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EROSION PROTECTION IN WELLS

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FIG. 1

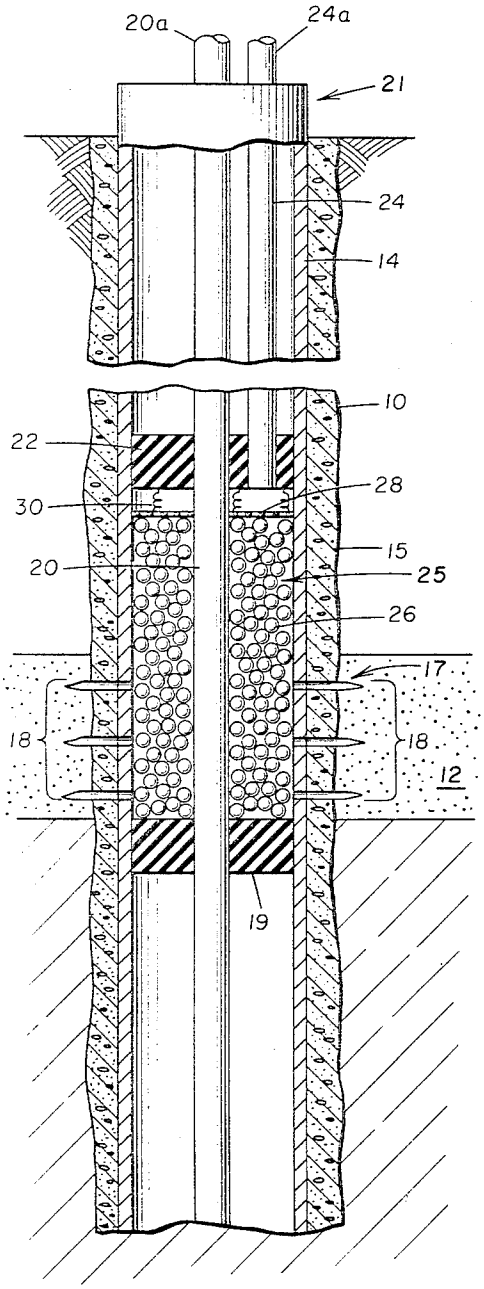
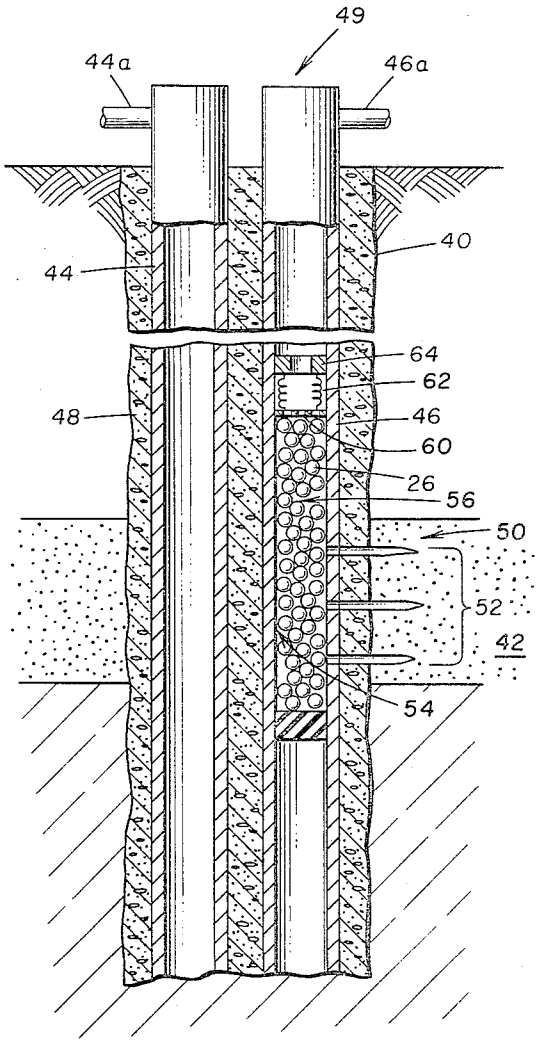


FIG. 2



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EROSION PROTECTION IN WELLS

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ABSTRACT OF THE DISCLOSURE

This specification discloses:

A method and apparatus for alleviating erosion of the surface of a tubing carrying fluid from a lower formation in a multiply completed well from the erosive effects of a fluid entering the well under pressure from a higher formation which include positive unconsolidated, erosive-resistant particles such as plastic spheres within the well adjacent the higher formation. The erosive fluid entering the well will impinge on the particles and be converted to turbulent flow before it reaches the surface to be protected. As the erosive fluid disintegrates some of the particles, other particles will move downward to replace them, thus maintaining a pack of particles between the incoming fluid and the surface to be protected.

This invention relates to the production of subterranean fluids through wells, and more particularly to a method and apparatus for alleviating erosion of downhole well equipment by detrital material contained in such subterranean fluids.

In the petroleum industry, downhole well equipment often is subjected to erosion due to the abrasive action of detrital material such as unconsolidated sand grains entrained in petroleum fluids as they enter the well. This problem most often is encountered in multiply completed wells which produce fluids from two or more levels in a well. The most common multiply completed wells are dual-completion wells in which oil or gas is produced from two vertically spaced subterranean formations. A conventional manner of dually producing such formations is to set and cement casing through both formations and then set a casing packer between the formations. A tubing string is extended through the packer with its lower open end landed adjacent the lower productive formation. The casing packer thus effectively seals off the annular space between the tubing and casing and isolates the lower formation, which is in fluid communication with the interior of the tubing string. The fluid from the lower formation thus flows through the tubing and to the surface of the well or wellhead separately from the fluid from the upper formation which is produced through perforations in the casing into the annulus between the casing and the tubing string. The fluid from the upper formation flows to the wellhead either directly through the annulus or through an additional tubing string.

Another form of dual-completion well is the so-called "slim hole" dually completed well. In this arrangement the well is not cased in the conventional manner and two parallel strings of tubing or small casing are cemented in the well. Each tubing string is perforated selectively at the level of one of the subterranean formations and each formation is separately produced through its respective tubing string.

In either form of multiple completion, a section of pipe such as well tubing extends past a productive formation and thus is exposed to the produced subterranean fluid as it enters the well either through perforations in the wall of the casing, as in the first above-described arrangement, or through the perforations in the wall of the tubing itself, as in the second above-described arrangement. The fluid usually is under substantial pressure and passes from the productive formation through the restricted perforations in the casing or tubing at high velocity and in jetted streams. This particularly is true where the fluid being produced is comprised primarily of gas. Such fluid often has a content of sand or other particulate detrital material which impinges against the pipe surface adjacent the perforations. Such detrital material entrained in the incoming fluid abrades and erodes the pipe surface, thus leading to pipe failure, and also intensifying the corrosion of the pipe.

In the past, numerous means have been employed in attempts to protect tubing surfaces and alleviate the erosion thereof. One technique involves the wrapping of layers of lead around the tubing on the theory that a malleable material would absorb some of the kinetic energy of the detrital material more readily than the tubing itself. Alternatively, hard, brittle material such as ceramics and glass and resilient materials such as rubber have been employed as protective materials for the tubing. While such techniques have met with some success, the resilient coatings usually being the most effective, none of these techniques have proven entirely satisfactory.

One difficulty experienced with the heretofore practiced procedures resides in the fact that the materials used, even though sometimes more resistant to the abrasive action of the detrital material than the metal pipe surfaces, still experience some erosion and ultimately fail, leaving the pipe surfaces exposed. This of course necessitates expensive workovers such as withdrawing the tubing, repairing it if necessary, and providing additional protective material.

In accordance with the instant invention, there is provided a new and improved method and apparatus for alleviating erosion of downhole equipment and which is not subject to the disadvantages of the heretofore practiced techniques. More particularly, the instant invention provides a method and apparatus wherein protective particles are interposed between the openings through which subterranean fluids are produced and the metal surfaces adjacent such openings and in which such protective particles are replenished continually as they are eroded away by the abrasive action of detrital material entrained in the incoming fluids.

In carrying out the present invention, there is provided a well traversing a subterranean formation from which it is desired to recover fluids such as petroleum gases. The well has a conduit therein with an open production interval at the level of the formation. The open production interval may be defined by a plurality of perforations as will be recognized by those skilled in the art. For example, the open production interval may be formed by gun perforating a section of the conduit adjacent the producing formation. In producing the well, fluid is flowed from the formation through the open production interval in the conduit and thence upwardly within the conduit to the surface of the well. In accordance with the invention, detrital material entrained in the produced fluid is contacted within the conduit and opposite the open production interval with a plurality of unconsolidated, erosion-resistant particles ot reduce the kinetic energy of the detrital material. The particles are of a shape having a curved, substantially continuous outer surface whereby relative movement between the particles is facilitated. As the erosion-resistant particles are disintegrated by the abrasive action of the entrained detrital material, additional erosion-resistant particles are supplied to the space in the conduit opposite the open production interval.

In a well assembly comprising a preferred embodiment of the invention, a pack of the above-described unconsolidated erosion-resistant particles is disposed within the

annular space between the well casing and tubing string opposite the open production interval and extends to a level above the top of the open production interval. Preferably, the pack of unconsolidated particles extends above the top of the open production interval by a distance at least as great as the length of the open production interval. Since these erosion-resistant particles are characterized by having a curved, substantially continuous outer surface, as the particles opposite the open production interval are disintegrated by the abrasive action of the detrital material entrained in the incoming fluids, particles in the pack above the open production interval continually fall into place and replace those thus destroyed. Thus, effective erosion protection is continuously provided for the metal tubing surface in the well opposite the open production interval, thus greatly increasing the time between workovers of the well or sometimes even making such workovers unnecessary.

For a better understanding of the instant invention, reference may be had to the following detailed description taken in conjunction with the accompanying drawings in which:

FIGURE 1 is an elevation partly in section illustrating one embodiment of the invention; and

FIGURE 2 is an elevation partly in section illustrating another embodiment of the invention.

With reference to FIGURE 1, there is shown a wellbore **10** traversing a productive formation **12** and provided with a first conduit or casing string **14**. The casing is cemented as indicated by **15** and the casing and surrounding cement sheath are provided with a plurality of perforations **17** which define an open production interval as indicated by brackets **18**. Although in most instances of carrying out the present invention the open production interval will be defined by a plurality of circular perforations formed by jet or gun-perforating techniques, it will be understood that other suitable arrangements may be used. For example, the open production interval may be formed by so-called "shop-perforated" or slotted pipe in which the openings are formed prior to insertion of the casing into the well. Also, the open production interval may be defined by one or more narrow longitudinally extending openings within the casing **14** and cement **15**. Such procedures of opening a casing to the flow of subterranean fluids are well known in the art and will not be described further. It will be understood, however, that the term "open production interval" as used herein and in the appended claims is intended to cover all such means of providing a flow path for the ingress of fluids from the exterior of the casing.

A packer **19** is disposed between the productive formation **12** and a lower productive formation (not shown) in order to isolate these formations from one another so that there is no communication between these formations within the well. A production tubing string **20** is disposed in the well as illustrated and extends from the wellhead **21** and is landed at a level (not shown) below the packer **19**, usually adjacent the lower productive formation. Fluids from the lower productive formation thus are produced through the interior of the tubing string **20** and carried to the surface of the well where they pass into a suitable gathering line **20***a*.

A second packer **22** is provided between the tubing string **20** and casing **14** at a point above the top of the productive formation **12**. A second tubing string **24** extends from the surface of the well and through the second packer **22** as shown. As is apparent from the drawing, the second tubing string **24** provides a production passage to the surface of the well for fluids produced from the productive formation **12**. At the wellhead, fluids from tubing string **24** are delivered into gathering line **24***a*.

The production equipment thus far described is conventional and does not by itself form any part of the present invention. Also, it will be understood that the arrangement thus far described is exemplary only and that other suitable arrangements may be used. For example, tubing **24** and packer **22** may be dispensed with and fluids from the productive formation **12** may be produced to the surface of the well directly through the annular space defined by the tubing **20** and the casing **14**. Alternatively, tubing string **20** may not extend to the wellhead, but instead may terminate within or above packer **22**, in which case fluid from the lower formation will pass from tubing **20** into the space between tubing **24** and casing **14** and thence upwardly to the wellhead. Also, while only a single casing string **14** is shown, it will be understood that the well may be provided with a plurality of casing strings. For example, the well may be provided with a suitable conductor pipe or surface string and one or more intermediate strings as will be understood by those skilled in the art. In addition, while the casing **14** in FIGURE 1 is shown as extending completely to the surface of the well, it will be understood that other suitable arrangements may be used. For example, the perforated outer conduit may take the form of a liner which is suspended from or otherwise extends into a casing string. Also, the perforated conduit may take the form of a so-called "scab liner" which does not extend up into a casing string but simply rests upon the bottom of the borehole and is cemented therein in accordance with conventional practices. In this case, all or part of the well above the perforated liner may be uncased. Such completion practices are well known to those skilled in the art and therefore will not described further.

In accordance with the instant invention, there is disposed within the space between tubing **20** and casing **14** and adjacent the open production interval **18** a pack **25** of unconsolidated, erosion-resistant particles **26**. The erosion-resistant particles may be made of any suitable material. For example, they may be formed of ceramic material, steel, or in some cases suitable plastics exhibiting favorable erosion-resistant and resilient properties. One such plastic which is particularly suitable for use in forming the erosion-resistant particles is high impact resistant polypropylene.

The erosion-resistant particles are of a shape having a curved, substantially continuous outer surface in order to facilitate relatively easy movement therebetween. It is particularly important that the particles be of a shape providing such a surface. Care should be taken to avoid the use of angular particles having predominantly flat surfaces which may lead to bridging within the pack and leave the tubing surface exposed to the jetted streams entering the well through the casing perforations. The erosion-resistant particles preferably are spherical although they may be of other suitable shapes. For example, they may take the form of spheroids or ellipsoids. Also, the curved outer surface need only be substantially continuous and may contain minor discontinuities such as those caused by impression markings. For example, the particles may be in the form of spheres having one or more impressions serving as indicia for identification purposes.

With the pack **25** disposed as shown in FIGURE 1, the incoming fluid streams emanating from perforations **17** are altered in directional flow as they impinge upon the erosion-resistant particles. The particles thus provide a baffling function which reduces the kinetic energy of the detrital material entrained in the incoming fluid and converts the initial laminar flow of this fluid to turbulent flow. Thus, little detritus will come into contact with the outer surface of tubing **20** and that which does so contact the tubing surface will be at a low kinetic energy state such that little or no erosion of the tubing surface is effected. The particles **26** will undergo erosion due to the abrasive action of the entrained detrital material and ultimately will be disintegrated. However, as this occurs, additional particles from the reservoir portion of pack **25** above the open production interval will fall into place within the space adjacent the open production interval, thus providing continuous erosion protection for the outer

surface of tubing 20. The movement of these particles is facilitated by the shape thereof.

As the incoming fluid flows upwardly through the pack of erosion-resistant particles, the velocity of the fluid and the pressure differential extending from the lower to the upper portion of the pack will tend to force the particles upwardly through the annular space between the tubing 20 and the casing 14. That is, the particles 26 will tend to become entrained in the produced fluid and carried upwardly through the annular space. In order to prevent this, there is provided in accordance with a preferred embodiment of the instant invention a perforate barrier means 28 which functions to restrict the upward movement of the particles. The barrier means may be of any suitable type that allows the passage of fluid therethrough and restricts movement of the particles, but it preferably will comprise a perforated plate slidably disposed in the annular space within the casing 14 and the tubing 20. By so disposing the annular plate 28, it is free to rest upon the top of the pack and to move downwardly therewith as the particles are disintegrated due to the abrasive action of the detrital material. This will prevent or at least alieviate substantial "chattering" of the erosion-resistant particles as they tend to move upwardly under the flow of fluid through the annulus and impinge upon the bottom of the plate 28.

The plate 28 mayl be formed of a relatively heavy material in order to exert sufficient downward force on the pack 25. The downward force exerted by the plate should be at least equal and preferably slightly greater than the upward force exhibited on the plate due to the flow of fluid through the annulus. Preferably, the plate is provided with one or more means biasing it downwardly. Such means may take the form of a plurality of coil springs 30 compressibly disposed between packer 22 and the plate 28.

In certain instances, the barrier means may be dispensed with. For example, if the particles 26 are formed of a relatively heavy material such as lead it may not be necessary to employ the barrier means in order to restrict upward movement of the particles. Also, although not usually preferred, a stationary barrier may be employed. For example, in the assembly shown in FIGURE 1, the packer 22 may be utilized as a barrier. In this case, a screen or other suitable means for restricting upward movement of the particles 26 should be secured across the mouth of tubing 24.

Turning now to FIGURE 2, there is shown an alternative form of the invention embodied within a dually completed well of the so-called "slim hole" type. With reference to FIGURE 2, there is shown a borehole 40 which extends from the surface of the earth and traverses a subterranean productive formation 42 and a lower formation (not shown). The borehole 40 contains at least two parallel production strings or flow tubings 44 and 46 which are cemented within the hole by means of cement 48. In the installation illustrated, pipe string 46 is completed for the production of fluids from formation 42 and pipe string 44 is completed for the production of fluids from the lower formation. That is, fluids from the productive formation 42 flow upwardly through the interior of string 46 to the wellhead 49 where they are passed into a suitable gathering line 46*a* and production fluids from the lower formation pass upwardly through the interior of string 44 where they are likewise passed to a suitable gathering line 44*a*. As in the embodiment of FIGURE 1, the flow tubing 46 is provided with perforations 50 which define an open production interval 52 within the wall thereof.

In well completions of the type illustrated in FIGURE 2, the predominant erosion problem is due to the impingement of detrital material against the inner surface of the pipe string opposite the open production interval. That is, as will be apparent from an examination of FIGURE 2, the surface generally indicated by reference numeral 54 is subject to erosion due to the abrasive action of detrital material entrained in fluids as they pass through the perforations 50 into the interior of pipe string 46.

In the well installation of FIGURE 2, there is provided in accordance with the instant invention a pack 56 comprising a plurality of erosion-resistant particles 26 of a shape having a curved, substantially continuous outer surface of the nature described above with respect to FIGURE 1. As in the embodiment of FIGURE 1, the pack 56 preferably is provided with a perforate barrier means 60 slidably disposed within the conduit 46. A plurality of coil springs 62 are compressively interposed between the barrier means 60 and an open packer 64 or other suitable means fixedly mounted within the conduit 46. The barrier means 60 functions similarly as the barrier means 28 in the embodiment of FIGURE 1 in order to restrict upward movement of the erosion-resistant particles 26.

Considerable latitude may be allowed as to the shape and size of the erosion-resistant particles. As noted previously the particles preferably are substantially spherical in shape. The particles should have a minimum diameter of one-eighth inch and preferably a minimum diameter of at least one-fourth inch in order to provide a sufficient surface area to the flow of incoming production fluid containing entrained detrital material. Preferably, the erosion-resistant particles are of a size having a least dimension greater than the least dimension of the perforations 17 or 50 in order to prevent the particles from entering into the perforations and possibly causing plugging thereof.

The maximum size of the erosion-resistant particles is determined by the dimensions of the conduits disposed in the well. In order to provide at least minimal protection, the erosion-resistant particles should be of a size sufficiently small to allow at least two particles to occupy the cross-sectional or lateral space between the open production interval in the well conduit and the metal surface opposite this interval which is subject to erosion by the detrital material entering the well. Preferably, the particles should be small enough to allow at least three particles to occupy this space. Thus, the erosion-resistant particles should be of a size the greatest dimension of which is at least less than one-half, and preferably less than one-third, of this cross-sectional space.

With regard to the installation shown in FIGURE 1, where the particles 26 are spherical and the casing 14 and tubing 20 are substantially cylindrical and disposed substantially concentrically with respect to one another as is the usual case, the erosion-resistant particles should have a diameter less than one-half the difference between the inner diameter of the casing 14 and the outer diameter of the tubing 20. Preferably, the erosion-resistant particles will have a diameter less than one-third of this difference in order that the cross-sectional space between the tubing and casing may accommodate at least three particles. The same considerations apply with regard to the embodiment of FIGURE 2, that is, the erosion-resistant particles should have a diameter less than one-half, and preferably less than one-third, of the inner diameter of conduit 46.

The length of the pack of erosion-resistant particles will depend upon various factors such as the erosion experience of the well involved, the material of which the particles are made, and the desired minimum time between workovers of the well. While these and other factors will vary considerably from well to well, in order to provide an adequate level of continuous erosion protection, the pack in practically all cases should be large enough to supply a reservoir of erosion-resistant particles at least equal to the particles disposed adjacent the open production interval. Thus, it is preferred in practicing the instant invention to utilize a pack of erosion-resistant particles which extends above the open production interval by a distance at least as great as the length of the

open production interval. In many cases, of course, it may be desirable to employ a pack of much greater size, for example, three or four times the length of the open production interval or even longer.

Having described certain specific embodiments of the instant invention, it will be understood that further modifications thereof may be suggested to those skilled in the art, and it is intended to cover all such modifications as fall within the scope of the appended claims.

What is claimed is:

1. In a well adapted for production of subterranean fluids, an assembly for alleviating erosion of downhole equipment, comprising:

a conduit disposed in said well, said conduit having an open production interval therein adapted for the passage of subterranean fluids into the interior of said conduit;

a pack of unconsolidated, erosion-resistant particles disposed within said conduit opposite said open production interval and extending to a level above the top of said open production interval, said particles being of a shape having a curved, substantially continuous outer surface whereby relative movement between the particles is facilitated;

barrier means slidably disposed in said conduit adjacent the upper end of said pack for restricting upward movement of said particles; and

means in said conduit for biasing said barrier means downwardly in said conduit.

2. The assembly of claim 1 wherein said pack of erosion-resistant particles extends above said open production interval by a distance at least as great as the length of said open production interval.

3. The assembly of claim 1 wherein said open production interval comprises a plurality of perforations in said conduit and said erosion-resistant particles have a least dimension greater than the least dimension of said perforations.

4. The assembly of claim 1 wherein said open production interval comprises a plurality of substantially circular perforations in said conduit and said erosion-resistant particles are substantially spherical in shape.

5. The assembly of claim 4 wherein said erosion-resistant particles have a diameter of at least one-eighth inch.

6. The assembly of claim 4 wherein said erosion-resistant particles have a diameter of at least one-fourth inch.

7. In a well adapted for the production of subterranean fluids, an assembly for alleviating erosion of downhole equipment, comprising:

a conduit disposed in said well, said conduit having an open production interval therein adapted for the passage of subterranean fluids into the interior of said conduit;

a second conduit of a smaller size than said first conduit disposed within said first conduit opposite said open production interval and extending to a level above said open production interval; and

a pack of unconsolidated erosion-resistant particles disposed within the space between said first and second conduits and extending from at least the bottom of said open production interval to a level above the top of said open production interval, said particles being of a shape having a curved, substantially continuous outer surface whereby relative movement between said particles is facilitated.

8. The assembly of claim 7 wherein said pack of erosion-resistant particles extends above said open production interval by a distance at least as great as the length of said open production interval.

9. The assembly of claim 7 further comprising barrier means adjacent the upper end of said pack for restricting upward movement of said particles.

10. The assembly of claim 9 wherein said barrier means is slidably disposed in said conduit and further comprising means for biasing said barrier means downwardly.

11. The assembly of claim 7 wherein said first and second conduits are substantially cylindrical and substantially concentric opposite said open production interval and said erosion-resistant particles are substantially spherical in shape and have a diameter less than one-half the difference between the inner diameter of said first conduit and the outer diameter of said second conduit.

12. The assembly of claim 11 wherein said erosion-resistant particles have a diameter less than one-third the difference between the inner diameter of said first conduit and the outer diameter of said second conduit.

13. The assembly of claim 11 wherein said open production interval comprises a plurality of perforations in said first conduit and said erosion-resistant particles have a diameter greater than the least dimension of said perforations.

14. In the recovery of fluids from a subterranean formation traversed by a well having a first conduit therein with an open production interval opposite said formation and a second conduit smaller than said first conduit disposed within said first conduit, the method comprising:

flowing fluid from said formation through the open production interval of said conduit and upward within the annulus defined by the inner surface of said first conduit and the outer surface of said second conduit, said fluid having entrained therein abrasive detrital material;

contacting said fluid within said annulus and opposite said open production interval with a plurality of unconsolidated, erosion-resistant particles of a shape having a curved, substantially continuous outer surface and having a greatest dimension less than one half the least cross-sectional dimension of said annulus;

reducing the kinetic energy of said fluid while simultaneously disintegrating at least some of said erosion-resistant particles under the abrasive action of said fluid; and

as said erosion-resistant particles are disintegrated, supplying additional erosion-resistant particles to the space within said annulus previously occupied by the disintegrated particles.

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