petroleum from one natural underground reservoir, recovering natural gas from natural sources, introducing said petroleum and gas into a depleted natural underground petroleum reservoir which is naturally sealed against loss of oil and gas, commingling said oil and gas in said reservoir, and storing such introduced oil in the reservoir for a prolonged period of time.

11. A method for conserving, storing and recovering petroleum comprising recovering crude petroleum from one natural underground reservoir in which the petroleum is subjected to loss by drainage, recovering natural gas from natural sources, introducing said petroleum and gas into a depleted natural underground petroleum reservoir which is naturally sealed against loss of oil and gas, commingling said oil and gas in said reservoir, and storing such introduced oil in the reservoir for a prolonged period of time to promote commingling of the introduced oil with the residual oil.

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