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CONSOLIDATING EARTH FORMATIONS WITH SATURATED SILICA SOLUTION

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ABSTRACT OF THE DISCLOSURE

A process for consolidating sand formations wherein silica is deposited from a solution on the silica sand grains at the points of contact between adjacent grains. The formation is first heated to a high temperature, preferably above 200° C., using high quality steam. The formation is then contacted with a saturated aqueous solution of silica while maintaining a constant flow of the solution through the formation. The excess solution is removed from the formation by inducing the aqueous solution to flow back to the well.

BACKGROUND OF THE INVENTION

The present invention relates to an in situ process for consolidating formations containing silica sands. More particularly, the invention relates to a process for consolidating formations containing siliceous materials around the periphery of wells that are drilled to produce petroleum deposits.

A considerable quantity of petroleum deposits are found in porous sand formations. When producing petroleum from sand formations, steps must be taken to insure that the sand does not enter the well. In some cases these steps are successful, but in others, particularly where the formation is comprised of loose, fine-grain sands, the steps are not successful.

These formations are normally referred to as incompetent earth formations, and it is the usual practice to protect the well by means of screens, liners, gravel packs or other types of mechanical devices for preventing the sand from entering the well. Even when these various steps are taken to protect the well, the sand grains tend to plug the screens and other mechanical devices and thus reduce the production from the well. When the production is reduced due to plugging of the screens or other devices, the well must be overhauled to clean out the screens and re-establish the original production rate.

In order to prevent the plugging of the screens and other devices, it has become common practice to consolidate incompetent formations by means of artificial cementing materials, such as silicates, polymeric resins and carbohydrates and the like. Also, sand have been consolidated by means of thermally converting the oil into an intergranular binding coat to fuse together portions of the sand grains and like procedures. These various sand controlling measures are described in U.S. Pats. 3,175,611; 3,121,462; 2,350,329; 3,205,946; 3,291,214 and 3,292,701.

The in-situ treatment of sands with artificial cementing materials is particularly helpful in treating incompetent formations. The in-situ treatment is designed to form a ring of competent porous sand within the earth formation around the well while leaving the borehole open for installation of various production equipment. The treatment is effective primarily because it cements each sand grain to an adjacent sand grain and thus prevents the individual sand grains from flowing into the well when the well is produced. Normally, when silicates are used it has been the practice to introduce the artificial cementing material in the form of a hot aqueous solution of various silicates. The silicates then filter out of the solution and attach themselves to the various sand grains. While this forms an

effective means for consolidating the formation, the silicate deposits also tend to plug the pore spaces between the individual sand grains. Thus, additional means must be used to maintain or re-establish the interconnected pore network of the formation with the borehole in order that fluid production may be obtained.

SUMMARY OF THE INVENTION

The present invention solves the problem of sand influx into the borehole by consolidating incompetent silica sand formations, as for example, quartz sand formations, in situ utilizing a supersaturated, aqueous solution of silica. The invention includes the steps of heating the formation to a relatively high operating temperature, preferably above 200° C. After the formation is heated, a hot water-silica solution is slowly injected into the formation and maintained in a state of constant circulation. In addition, the water-silica solution is maintained in a supersaturated condition with respect to the equilibrium solubility of the silica sand which composes the formation. After the water-silica solution has circulated through the formation, a backflow of the solution into the well is induced by lowering the well bore pressure as by pumping, flowing the well or similar procedures. During the backflow step, the silica solution is maintained in a supersaturated state by cooling the solution through heat losses to the surrounding formation or by promoting flashing of the water to produce steam. The latter effect can be produced by lowering the well pressure opposite the formation below the vapor pressure of the water phase and thereby causing a concentration of the silica in the remaining liquid phase.

The heating of the formation is preferably accomplished by injecting a high-quality or superheated steam into the formation. The use of a high-quality steam rather than hot water is necessary to limit any tendency of the formation sands to compact as a result of dissolution of the sand grains in the presence of water. Since the solubility of silica in steam is low compared to the solubility of silica in water, the tendency of the formation to plug or compact by the dissolution of the formation silica in the injected fluid is substantially eliminated.

DESCRIPTION OF A PREFERRED EMBODIMENT

The present invention can be practiced in substantially any silica sand formation that is penetrated by a well. Normally the formation to be treated is isolated by means of packers, while a tubing string is provided for establishing communication between the surface and the isolated formation. The tubing string is used to inject the steam to heat the formation prior to injecting the saturaed aqueous solution of silica.

After the formation is isolated, the injection of high-quality, high-temperature steam is initiated. The steam preferably has a quality of at least 98 percent and a temperature of at least 200° C. The pressure of the steam may be varied depending on the formation conditions although the chosen pressure must be high enough to cause the steam to flow into the formation.

The injection of the steam is continued until the formation within a radius of several feet from the well bore has been heated to the steam temperature. During the injection of the steam, it is preferable if the steam is injected at a rate that maintains the steam at a relatively high quality adjacent the surface of the well as the isloated formation. This reduces the tendency of the sand to compact due to the dissolving of the sand grains at the grain-to-grain contacts in the formation. This is important since any compacting of the formation adjacent to the well may impair fluid communication between the formation and the borehole.

Immediately following the steam injection, an amount of hot water-silica solution equal to the pore volume of

the heated sand zone is injected into the formation. The water temperature should be at, or preferably above, the original steam temperature, and the injection rate should be kept low to increase the total time for the reaction within the sand while still maintaining fluid circulation. The injected hot water is supersaturated with silica with respect to equilibrium solubility of the silica sand. The injected hot water can be supersaturated with respect to the silica sand by the addition of silicic acid or some other form of amorphous soluble silica.

Under the operating conditions prescribed herein silica will be deposited rapidly in the form of quartz so long as the silica concentration in solution exceeds the equilibrium solubility of quartz. The silica deposits as a very thin, strongly adhering rim of microcrcrystalline quartz crystals on the exposed surfaces of the sand grains, particularly near and at the grain-to-grain contacts. The adjacent rims merge at the grain contacts becoming interlocked and cemented to one another. This results in the cohesive bonding of the individual sand grains in the formation around the borehole.

An important feature of the invention is the maintaining of a constant circulation of the supersaturated hot silica solution to avoid plugging of the formation and to increase the rate of microcrystalline quartz growth on the sand grain surfaces. While it is important to maintain circulation, it should be at a relatively low rate to permit the quartz crystal growth on the formation sands to form a bond at the grain-to-grain contacts between the various sand grains. While it is desirable to have the silica deposited at the grain-to-grain contacts, it is, of course, necessary to maintain the porosity of the formation to permit subsequent producing of the formation.

Following the injection of the supersaturated hot water-silica solution, circulation is maintained by inducing the solution to flow back to the well bore by lowering the well bore pressure. The well bore pressure may be reduced by flowing the well, pumping, or other means. During the back flow the injected solution is maintained in a supersaturated state by (1) cooling the water through heat losses to the surrounding formation, and (2) by flashing a portion of the water in the solution to steam in the vicinity of the well bore. Steam flashing is accomplished by lowering the well bore pressure below the vapor pressure of the water phase. During steam flashing the silica stays behind in the liquid phase. As a result, the dissolved silica concentration is increased to maintain the desired supersaturated state. Steam flashing can be used to produce rapid deposition of microcrystalline quartz in the formation.

The backflowing of the injected supersaturated liquid from the formation is important to maintain the porosity of the formation. The removal of the supersaturated liquid from the formation serves both to maintain the porosity as well as remove the excess silica from the formation. Thus, as the formation cools and circulation of the silica solution continues, the intergrain contact points will be permanently bonded by the deposited silica, while at the same time the communication paths in the formation will remain open.

The above method can be modified where, in addition to quartz sand, the formation contains cryptocrystalline or amorphous forms of silica sand in a sufficient quantity to form a saturated silica solution in situ. It is well known that the amorphous forms of silica sand, such as chert, have a higher solubility rate and a higher solubility equilibrium in water than quartz sands. Under these circumstances the above process can be modified by permitting a portion of the injected steam to cool and condense to form a water phase in the formation. After the formation of the water phase, sufficient time is allowed to elapse for

the water to obtain an equilibrium saturation of silica with respect to the amorphous or cryptocrystalline forms of silica in the formation. After the water is saturated, it is slowly produced back to the well bore while maintaining a high concentration of silica in solution by lowering the pressure in the formation to cause a portion of the solution to flash to steam. The silica which deposits from the solution as quartz will represent a stable solid form of silica in the high-temperature environment.

Both of the above methods take advantage of cooling the formation by natural means or by steam flashing to maintain a supersaturated silica solution in the sand formation. Further, both methods maintain a constant circulation of the supersaturated liquid phase through the formation to maintain the porosity of the formation. Likewise, both of the methods utilize a high quality or superheated steam to initially heat the formation to increase the rate of silica deposition as quartz and to minimize the silica-sand dissolution and sand compaction in the vicinity of the well bore. The second method has the additional advantage of generating the saturated silica solution in situ where the formation contains the proper type of silica to form such a solution. In the absence of this type of formation, the silica solution can best be generated at the surface and then injected into the well bore.

I claim as my invention:

1. A process for consolidation of an unconsolidated silica sand formation surrounding a well, said process comprising:

injecting a high quality steam through said well into the formation until the sand within a radius of several feet from the well is heated to a high temperature;

stopping said steam injection and then contacting the heated unconsolidated sand with a saturated aqueous solution of silica, said silica solution being prepared at the surface and then injected into the formation; and

continuously flowing the aqueous solution through the formation.

2. The process of claim **1** wherein the formation is raised to a temperature of at least 200° C.

3. The process of claim **1** wherein the aqueous solution is a hot water solution having a temperature at least equal to the temperature of the steam, an amount of said aqueous solution equal to the pore volume of the heated formation being injected.

4. The process of claim **1** wherein after the aqueous solution has circulated through the formation it is backflowed into the well and maintained saturated by cooling.

5. The process of claim **4** wherein the aqueous solution is cooled by promoting flashing of the portion of the water in the aqueous solution to steam and by heat losses to the formation.

6. The process of claim **1** wherein the aqueous solution is supersaturated silica.

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