METHODS AND APPARATUS FOR SAND CONTROL IN UNDERGROUND BOREHOLES

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References Cited
UNITED STATES PATENTS
3,126,963 3/1964 Graham ........................................ 166/51
3,329,205 7/1967 Brown ........................................ 166/278
3,548,936 12/1970 Kilgore et al. .......................... 166/216
3,627,046 12/1971 Miller et al. ........................... 166/278

9 Claims, 20 Drawing Figures

ABSTRACT
Methods and apparatus for retarding the migration of formation sand and fines into the production area of an oil well borehole include utilizing a spherical aggregate of high uniform sphericity and placing the aggregate in the borehole and pushing a production liner into place in the aggregate. Other methods and apparatus disclosed utilize one-trip placement of the aggregate, and, tool systems to allow placement of the aggregate in closely premeasured distinct stages.
FIG. 15

FIG. 16
VISUAL DETERMINATION OF ROUNDEDNESS AND SPHERICITY OF SAND GRAINS

FIG. 17
METHODS AND APPARATUS FOR SAND CONTROL IN UNDERGROUND BOREHOLES

BACKGROUND OF THE INVENTION

In underground formations penetrated by drilled boreholes wherein the formations contain loose sands and soft sandstone strata, a constant problem in well flow through the borehole involves the migration of the loose sands and degraded sandstone into the wellbore due to destruction of the formation caused by the pressure and flow of the fluids therethrough.

While numerous techniques have been used to prevent this migration of fine particles which clog the production system and seriously erode the tools in the string, two basic techniques have evolved. The first is basically a chemical treatment involving injection of a fluid into the formation and reacting the fluid chemically or with heat to set up a permeable gel or solid to retain the sand while allowing fluid flow therethrough. This method suffers from a lack of homogeneity caused by voids in the gel due to incomplete saturation of the initial fluid and the setting fluid.

The second technique involves a physical technique of placing a graded aggregate in the borehole to form a porous screen between the production string and the formation wall. This technique is commonly referred to as gravel packing and generally involves the placement of finely graded aggregate such as Ottawa sand, walnut shells, glass beads, etc., through a crossover tool or by a washing-in tool.

These tools suffer from the disadvantages of complexity, contamination of pumps, and moving parts with the aggregate, and a lengthy multi-step process of gravel placement. For instance, when the liner is washed into place, at least two runs of the tool string into the wellbore are required.

Also the prior devices result in a great infusion of circulating fluid into the formation to place the aggregate. This is undesirable in that it interferes with the normal flow of formation fluids to the wellbore.

The present invention overcomes these disadvantages by providing apparatus and methods for placing the aggregate in a single step and for placing the aggregate with a minimum of fluid loss to the formation.

BRIEF DESCRIPTION OF THE DRAWINGS

FIGS. 1 through 6 are cross-sectional, partially schematic illustrations of a tool string and operational steps for a one-trip placement;

FIGS. 7 through 9 illustrate in cross-section apparatus and operational steps for an alternate embodiment of aggregate placement;

FIGS. 10 through 14 illustrate in cross-section a tool string and its operational modes for formation treatment and aggregate placement;

FIGS. 15 and 16 are bar graphs showing a comparison of aggregates;

FIG. 17 is a pictorial chart for determination of the physical parameters of different aggregates;

FIGS. 18 through 20 illustrate in cross-section a tool system and steps of operation for placement of spherical aggregates.
After the packer has set, the injection rate is established by continued pressurization of the tubing string to the point where the shear means holding seat 20 in sleeve 19 is sheared and the valve member 36 and seat 20 move downward to land on member 32 as illustrated in FIG. 3. It should be noted that the shear value of the shear means holding ring 20 in sleeve 19 is selected to be higher than that pressure needed to fully set the packer slip 16 and elements 17.

After shearing ring 20 with pressure on valve member 36, fluid can then be injected down the tubing, through the two sets of multiple ports 21 and 27, and into the formation to provide any desirable type of treatment such as acidizing in any desired quantity.

When the formation treatment has been completed, and it is desirable to effect a placement of aggregate to prevent backflow of formation sand and fines into the production string, a slurry comprising a carrier fluid and a graded, substantially spherical aggregate is pumped through the tubing behind the injection fluid to flow through ports 21 and 27 as indicated by the flow arrows in FIG. 4. The fluid flows outward through perforations 13 in the casing, which perforations retain the aggregate as indicated in FIG. 4. It should also be noted that screen 30 is selected with mesh openings small enough to prevent passage of the graded aggregate therethrough.

FIG. 5 illustrates the apparatus after the entire aggregate pack has been pumped into position and the string is ready for production. In FIG. 5 the inner sleeve 19 has been moved downward with mandrel 15 by manipulation of the tubing or other means such as tubing rotation or wirlie. Upper seals 35 now seal off communication from ports 21 to ports 27.

FIG. 6 indicates the final step to place the string on production which involves once again applying hydraulic pressure to the tubing in an amount sufficient to shear valve ring 26 loose and move it downward to the bottom of the screen 30. Screen 30 is chosen long enough so that the presence of the two valve members and valve rings do not significantly interfere with production flow.

Production fluids now may enter perforations 13, flow through the aggregate pack and through screen 30 into the tubing string.

The advantages of the above invention are obvious. A viscous-slurry, sand-control tool string has been described which allows the treatment to be performed with only one-trip of the string into the hole. A great reduction in time and rig expense is realized. The savings in time and expense are not achieved by sacrificing simplicity and dependability. A complicated crossover type tool with high flow restriction and close machine tolerances is obviated.

Alternate Embodiment

FIGS. 7 through 9 illustrate apparatus and a method for placing an aggregate pack in a wellbore between a production screen and the well casing or borehole wall.

In FIG. 7 a tubing string 110 carrying a packer 111 is lowered into the cased wellbore, which casing has perforations therethrough at 112 to allow communication with the formation. The packer is set in the casing by conventional means and the aggregate slurry is placed in the desired interval by normal squeeze techniques. A small amount of the aggregate carrier fluid is passed into the formation as the slurry is injected.

After the entire aggregate pack is placed in the interval, the packer is released and the injection string is pulled from the well. The production string 113 carrying a production packer 114 and a control screen 115 is then lowered into the well as shown in FIG. 8.

Weight is then set down on the production string and the control screen is pushed into the aggregate slurry to form the aggregate pack around the screen, as shown in FIG. 9. Well fluids are then produced through the casing perfs 112, the aggregate, and the control screen 115.

This method offers many clear advantages including maintaining the integrity of the production string from the aggregate material. Many times a material such as inert vitreous spheres may be utilized as the aggregate which spheres are very strong compared to the normal gravel pack. When these are formed in a control pack by the use of a crossover tool or by washing in the screen, these tough particles get into the working mechanisms of the tools and of the oil-well pumps. Whereas normal gravel is merely crushed in the mechanisms, the hard vitreous spheres are not and cause extreme wear and peening damage to the parts they come in contact with. The advantage of this system is that the aggregate is never allowed access to the inner bore of the production string since the tubing and control screen remain joined and intact at all times and impervious to aggregate penetration therethrough.

Other advantages involve the minimal amount of equipment used to complete the job. No washing of the screen into place nor complex crossover tools are required. Much of the pack can be placed with a dump bailer thereby reducing fluid loss to the formation. Since no large amounts of fluids are circulated through the sand control screen during placement, screen plugging problems during the treatment are reduced.

It also should be noted that the elimination of complex equipment involved with building an aggregate pack outside the screen allows the placement of a pre-packed screen inside of the aggregate pack. This use of a pre-packed screen will result in a wellbore configuration which is much more efficient and of greater durability than the prior methods. A pre-packed screen is one which has a bonded layer or multiple bonded layer of aggregate outside the screen, bonded thereto by a permeable binder to provide a sand barrier outside the screen. The pre-packed screen is formed prior to lowering the tubing string into the well.

Formation support is achieved by the pack as it is placed. The running of the screen into the pack is done with this formation support which minimizes the danger of having the very expensive string getting stuck in the hole during installation.

Use of fewer tools and steps means decreased rig time and reduced expense as well as greater simplicity of operation.

The placement of the pack in the unobstructed bore passage prior to placement of the screen greatly reduces the likelihood of voids in the pack. If any voids are present in the pack as it is placed, these would tend to be filled with packing material as the screen is inserted into the pack. The high uniformity achieved in the pack with this method provides the best possible filter.

In addition to the above method steps, an additional advantage can be realized with the process above by making the carrier vehicle a thixotropic gel or highly
viscous fluid in which the aggregates are substantially suspended. This results in greatly reducing the force required to push the screen into the aggregate. It also reduces even further the amount of fluid lost to the formation.

Also with this method, exceptionally long intervals can be packed by successive squeeze injections done with multiple batches of aggregates.

Third Embodiment

FIGS. 10 through 14 illustrate a third embodiment of the sand control process in which a viscous slurry aggregate placement tool string and its modes of operation are disclosed.

In FIG. 10, a tubing string 210 carrying a sliding port valve sleeve 211 contains in slidable telescoped attachment an inner ported valve sleeve 212 having ports 214 alignable with ports 213 of sleeve 211. Sleeve 212 has attached thereto a packer mandrel 215 upon which is carried an hydraulically actuated, permanent type packer 216 of the type delineated in the aforementioned U.S. Patents on packers.

A tailpipe 217 is attached to the packer 216 and carries at its lower end, ported collar 218 having ports 219 through the wall thereof. Collar 218 also has a sealbore 220 which is a reduced machined diameter adapted to receive a tubular conduit therein having circumferential seals on it.

Mandrel 215 passes through packer 216 and carries at its lower end a ported seal sleeve 221 engaged in sealbore 220 in sealing telescopic relationship. Sleeve 221 has ports 222 through the wall thereof aligned with ports 219 of collar 218. Sleeve 221 also has an upper valve seating ring 223 shearably attached therein above ports 222 and a lower valve seating ring 224 attached therein below ports 222. A valve member 225 is preferentially seated in lower seat 224 when the tool is assembled at the surface.

A section of adapter conduit 227 is attached to the lower end of a tubular adapter 226 connected to collar 218. A sand control screen 228 is attached to the conduit 227 and has a bottom cap 229 thereon. It should be noted that all of the figures are drawn partially in schematic and the actual lengths of the conduits and sand control screens as well as the aggregate packs may be substantially longer with respect to the other tools than is graphically illustrated.

FIG. 10 illustrates the tool string substantially as it is run in the well. After placement of the string, a second valve member 230 is dropped or pumped down the tubing to seat on seating ring 223 which isolates ports 219 and 222 from the tubing bore. Fluidic pressure is then applied to the tubing, setting the hydraulic packer.

After the packer is set into the casing, hydraulic pressure is increased until the seating ring 223 is sheared out of sleeve 221 allowing the ring and valve member 230 to drop down, exposing ports 219 and 222 to the tubing bore passage. At this point, any required formation treatment, such as acidizing, can be accomplished as illustrated in FIG. 11, by pumping down the tubing and out ports 222 and 219 into the annulus and through casing perforations 231 into the formation.

After the injection of treating fluid, valve 211 is opened by manipulating the tubing string vertically to align ports 213 and 214. The treatment fluid can be displaced from the tubing and up the annulus by injecting a slurry of aggregate and viscous carrier fluid down the tubing. Because of the treatment fluid in the formation and the consequent high resistance to the introduction of further fluid into the formation, pumping of aggregate slurry down the tubing will displace the treatment fluid out of the tubing through ports 213 and 214 to pass up the annulus to the surface. This is clearly illustrated in FIG. 12.

After the first batch of aggregate has reached valve 211, the valve is closed by tubing reciprocation and the aggregate slurry is squeezed through the packer out ports 222 and 219 and around the sand control screen 228, as shown in FIG. 13. A portion of the carrier fluid moves under squeeze pressure out into the formation. After this batch of aggregate has been placed, additional batches can be squeezed with a minimum amount of fluid injection into the formation by repeating the steps of FIGS. 12 and 13 for each batch of aggregate.

After the total amount of aggregate has been placed, the tubing string and mandrel are pulled from inside the packer and a production string 232 is run in the packer with a seal nipple 233 located at the lower end. This nipple has seals 234 thereon which engage seal bore 220 in sealing relationship and provide a closed production flow passage from the aggregate pack through the production string. This apparatus is illustrated in FIG. 14.

The advantages of this embodiment are manifold. The packer used throughout the entire process is the same one and remains in the well during production also. This eliminates multiple setting and unsettings of packers and the possibility of a stuck packer. The packer is set hydraulically so that no tubing rotation is necessary and also the packer is selectively retrievable at any time during the operations without requiring a separate trip with the tubing string. This is accomplished by running a retrieving tool as a part of the tubing string below the packer which can be selectively actuated to retrieve the packer at any time desired.

The valve utilized above the packer is actuated by reciprocation of the tubing string and requires no tubing rotation. The use of the valve above the packer to allow the circulation of batches of slurry into the well, not only prevents the loss of large quantities of fluid from the formation during the squeezing operation but also allows building the aggregate pack in stages. This means that one stage after another can be placed until the desired pressure increase across the pack is obtained indicating an optimum pack.

This further prevents the need for a large over-design of a single or dual stage which requires a long hookup between the packer and the sand control screen. This tool allows the sand control screen to be placed at less than 100 feet from the packer whereas the prior single or dual stage operations have required up to 1200 feet. Thus, when two or more zones in the same well are to be packed, this invention is especially desirable.

A further advantage of this invention is that all extraneous ports are removed from the well before production, i.e. seating rings, valve members, etc.

Fourth Embodiment

FIGS. 15 through 20 illustrate a method of forming an aggregate pack which is particularly advantageous for use in wells which are treated by fluids which return through the aggregate pack and screen and into the tubing.

Because of the nature of the aggregates formerly used in this type of well treatment, which aggregates
contain particles having a low degree of roundness, large amounts of fines are created during the pumping operation because of the shear forces placed on the angular particles under the high fluidic flow forces. These fines, which should be distinguished from formation fines and sand, are generated entirely within the aggregate pack itself by the high shear forces and the abrasion of the aggregate particles against each other, and cause the extremely undesirable effect of substantially plugging the sand control screen.

This invention utilizes a manufactured aggregate of uniformly high sphericity and roundness to almost totally eliminate the plugging of the sand screen by internally generated aggregate fines.

FIG. 15 illustrates sphericity and roundness of a graded sample of standard 20-40 mesh round gravel used in normal gravel packing operations. The chart was obtained by taking a random sample of the gravel and visually comparing each individual particle against the chart illustrated in FIG. 17 to arrive at the sphericity and roundness of each particle in the sample. A sample size of 255 gravels was used to determine the grading average for gravel.

As can be seen from FIG. 15, the number of gravel particles that achieved a high sphericity and roundness of 0.9 or better was only a little over 6 percent. Only about 27 percent achieved a sphericity and roundness of 0.7. Thus, the number of gravel particles having a sphericity and roundness of 0.7 or better was found to be only 33 percent.

FIG. 16 illustrates the sphericity and roundness of a manufactured aggregate used in this invention to greatly eliminate fines in the pack. The sample selected was a 240 particle random sample of 20-40 mesh smooth vitreous spheres manufactured by the Union Carbide Corporation under the tradename UCAR Pac.

This material is utilized because of the high percentage of particles having a sphericity and roundness exceeding 0.9. The measured sample had more than 56 percent of its particles having 0.9 or better roundness and sphericity as compared to only six percent of the gravel. Approximately 70 percent of the manufactured aggregate equaled or exceeded 0.7 as compared to only 33 percent of the gravel.

A highly effective method of placing the vitreous spheres into an aggregate pack is disclosed in FIGS. 18 through 20.

In FIG. 18, a sand control screen 310 is lowered into a cased wellbore 311 having perforations 312 communicating with the producing formation 313. The screen 310 is releasably attached, for instance by threads or telescoping 3-slot arrangement, to a conduit string 314 which also carries a wash pipe 315 extending downward therefrom into concentric alignment inside screen 310.

The aggregate slurry is pumped down the annulus between the conduit 314 and the casing 311 into the interval of the well needing the aggregate pack. The carrier fluid flows through the control screen 310 and moves up the wash pipe 315 into the conduit string 314 and up to the surface.

The wash pipe 315, with its lower end near the lower end of the sand control screen, insures that the aggregate in the slurry moves completely to the bottom of the screen rather than bridging near the upper end of it.

It is during this placement stage, when the aggregate pack is formed by pumping aggregate-laden fluid down the casing-conduit annulus and taking fluid returns through the screen, that the aggregate particles are subjected to the greatest shear forces and the maximum amount of fines would otherwise be collected at the screen.

After the pack is completed, the conduit string is released from the control screen and removed from the well along with the wash pipe. This results in a configuration as shown in FIG. 19. A production string 316 is then run with a packer 317 and sealingly connected to the sand control screen. The packer is then set and the well placed on production.

It is believed that the large absence in fines using this process may be due in part to the particles lack of angular corners or protrusions which tend to shear off from the particle and form fines. To avoid the shear effect, the fines must have both a high degree of sphericity and a high degree of roundness. In mature, a grain of sand approaches a spherical shape as it is moved by wind or water from one location to another due to the shearing and wearing off of the angularities. This process may occur over a long period of time and results in a particle which hardly ever loses all of its angularity. Also the sand grain will have imperfections, voids, impurities and weakened shear planes running throughout its structure.

During the gravel placement, the sand grains (which are called "gravel") are subjected to high shear forces from the large pressure differential across the packed sand and abrasion caused by the high pressure flow of placement fluid through the pack. This especially becomes a problem in treatments where returns are taken through the screen because large volumes of fluid are moved through the packed grains and the screen under large differential pressures. Enough fines can be created by this type of treatment with conventional gravel to plug the sand control screen before production is even initiated in the well.

The forces applied to the spherical particles are almost totally compressive as opposed to the shear forces on the gravel particles. The abrasion of angular particles against angular particles is eliminated with the spherical aggregate. The spherical shape contributes also the high compressive strength and the particles themselves are manufactured without the large imperfections and weak shear planes of the sand grains.

A close observation of the chart of FIG. 17 will show that neither roundness nor sphericity alone will sufficiently define the optimum particle shape but the best aggregate for sand control must exhibit both high sphericity and high roundness.

For example a particle could have a roundness of 0.9 and a sphericity of only 0.3 and have a smooth rounded surface. Yet the particle would be elongated and have a small cross-sectional diameter which would be subject to high stress under flow conditions in an aggregate pack.

Generally, the two parameters of sphericity and roundness are interrelated but not equivalent. Sphericity is determined by the largest diagonal diameter and the particle volume, while roundness depends upon the general cross-sectional profile and smoothness of surface. Sphericity is the cube root of the ratio of the actual volume of the particle to the volume of a sphere having as its diameter, the diameter of the actual parti-
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3. The placement apparatus of claim 2 wherein said second ported valve means comprises one or more ports through the wall of said housing means and one or more ports through the wall of said mandrel means, said housing means ports arranged in alignment with said mandrel means ports.

4. The aggregate placement apparatus of claim 1 wherein said shearable valve means comprises an annular valve seat held in said mandrel means by shear means and adapted to receive in sealing engagement a valve member introduced down the well conduit through said mandrel means.

5. The aggregate placement apparatus of claim 1 wherein said check valve means comprises an annular valve seat secured in said mandrel means and a valve member adapted to seat in said valve seat and seal off the opening therefrom.

6. The aggregate placement apparatus of claim 1 wherein said packer means comprises an hydraulically actuated well packer having expandable resilient packer means and fluid communication means communicating with said mandrel means above said shearable valve means.

7. A method of treating an underground formation in a wellbore, said method comprising: lowering into the wellbore a tool string containing upper and lower valve means, packer means, and a sand control screen; setting the packer into sealing engagement with the wellbore by providing a flow communication channel through the tool string to the packer means; providing a valve seat in the tool string below the flow channel and above the lower valve means; pumping a valve member down the tool string to seat in the valve seat; and, pressurizing the fluid above the seated valve to actuate the packer means; injecting an aggregate slurry into the tool string, through the lower valve means, and into the borehole around the sand control screen; and, establishing a flow communication channel from the formation, through the sand control screen and up the tool string.

8. The method of claim 7 further comprising the steps of: injecting treating fluid through the tool string and out the lower valve means below the packer means and into the formation after said setting step; and, displacing the treating fluid remaining in the string out the upper valve means prior to said aggregate injecting step.

9. A method of placing an aggregate pack around a sand screen in a wellbore, said method comprising: placing in the wellbore a conduit string having a permanent hydraulic packer, a permanent tubular housing, a removable tubular mandrel inside the packer and housing, a check valve in lower end of the mandrel, valve means below the packer, and a sand control screen below the housing; closing the bore through the mandrel below the packer; applying hydraulic pressure to the conduit string to actuate the packer; shearing the bore closure below the packer from the mandrel; injecting a slurry containing a carrier fluid and an aggregate material into the conduit string and
through the valve means into the wellbore around the sand-screen; squeezing the slurry to force the carrier fluid into the formation and the aggregate to pack in the wellbore; removing the mandrel and conduit string from the wellbore; and, lowering a production string through the packer into sealing engagement in the housing below the valve means thereby opening a flow communication bore from the sand-screen through the production string.