METHOD OF FORMATION CONSOLIDATION

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This invention relates to the treatment of wells such as those producing oil or gas wherein the producing formation is an unconsolidated or poorly consolidated sand or sandstone. More particularly it is directed to an improved method of consolidating such formations by a method which will not cause a prohibitive reduction in the permeability of the formation.

In the production of fluids from subterranean geological formations, difficulties are often encountered because certain of the producing formations are composed of unconsolidated sands or loosely consolidated sandstones. The presence of such unconsolidated sands in the production zone surrounding the well bore causes several types of problems in the completion and production of such wells. The production of fluids from a well which is based in such a formation frequently results in the concurrent production of sand particles which are undesirable because the unconsolidated formation lifts the well bore with said particles, thus blocking the well bore and restricting the production therefrom. The damage is also extended to the pumps and surface lines of the production facilities above the well bore because of the abrasive and erosive actions of the sand grains and particles entrained in the fluids which are produced. The normal methods of production do not provide satisfactory results when applied to these sand formations and it has become necessary to develop new production methods specifically designed for such formations.

Previous efforts have heretofore been attempted for consolidating such formation surrounding a well bore. Although certain of the methods proposed heretofore accomplished the desired sealing or cementing of the unconsolidated sands, the result is a formation that has only a slight permeability to oil or gas. The known methods of reducing sand production have all achieved a certain degree of success but the degree of success which none of the methods have been able to overcome successfully. Furthermore, the degree of such success is more reduced when the conditions of temperature and corrosion are greater than normal.

It is therefore a primary object of the present invention to provide a method of consolidating incompetent oil and gas formations which obviates the disadvantages of the prior art methods, especially under conditions of high temperatures, corrosion, and erosion.

Another object of our invention is to provide an improved method for consolidating loose sand formations with the greatest possible increase in sand utilization of the porosity and permeability characteristics of the sand within the formation surrounding the well bore.

Another object of this invention is to provide a method of well completion for primary or secondary recovery wells which will allow them to be subjected to repeated clean-out in well or near-well combustion without disrupting the formation production facilities.

Other objects and advantages of this invention will become apparent during the course of the following description.

This invention broadly relates to an improved method of consolidation capable of achieving the above objects by treating incompetent hydrocarbon producing formations to effect the placement or creation of a permeable, ceramic-type consolidated zone surrounding the well bore penetrating said unconsolidated formation.

One embodiment of this invention is to subject said formation surrounding the well bore to in situ combustion following the injection of a heat refractory cement into a zone immediately surrounding the well bore and production of the formation. Another embodiment of the invention comprises in situ combustion, as above, followed by the injection of a silicate binder and production of the formation. The invention may be carried out also in a solvent treatment of the formation surrounding the well bore followed by the injection of a heat refractory cement and production of the formation. Still further embodiment of the invention comprises subjecting the formation to solvent wash, as above, followed by the injection of a silicate binder and production of the formation.

All sand consolidation agents are more effective when applied to formations which have been made devoid of all water and residual crude oils, but this ideal condition has not been previously obtainable in field operations. The improved method disclosed herein allows the incompetent formation to be placed in the above ideal condition and more effectively treated by one of the alternate approaches. Therefore the first step of this improved method of well treatment is to clean the sand grains and particles of the incompetent formation to the desired distance about the well bore. This can be accomplished by conducting in situ combustion, or by subjecting said zone about the well bore to a solvent wash.

The approach to rendering the incompetent zone about the well bore devoid of all but clean unconsolidated sand grains and particles can be accomplished effectively by in situ combustion as known in the art. In situ combustion requires that the formation have sufficient combustible material, combustion supporting gas, and an ignition level temperature prior to initiation. This can be accomplished by any known means such as injecting or utilizing in situ hydrocarbons; injecting air; and heating the air to the required temperature with heating means such as a downhole heater. After ignition of the combustion, the injection of a combustion supporting gas is continued to move the resultant combustion front outwardly from the well bore to the desired distance from one (1) to twenty (20) feet preferably in the order of five (5) feet. The leading edge of the combustion front is characterized by a temperature gradient of 700° to 1500° F./ft., which distills and cracks all liquids within the formation causing them to be driven ahead of the front. The cracking results in the deposition of a small portion of the residual hydrocarbons in the formation in the form of petroleum coke which is also combusted and removed as fuel for the front as it passes said coke.

The sand grains and particles and the pore spaces of the zone which have been subjected to the in situ combustion are thoroughly cleaned and the result is the desirable clean unconsolidated sand which is preferred for consolidation because the passage of said front through a zone removes all liquids and combustible material therefrom. The formation radially ahead of the point where the combustion is terminated is characterized by a zone of coke followed by an oil saturated zone which supplies certain cohesive properties to that portion of the formation.

The invention herein discloses the other approach to cleaning the sand to be that of conventional solvent washout by injection and flushing to remove all material from the sand grains and particles. Solvents suitable for the dissolution and removal of hydrocarbons, such as carbon tetrachloride, acetone, benzene, etc., are injected under pressure to move the hydrocarbonaceous material away from the well bore either to the surface or into the formation.
The injection is continued until a sufficient amount of solvent is injected, whereupon air or gas is injected to cause the solvent to be evaporated or driven further into the formation.

A portion of the incompetent formation, upon being made devoid of all hydrocarbons and other liquids by either of the above approaches, is then in condition to be subjected to efforts of consolidation. This consolidation can also be conducted in one of several manners disclosed heretofore as a step in the method of this invention, in order that the desired permeable, permeable synthetic sandstone, either the sand and the refractive cement, or the loose sand and the consolidating binder, can be established within the formation. Until completion of the step of rendering the incompetent formation devoid of undesirable matter as set forth above, the next step is to consolidate the sand grains and particles so that orderly production may be established and maintained in the formation. The portion of the formation about the well bore which has been rendered even more incompetent by the cleaning effect of solvent injection or combustion consists solely of loose sand grains and particles which must be further treated.

The clean, unconsolidated sand of said formation is transformed into a consolidated formation capable of efficient production by one of two alternative approaches disclosed herein. The first approach to consolidation requires a portion of the unconsolidated sand about the well bore to be removed to the desired distance, which can be accomplished by conventional means such as boring or reverse circulating with fluids. This removal of sand is accomplished within the formation outwardly from the well bore to establish a cavity about said well bore. The cavity may be extended to a diameter equal to distance to which in situ combustion or solvent injection has been conducted, but in either case the outer periphery of the cavity is supported by either the coke created by the combustion or the cohesive mixture of unconsolidated formation and formation hydrocarbons. After the removal of said clean sand grains and particles from about the well bore, the void of the cavity is substantially filled, by dumping or pumping, with a mixture of highly refractive silica cement and sand. The cement can be injected by normal pumping means and the sand mixed therewith is properly controlled in order that the desired features of porosity and permeability are obtained. This creates a cement plug of a permeable, ceramic type in and about the well bore which effectively consolidates the formation and is capable of withstanding severe conditions of corrosion and aggravated by elevated temperatures. This porosity and permeability of the cement plug may be further increased by injecting air through the plug during the period of dehydration and setting. This plug is thereafter drilled through subsequent to sufficient setting and production is accomplished through the remainder of the ceramic type of consolidation of this synthetic sandstone within the surrounding incompetent formation.

The consolidation of a formation using a highly refractive cement may also be utilized without the initial step of cleaning the formation with solvents or combustion, providing the formation characteristics are such that a sufficient cavity can be created by conventional means without the initial removal of the naturally occurring cohesive factors.

A second approach to consolidating the previously cleaned incompetent formation is to inject therein a suitable silicate binder, such as a sodium solution of sodium silicate. The binder is injected through the well bore under pressure by conventional means in sufficient amounts to extend throughout the formation surrounding said well bore to the desired distance. Immediately subsequent to the injection of said binder, air or another non-reactive gas is injected to control and achieve the proper saturation of the clean sand with binder to create permeability throughout the zone, and to effect a partial drying of the binder within the pore spaces. Thereafter, an acid, preferably a strong mineral acid such as hydrochloric, in the aqueous or anhydrous gaseous state is injected into the formation where it reacts with the previously injected binder. The reaction of the acid and binder causes the sand grains and particles to be consolidated by the creation of insoluble acid silicates which are precipitated in such a manner as to establish a permeable, ceramic-type zone of consolidated sand surrounding the well bore. The conversion reaction to insoluble silicate may be carried to completion by injecting dry air which has been heated to about 300° F.

Subsequent to the establishment of the desired consolidated zone of synthetic sandstone by the above efforts, the formation is returned to production in the normal manner as known in the art. This production will be free from the concurrent production of sand grains and particles and there will accordingly be increased production rates and economics. The previously incompetent formation is thereby rendered competent and the permeability and porosity of the predominant sand grains and particles are retained to allow production to be accomplished in an efficient and effective manner without the previous concurrent undesirable grain and particle production.

Furthermore the method disclosed herein can be utilized indefinitely because the consolidated portion of the formation which has been created is in an efficiently heat and corrosion resistant that it may be re-conditioned, if necessary, by initiating in situ combustion in or near said well bore to remove any undesirable deposits which accumulate in the synthetic sandstone. Therefore the formation may be maintained as producing one for an indefinite period in this state of improved efficiency with a maximum of maintenance economy.

In order to disclose the nature of the present invention still more clearly the following illustrative examples will be given. It is to be understood that the invention is not to be limited to the specific conditions or details set forth in these examples except insofar as such limitations are specified in the appended claims.

Example 1

The well has been drilled to a depth at which the well bore exists in a producing stratum of a formation which is composed of unconsolidated and loosely packed sand. A screen or cased liner is then installed in the well bore in preparation for cleaning the unconsolidated sand of the surrounding formation by the method of in situ combustion. The sand is then burned with a burner or bottom hole heater of the proper capacity, and in situ combustion is conducted by means known in the art. The combustion process may be supplemented by continuing to inject hot gases containing oxygen to accomplish the cleaning to a distance of five feet. The well is kept clean and dry and is cooled by the continued injection and circulation of air in the well bore. An amount of aqueous solution of sodium silicate sufficient to partially saturate the cleaned sand is then injected with air pressure as required until the sodium silicate is distributed throughout the cleaned sand. Air saturation and permeability is created by additional air injection for a sufficient time to permit a partial drying of the silicate solution in the formation, at which time a dilute liquid or gaseous mixture of hydrochloric acid, is injected in sufficient quantity to form silicate acid which converts ultimately to silicon dioxide. These reactions may be illustrated by Equations 1 and 2:

\[
\begin{align*}
Na_2SiO_3 + H_2O + 2HCl & \rightarrow H_2SiO_4 + 2NaCl \\
Na_2SiO_3 + 2H_2O & \rightarrow 2SiO_2 + 2H_2O + H_2SiO_4
\end{align*}
\]

These reactions show the types of reactions which take place and various forms of the silicates react in these general ways. Hot or cold air is injected until sufficient time is afforded for completion of these reactions and the acid silicate is irreversibly dehydrated, as represented by Equation 2, whereupon the well is returned to production.
Example 2

The consolidation method described in Example 1 is accomplished in exactly the same manner except with reference to the method used to clean the unconsolidated sand of the formation. The cleaning is done by washing the well out with any of the available solvents, such as benzene, toluene, carbon disulfide, acetone, or low-cost solvent cuts available from a petroleum refinery, and then applying sufficient air pressure to force the solvent out into the formation. The well is then closed, dried out and completed as in Example 1.

Example 3

The unconsolidated sand of the formation is cleaned as described in Examples 1 or 2, but another technique of well completion is used. A portion of the clean loose sand of the formation is removed from about the well bore by any conventional method. A mixture of clean silica sand and a high temperature ceramic cement, such as No. 31 Saueressen cement, is dumped or pumped into the hole under pressure. The sand and cement mixture form a consolidated zone in the cavity where the clean sand was removed and after it has been allowed to set up, the well bore is extended through the plug by drilling and the well is completed in a conventional manner.

Example 4

The reservoir contains a sufficiently heavy crude oil, or is otherwise sufficiently competent, so that the unconsolidated loose sand surrounding the well bore is removed without prior cleaning in an amount sufficient to create an area in which high temperature refractory cement may be injected. This removal is accomplished by jetting or underreaming the area around the well bore and the cement of the type set forth in Example 3 is utilized with well completion following in the normal manner, i.e., behind pipe or as a permeable cement plug, back with subsequent open hole completion through the plug after extending the well bore by drilling.

It will be understood that the examples included herein are illustrative only and that the invention is to be taken as limited only by the scope of the appended claims.

We claim:

1. A method of consolidating an incompetent formation of unconsolidated or loosely consolidated sands and clays traversed by a well bore which comprises the steps of cleaning a portion of said formation surrounding the well bore; injecting a silicate binder into the clean sand surrounding the well bore; injecting a nonreactive gas into said formation to achieve permeability and dry the binder; and injecting an acid into the formation which forms a consolidated permeable porous synthetic sandstone within the formation.

2. The method in accordance with claim 1 wherein the silicate binder is an aqueous solution of sodium silicate.

3. The method in accordance with claim 1 wherein the nonreactive gas injected into the formation and binder is air.

4. The method in accordance with claim 1 wherein the nonreactive gas injected into the formation and binder is air heated to a temperature of 300° F.

5. The method in accordance with claim 1 wherein the acid injected is a strong mineral acid.

6. The method in accordance with claim 1 wherein the acid injected is a hydrochloric acid.

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