United States Patent

Waid

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[54] RESIN CONSOLIDATED SANDPACK

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[52] **U.S. Cl.**.....**166/276,** 166/290

[51] **Int. Cl.** **E21b 43/04**

[58] **Field of Search**.....166/276, 278, 290, 295

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[57] **ABSTRACT**

In sandpacking a cased and perforated well completed into an unconsolidated reservoir, a slurry of sand grains that are coated with a self curing epoxy resin formulation is pumped into the well by a procedure that ensures the filling of perforations and formation voids with a mass of resin-coated sand which will consolidate downhole and subsequently be drilled out to leave the interior of the casing free of obstructions.

10 Claims, 3 Drawing Figures

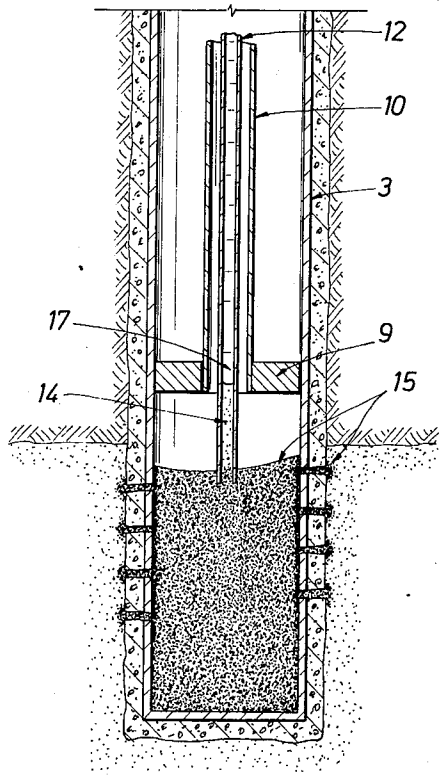


FIG. 1

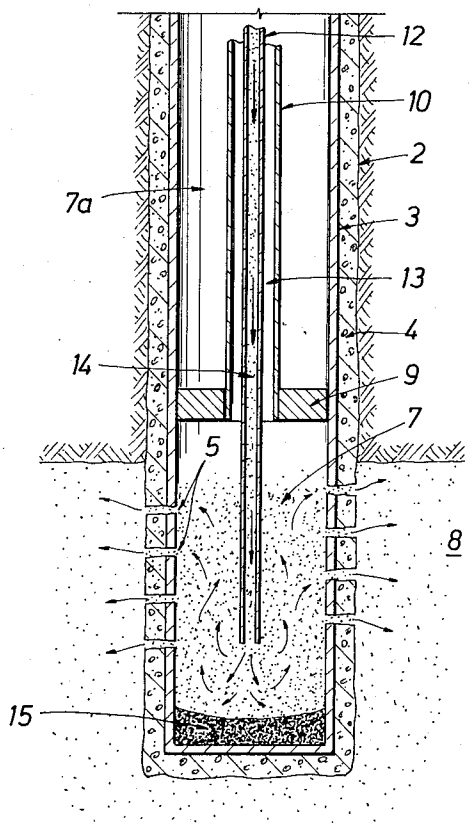


FIG. 2

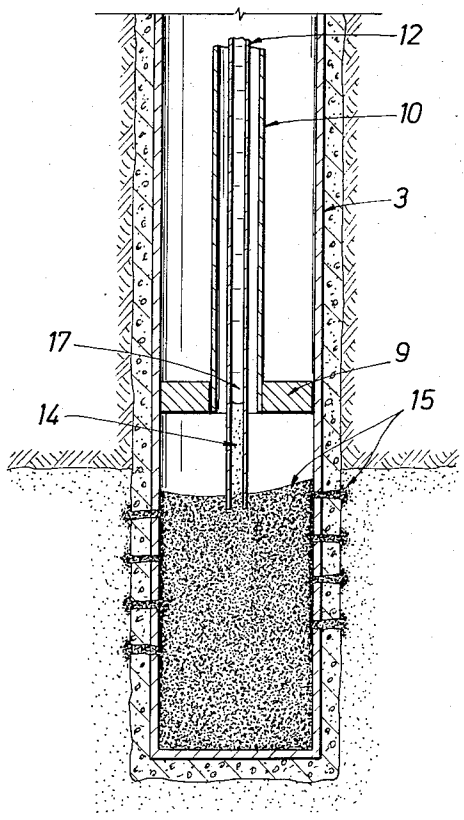
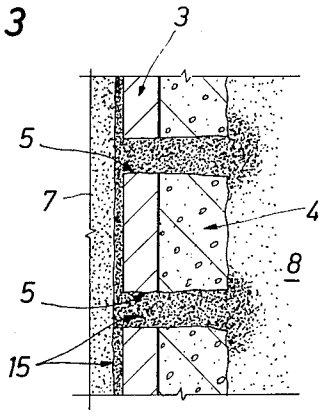


FIG. 3



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RESIN CONSOLIDATED SANDPACK

BACKGROUND OF THE INVENTION

The invention is a well treatment for providing a resin consolidated sandpack within a well that was completed in an unconsolidated reservoir by means of casing and perforating equipment and techniques. The present invention is particularly useful as a remedial treatment for filling voids and replacing sand that was removed from the reservoir formation while fluid was being produced from the well.

Many wells are cased and perforated within unconsolidated reservoirs. In such wells, the inflowing of sand into the well conduits is a serious problem and may lead to a loss of the well. Where sand inflows have occurred voids are left within the reservoir formation. If the voids are left open, the formation is weakened and may collapse even though a sand consolidation treatment has been employed to consolidate the reservoir formation in the vicinity of the perforations.

It is known that such voids in unconsolidated reservoirs can be repacked by injecting a slurry of sand in a liquid that carries the sand through the perforation tunnels and into the voids, where it is screened out against the face of the reservoir formation. Such a transportation of sand into the voids is accompanied by the deposition and piling up of a mass of sand within the casing, where some of the liquid remains static and the sand settles out of suspension.

In a conventional sandpacking process, sand grains are coated with an uncured resin that is subsequently cured when contacted by a catalyst. A slurry of such coated grains is pumped into the well. The sand which is deposited within the casing is removed by a liquid circulating sand removing operation. Then, fluid containing a catalyst is injected in order to initiate the curing of the resinous material on the sand grains. In such a sand removing operation, a string of tubing is usually extended within the casing to a depth near the top of the sand, fluid is pumped into the well through the casing annulus (i.e., the space between the casing and the tubing) while sand-laden fluid is flowed out of the well through the tubing and the tubing is lowered to keep its lower end near the top of the sand. During such an operation, unconsolidated sand in the perforations and voids tends to be removed, for example, due to the backflowing of the sand carrier fluid from locations within the reservoir formation into which it was injected at a relatively high pressure in order to ensure that the sand was transported through the perforations and into the voids.

SUMMARY OF THE INVENTION

In accordance with this invention a cased and perforated portion of a well completed into an unconsolidated reservoir is sandpacked by the following combination of steps. Sand grains are coated with a self curing epoxy resin formulation and suspended in a carrier liquid. The suspension is pumped into the well through tubing extending to a point of discharge near the lowest perforation. Each time the perforated casing and the adjacent voids have become filled with a mass of deposited sand extending up to the depth of the point of discharge, the point of discharge is raised, until the sand deposits extend above the highest perforation. The pumping in of suspension is then stopped and the resinous coating on the sand grains is allowed to cure. The interior of the casing is subsequently drilled free of the consolidated mass of sand which is formed within the casing, throughout the length of the perforated interval.

In a particularly suitable procedure, the present invention is conducted by:

1. Mechanically isolating the perforated interval from an inflow of fluid standing within the borehole and placing a sand consolidating resin-compatible fluid in the perforated portion of casing and adjacent portions of earth formation.

2. Installing (or arranging) a conduit so that it extends from a surface location to the perforated interval and is adapted to be lengthened or shortened to position the bottom of the conduit at different depths within the perforated interval.

3. Forming a slurry of sand grains that are coated with resin-forming material and suspended in a liquid and pumping into the conduit an amount of slurry that contains sufficient sand grains to refortify the formation (by replacing produced formation sand with resin-coated sand) and fill the perforated interval of the casing from below the lowest perforation to a point above the uppermost perforation (but below the location of the device, such as a squeeze packer, by which the perforated interval is mechanically isolated).

4. Displacing the slurry from the lower end of the conduit while it is located near the bottom perforation and raising end of the conduit at a rate such that the packing of the formation and the settling of sand grains in the borehole at each of a succession of depths within the perforated interval is indicated by a decrease in the fluid injectivity (which causes a corresponding surface pressure increase, when the rate of inflow is constant); and

5. After allowing the resin-forming material to solidify, drilling through the consolidated sand and that has formed within the well casing, so that the borehole is unobstructed.

DRAWINGS

FIG. 1 is a schematic partially cross-sectional illustration of a cased and perforated interval of a well borehole equipped for practicing the present invention.

FIG. 2 is a similar illustration at a later stage of operating the present process.

FIG. 3 is a similar illustration of an enlarged portion of the casing and perforation tunnels within such an interval.

DESCRIPTION OF THE INVENTION

FIG. 1 shows well bore 2 containing casing 3 surrounded by a sheath of cement 4. The casing is penetrated by perforations 5 having perforation tunnels extending from the borehole interior 7 to a surrounding unconsolidated reservoir 8. The perforated interval of borehole is isolated from an inflow of fluid standing in upper portion 7 *a* borehole interior by packing means 9 (such as a standard squeeze packer) surrounding pipe string 10.

Tubing string 12 is extended through pipe 10 to provide a conduit arranged to extend between a surface location and any of a series of depths within the isolated interval of the borehole. Tubing 12 is extended through

a sealing means (not shown) such as a hydraulic blowout preventer means near the wellhead in order to maintain a seal across the annular space **13** between tubing **12** and pipe **10** while permitting vertical movement of the tubing **12**. Alternatively, a conduit can be arranged to extend between a surface location and various depths within the isolated interval by using an arrangement of pipe string **10** and packer **9** (without tubing **12**), that provides an elongated section of external seals along the pipe string **10** (used as tubing) and a polished-bore packer that slideably seals against the external seals so that the pipe **10** can be moved through the packer to position it at various depths within the isolated interval (for example, by means of an Otis Permatrieve Packer).

As known to those skilled in the art, each of the above described well drilling and completion operations can be accomplished by means of various items of commercially available equipment and techniques.

FIG. **1** shows fluid **14**, comprising a slurry of resin-coated grains, being pumped through and displaced out of the lower end of tubing **12** while it ends near the bottom of the perforated interval of casing. Such a slurry displacement tends to form a turbulent zone near the end of the tubing and insures that the grains remain suspended in fluid and are carried by the fluid that flows through perforations **5** and into reservoir **8** as indicated by the arrows. Some of the so-injected resin-coated grains fall out of suspension forming a sand build-up, in the form of a mass **15**, as they settle out of the relatively static portions of the grain suspending fluid within the borehole and some are screened out against the face of the reservoir to form a mass **15** (see FIGS. **2** and **3**) as the grain suspending liquid flows into the reservoir.

FIG. **2** shows a later stage of the same process, after tubing string **12** has been raised. The tubing is raised each time the packing of the perforations below the tubing end has caused a sand mass **15** to be built up within the borehole to near the end of the tubing **12**. Each time such a build-up occurs, the inflowing fluid is forced to flow through more of the sand mass. This causes a significant reduction in injectivity and, if the fluid is being injected at a constant rate, a surge of greater injection pressure can be detected at the surface location.

In the present process, a slurry conveying conduit, such as tubing **12**, is preferably moved up in increments (such as **1** foot increments) that each contain only a few (such as **4**) perforations. The movements are preferably spaced to provide a rate slow enough so that the build-up of sand to near the point of discharge at the end of the inflow conduit, causes a reduction in injectivity at each increment. Such an injectivity change indicates that the perforations below the point of discharge have been fully packed with sand and packed sand has built up within the borehole to the end of the inflow conduit. The injection of slurry is preferably continued while the inflow conduit is being raised, but can be interrupted before, during or after each raising of the conduit, if necessary.

The amount of slurry that is injected is important. It should contain sufficient resin-coated sand to replace produced formation sand with resin-coated sand and to fill the interior of the borehole from below the bottom perforation to above the top perforation, without extending into contact with the packing device used to isolate the perforated interval. The volume of the liquid into which such an amount of resin-coated sand grains are suspended can be varied to accommodate the viscosity of the suspending liquid, the slurry density capabilities of the slurry pumping devices, etc.

The present process is particularly suited for use in wells from which sand has been produced, such as those receiving a remedial treatment. The amount of sand needed to fill a length of casing equalling the perforated interval should be increased by an amount sufficient to replace the produced sand. The exact amounts of such increases will vary depending upon the reservoirs but in typical Gulf Coast Miocene fields, such replacement amounts are from about eight to 10 sacks (100 pound sacks) of the coated sand per foot of perforations from which sand has been produced.

The slurry of resin-coated sand has been displaced through the injection conduit and out its lower end by chasing it with a relatively inert fluid **17**, as shown in FIG. **2**. The chasing or displacing fluid, or at least the frontal portion of it, is preferably a solid-free hydrocarbon, such as diesel oil.

In comparison with previously proposed types of sand control measures that utilize grain-interbonding resins, the present invention utilizes a relatively limited quantity of resin. In comparison with an in-situ epoxy resin sand consolidation of the reservoir sand, the present process has the advantage of: (1) combining the processes of sandpacking and consolidating into one step, in contrast to separate steps, and thus providing a saving in rig-time (which is particularly valuable in situations in which rig costs are high, such as in offshore locations); and (2) providing key features of sandpacking such as leaving an unrestricted well bore adapted to receive substantially any downhole operations. In addition, and possibly most important, the present process provides a saving (relative to a standard in situ formation sand consolidation with epoxy resin) in which the material costs are reduced by 30 to 50 percent— while increasing the remedial efficiency and durability of the treatment.

After the resin-forming sand-grain coating materials have been allowed sufficient time to become hard at the reservoir temperature, well treating equipment items such as the inflow conduit **12**, packer **9**, tubing string **10**, etc., are removed from the well. A drill string assembly such as a rotary drill string containing a bit and scraper are run in and operated to drill out the plug of consolidated sand slurry that is formed within the borehole. This opens the borehole to substantially its full internal diameter while leaving a resin-consolidated, permeable, integral mass of sand in each of the perforations **5** (see FIG. **3**) so that voids caused by removal of formation sand while producing the well and the perforation tunnels are filled with the resin-consolidated sand from locations within the casing and the borehole to locations within the reservoir formation.

In a preferred procedure, the slurry of resin-coated grains is formed by coating solid granular particles with a solution of an epoxy resin-forming material and amino group containing curing agent dissolved in a liquid polar organic solvent and suspended in a liquid

carrier (such as a hydrocarbon carrier) that has a limited solubility that provides a limited partitioning (or partial extraction) of the polar solvent between the resin-forming components and the liquid carrier. Such a carrier liquid controls the curing or polymerizing rate of the resin-forming components that coat the grains to an extent that can be adjusted so that, under the downhole temperature conditions, the coated grains are interbonded to form a high compressive strength epoxy resin-coated consolidated sand and/or gravel pack. Such an epoxy resin-forming material is one that contains polyepoxide radicals having a plurality of vicinal epoxy groups and such an amino group containing curing agent is a poly-functional amine having a plurality of nitrogen atoms with at least one hydrogen atom attached to each nitrogen atom. A particularly suitable liquid carrier is a relatively viscous hydrocarbon, such as Valvata No. 78 or Valvata No. 79 (lubricating oil, available from Shell Oil Company) having a viscosity of 35 cp at 72° F.

In a preferred procedure for injecting a slurry of resin-coated sand grains, the slurry is pumped through the conduit extending between a surface location and the isolated portion of the borehole at a rate that generates a fluidized bed of the coated grains near the end of the inflow conduit at each of at least several locations adjacent to relatively short increments within the perforated interval. In a particularly preferred embodiment, the slurry is so injected at a pressure that is sufficient to create cylindrical fractures between the casing and/or cement and the surrounding reservoir sands, but is insufficient to initiate and propagate fractures that extend away from the well.

The present invention has been tested successfully in the field in situations in which other sand consolidation measures have failed or, have been indicated by experience to be inapplicable. The test conditions and results are summarized in Table I. Except where it is otherwise indicated, the sandpacked placement techniques and equipment were substantially as described above. In each case the sand used was coated with Eposand 112.

pack within a cased and perforated interval of a well bore comprising:

positioning within the borehole, means for mechanically isolating the perforated interval from an inflow of the fluid standing within the borehole;

arranging a conduit to extend from a surface location to within the borehole so that it can be moved vertically from one to a series of depths within said perforated interval;

pumping into the conduit a slurry, comprising sand grains coated with a self curing epoxy resin-forming material and suspended in liquid, using an amount of slurry that contains sufficient grains to refortify the formation by replacing the produced formation sand with resin-coated sand and to fill the casing within the perforated interval of the borehole from below the lowest perforation to above the uppermost perforation but below said means for mechanically isolating the perforated interval;

displacing an initial portion of said slurry from the lower end of said conduit while it is located near the bottom perforation and raising the conduit at a rate such that sufficient sand slurry is pumped to the formation to cause the filling of the borehole with sand grains and a decrease in fluid injectivity at each of a succession of depths within said perforated interval; and

after allowing said resin-forming material to solidify on said sand grains, drilling through the consolidated sand within the borehole.

2. The process of claim 1 in which said sand grains are coated with a solution of epoxy resin-forming material and amino group containing curing agent dissolved in liquid polar organic solvent and the so-coated grains are suspended in liquid hydrocarbon having a limited miscibility with said polar organic solvent.

3. The process of claim 1 in which from about eight to 10 100 pound sacks of coated sand grains are used per foot of perforation through which sand has previously been produced.

4. The process of claim 1 in which said slurry is displaced into the perforated interval at a rate that creates

TABLE I

Perforated interval (feet)	Quantity of sand (100 lb. sacks)	Placement method	Previous well condition	Results and conclusions
5	16	Otis Permatrieve Packer w/20' seals; 2⅜" tubing with tail pipe movement.	Sanded up zone on vacuum. Lost circulation zone.	Produced trace of sand during first day of testing. No sand thereafter. Cumulative production since job 93,000 BO plus 139,000 BW. Job execution excellent. Well now shut in due to casing problems uphole.
8	20	Otis Permatrieve Packer w/20' seals; 2⅜" work string with tail pipe movement.	Sand producing well; failed screen and liner, lost circulation zone.	Used revised pumping methods but were unable to underdisplace since zone on vacuum. Made sand but did not stand up.
8	40	Standard squeeze packer with 1¼" work string and tail pipe movement.	----do----	Re-treatment of previous (above) job to insure sand pack. Got pressure increase indicating packing each time before tail pipe moved. Made trace of sand initially, none thereafter. Cumulative production since job is 25,000 BO plus 35,000 BW with no sand.
5	40	----do----	Sand producing well; failed screen and liner, lost circulation zone. Screen and liner plugged with migrating formation fines.	Treated and produced 3,500 BO plus 46,000 BW before casing holes uphole forced zone to be temporarily abandoned. EPOSANPAC was successful and not related to loss of zone.
3	20	----do----	Failed screen and liner and EPOSAND 9 job. Casing collapse in perforated interval.	Well brought in making 1% sand. Sand cleaned up to produce at rate of 30 BO plus 540 BW.
3	30	Standard squeeze packer with 1¼" treating string and tail pipe movement.	Sanded up after being brought in at 80 BO plus 0 BWPD.	Stabilized test after job 74 BO plus 0 BWPD.

What is claimed is:

1. A process for forming a resin-consolidated sand-

turbulence near the end of the conduit through which the slurry is displaced.

5. The process of claim 1 in which said slurry is injected at a substantially constant rate and said indications of decreases in injectivity comprise surges in a pressure required to sustain said rate.

6. A process for treating a cased and perforated interval of a well by sandpacking the well with grains that are coated with a self-curing epoxy resin formulation and suspended in a liquid hydrocarbon, comprising:

pumping said suspension of grains into the well through a conduit having a point of discharge near the lowest of said perforations;

raising said point of discharge each time the height of masses of sand deposited within said casing and perforations have reached said point of discharge so that the point of discharge is reached at each of a succession of depths between the depths of the lowest and highest of said perforations;

terminating the inflowing of the suspension when the mass of sand extends above the highest of said perforations;

allowing said resin formulation to cure and consolidate said deposited masses of sand grains; and

drilling out sand that was consolidated within the casing.

7. The process of claim 6 in which said cased and perforated interval is one through which fluid and sand have been produced and the amount of suspension that is pumped into said well is sufficient to repack voids in the reservoir with a deposited mass of coated sand grains.

8. The process of claim 6 in which said suspension is injected at a substantially constant rate so that when the heights of said deposited masses of sand grains have reached the discharge point, a surface indication is provided by the increased injection pressure required to maintain the constant rate of inflow.

9. The process of claim 6 in which said suspension is pumped into the perforated interval at a rate that creates turbulence near said point of discharge.

10. The process of claim 6 in which said epoxy resin formulation is a solution of epoxy resin-forming material and amino group containing curing agent dissolved in liquid polar organic solvent and said grain suspending liquid is a liquid hydrocarbon having limited miscibility with said polar organic solvent.

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