United States Patent

Saucier

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[54] METHOD OF GRAVEL-PACKING A PRODUCTION WELL BOREHOLE

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Related U.S. Application Data

[63] Continuation of Ser. No. 820,758, May 1, 1969, abandoned.

[52] **U.S. Cl.** **166/252**, 166/268, 166/278

[51] **Int. Cl.** **E21b 43/04**, E21b 43/16

[58] **Field of Search** 166/250, 252, 266–275, 166/276, 278, 227, 51

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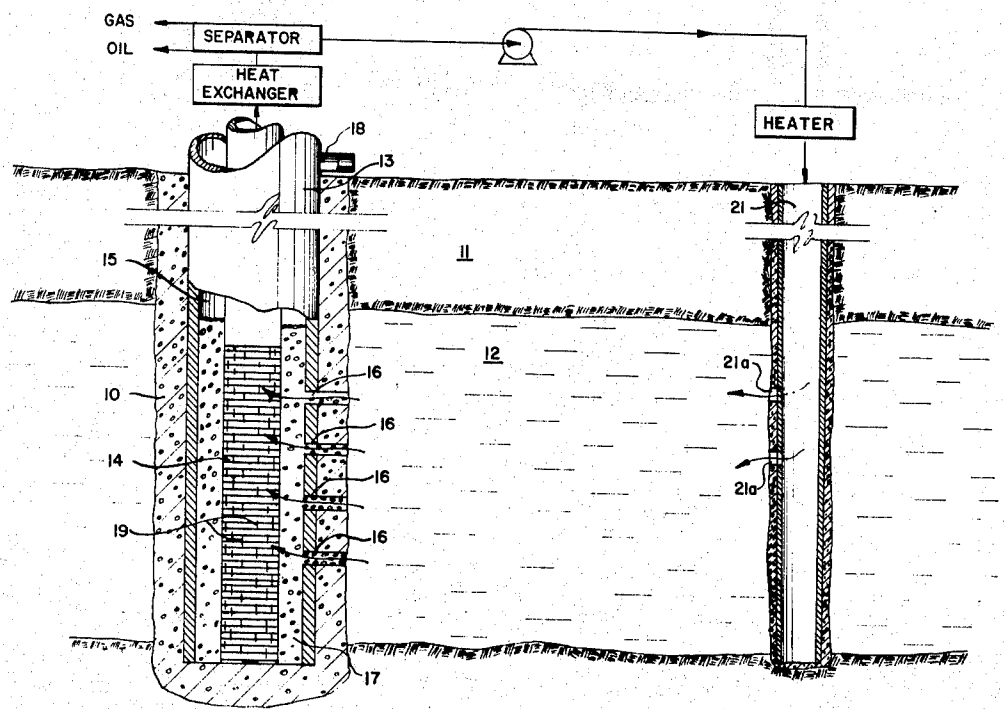
[57] **ABSTRACT**

A method of gravel-packing a well borehole extending into an interval of a hydrocarbon-bearing subterranean earth formation by determining the median size of the sand grains in the interval and forming a pumpable slurry of liquid containing granular particles having a relatively narrow range of grain sizes with a median grain size from about 5 to 7 times larger than the median size of grains in the interval. Perforations are formed in a conduit sized to exclude passage of substantially all the slurried granular particles and the conduit is positioned in the well borehole at a depth adjacent to the interval, thereby forming an annulus between the conduit and the interval. A fluid including the slurry is then flowed into the annulus and into contact with the exterior of the conduit until the annulus is substantially filled with the granular particles. Fluids are then flowed from an injection well borehole into the gravel-packed well borehole for recovering of hydrocarbon-bearing fluids therefrom.

8 Claims, 3 Drawing Figures



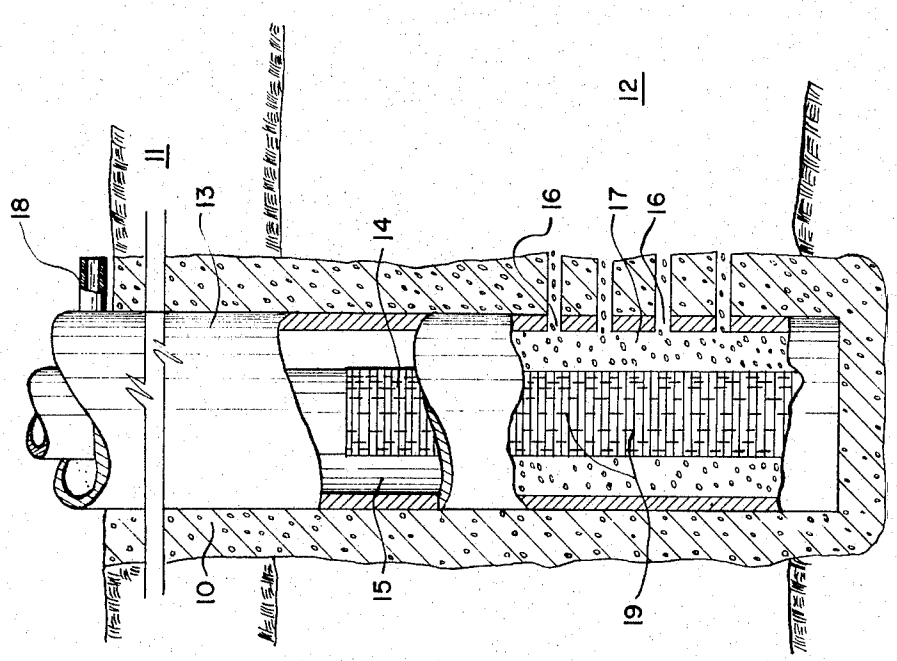


FIG. 1

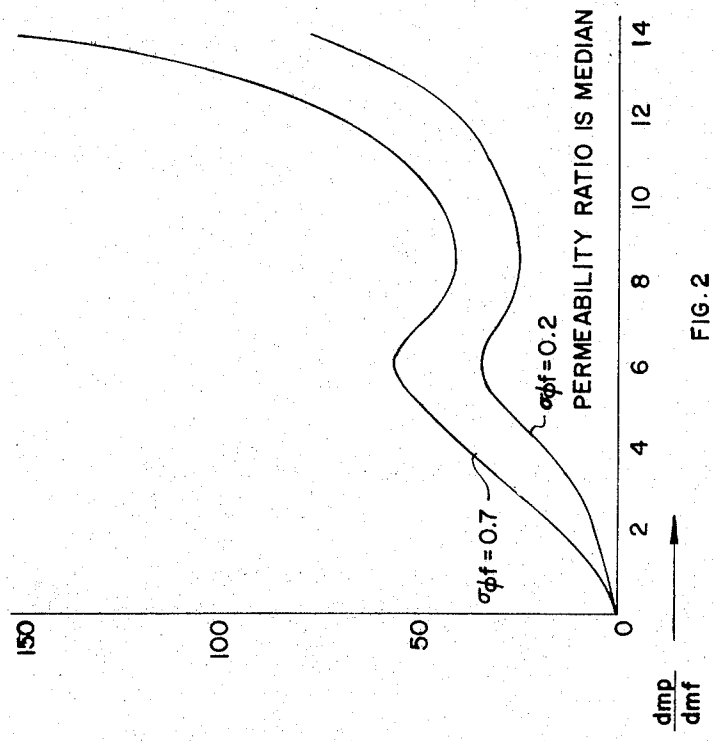


FIG. 2

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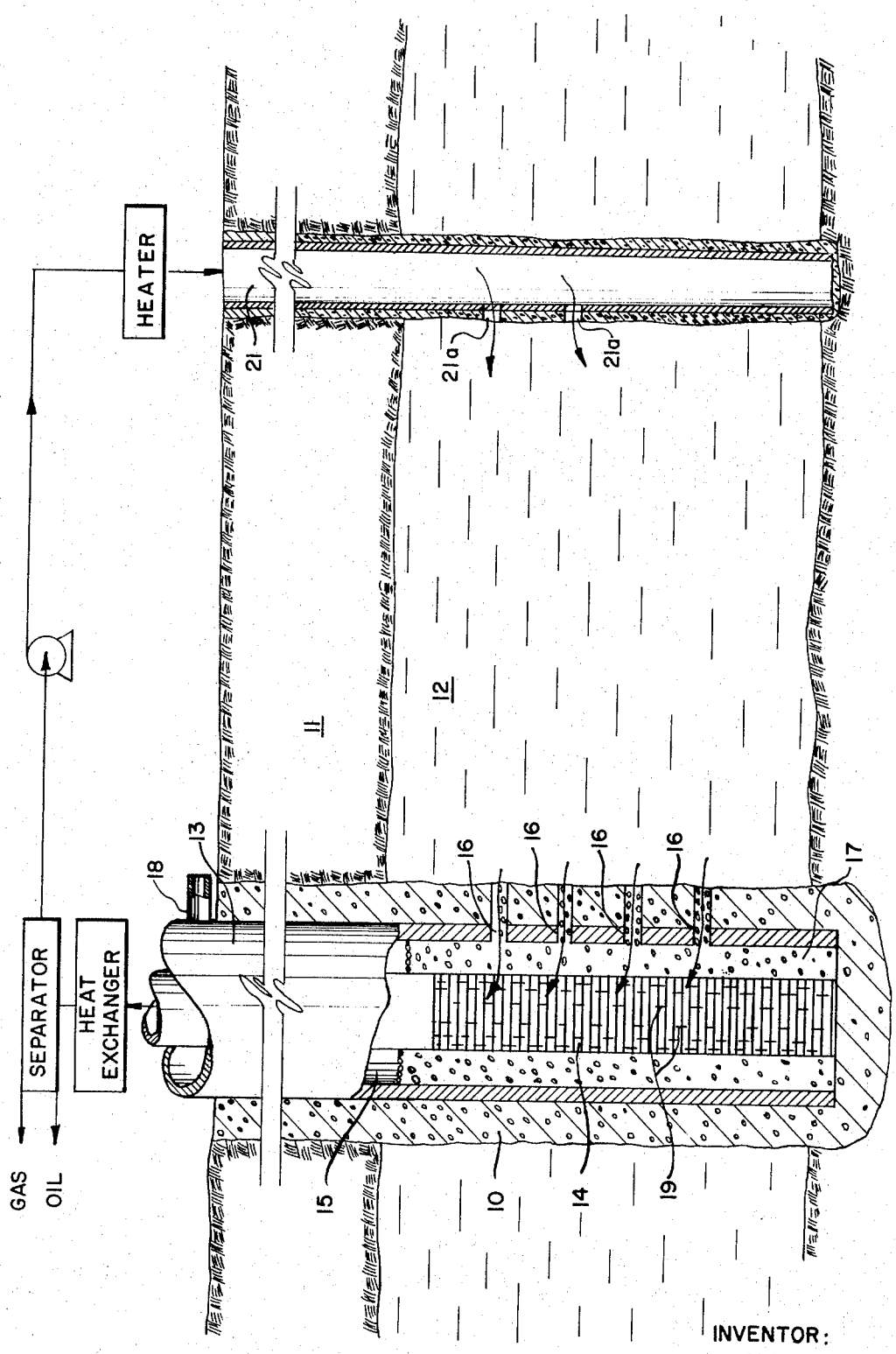

FIG. 3

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METHOD OF GRAVEL-PACKING A PRODUCTION WELL BOREHOLE

This application is a continuation of Ser. No. 820,758, filed May 1, 1969, now abandoned.

BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention relates to gravel-packing a screen or liner in the borehole of a well; and, more particularly, to a method for preventing the movement around and into a well borehole of individual particles comprising an unconsolidated rock formation.

2. Description of the Prior Art

Many underground rock formations are unconsolidated or so poorly consolidated that they disintegrate under the forces exerted upon them by the weight of the overbearing rock and by the flow of formation fluids into a well bore penetrating the formation. Such rock formations are hereinafter referred to generally as unconsolidated formations. It has been found that, when fluids flow from an unconsolidated formation into a well borehole, the displacement of formation particles into the well borehole permits the movement of additional particles farther back in the formation and results in plugging of the well borehole and of the formation flow channels around the well borehole. To prevent the rearrangement of the formation particles under the forces of fluid flow and overburden pressure, it is necessary to prevent substantially the movement of formation particles into the well borehole. It is possible to assure the substantially complete prevention of the movement of formation particles around or into the well borehole by providing mechanical support for the formation particles around the well borehole. Such mechanical support should impart to the formation particles a force directed outwardly from the well borehole whereby the formation particles are retained essentially undisturbed during the production of formation fluids.

Various methods have been suggested for alleviating the problems involved in producing fluids from an unconsolidated formation. In one such method, a slotted or otherwise perforated pipe or liner is centralized in the well borehole and the annulus between the liner and the wall of the well borehole is packed with gravel. The gravel pack is used to filter the formation particles from the produced fluids to prevent their entry into the liner.

Many advantages are visualized for the wellbore equipped with a gravel-packed liner, all of which tend to increase its production efficiency. When properly placed in the annular space between the wall of the wellbore and the perforated liner, gravel supports the walls, prevents caving of loose material against the liner and serves to restrain sand from unconsolidated and disintegrating strata so that it may not enter the wellbore. More effective screening of sand, possible by this means, diminishes the destructive influence of sand scouring on wellbore equipment and tends to reduce maintenance costs. Equipment repairs and wellbore clean-out operations are less frequent and the wellbore is able to produce for a greater part of the time than would otherwise be the case. The wellbore so protected is therefore capable of maintaining a larger average monthly production rate. With gravel to sustain the walls of the wellbore, it is possible to form and maintain a hole of larger diameter through the producing formation without elsewhere increasing the normal diameter of the wellbore or that of the wellbore casing. The larger diameter hole through the producing zone results in increased production efficiency.

To be effective in sand screening, it was heretofore believed to be essential that the perforated liner be completely enveloped through the producing formation with a gravel sheath of suitable thickness; that the perforations in the liner be of such size as completely to exclude all the gravel and that the gravel particles be of such size and so compacted as to permit only the very smallest sand particles to pass through with the formation fluids into the wellbore. The coarser sand particles must bridge over the openings between the gravel particles at or near the sand-gravel interface. These coarse sand particles in turn serve as a barrier for finer sand grains and thus, in time, a combination gravel-sand screen is built up that is stable for the particular flow conditions obtaining.

The size of the gravel particles should be proportioned to the prevailing size of the sand particles to be restrained. Sand grains are of assorted sizes and shapes and it is difficult to apply mathematical principles to them. According to Coberly and Wagner in "Some Considerations in the Selection and Installation of Gravel Packs for Oil Wells," AIME Tech. Publ. No. 960, 1937, a gravel pack having granular particles of 10 times the formation grain size at the 10 percent coarse point on a cumulative sieve analysis would provide effective sand control. Numerous failures using this criterion were noted, especially under disturbed fluid flow conditions. Tausch and Corley in "Sand Exclusions in Oil and Gas Wells," 1958, *Drilling and Prod. Prac., API*, pp. 66–82, summarized the gravel-packing situation and noted that conventional gravel-packing processes comprise the steps of (a) conducting a screen analysis of the size of the grains in the interval of earth formation to be packed, (b) slurrying gravel particles having a median size of about 8 to 14 times that of the 10 percent coarse point of the screen analysis, and (c) installing the packing grains and a screen having approximately sized perforations in the well in the manner described above.

Thus, prior art procedures stress the importance of utilizing the maximum feasible extent of a bridging effect in order to keep the size of the packing grains as large as possible. Such sizes are generally around 10 times the formation grain size. This teaching is consistent with the known fact that the permeability of a mass of particles tends to decrease with decreases in the size of the particles. Known techniques have proven inadequate in coping with sand production problems encountered in the field, especially under disturbed flow conditions induced by surges and gas evolution.

SUMMARY OF THE INVENTION

It is an object of this invention to provide an improved method for gravel-packing a well borehole extending into a subterranean earth formation.

It is a further object of this invention to provide a method for gravel-packing a well borehole in such a manner that the permeability of the pack remains unimpaired under disturbed flow conditions.

These and other objects are preferably accomplished by determining the median size of the sand grain in an interval of subterranean earth formation and forming a pumpable slurry of liquid containing granular particles having a relatively narrow range of grain sizes with a median grain size from about 5 to 7 times larger than the median size of grains in the interval. Perforations are formed in a conduit sized to exclude passage of substantially all of the slurried granular particles and the conduit is positioned in a well borehole extending into the earth formation at a depth adjacent to the interval, thereby forming an annulus between the conduit and the interval. A fluid including the slurry is then flowed into the annulus and into contact with the exterior of the conduit until the annulus is substantially filled with the granular particles.

BRIEF DESCRIPTION OF THE DRAWING

FIG. 1 is a vertical sectional view of a well borehole having a gravel-packed slotted liner or screen placed therein in accordance with the teaching of my invention;

FIG. 2 is a graph illustrating one of the features of my invention; and

FIG. 3 is a vertical sectional view of the well borehole of FIG. 1 showing fluids being produced from the formation thereof.

DESCRIPTION OF THE PREFERRED EMBODIMENT

During the normal operation of a gravel-packed well borehole extending into a subterranean earth formation, I have found that the effects of particle bridging should be minimized and the effective permeability of specified relatively finely grained gravel pack is actually greater than that of a conventional relatively coarsely grained gravel pack. In accordance with my invention, therefore, the use of a specified gravel size involves a gravel packing process that is distinct in respect to using a non-conventional item of data concerning the formation grain sizes (i.e., the median size, rather than the 10 percent coarse size used in prior art processes), a non-conventionally smaller packing grain size and a non-conventionally smaller size of openings in the screen or liner to be installed in a well borehole. Although the techniques of my invention will be described further hereinbelow with respect to perforated casing types of well completions, obviously the same techniques are applicable to so-called "open hole" types of well completions.

Referring now to the drawing, FIG. 1 shows a well borehole 10 extending through a subterranean earth formation 11 into communication with a permeable interval 12. It is to be understood that interval 12 is a relatively unconsolidated or poorly consolidated portion of earth formation 11, thus raising problems in producing hydrocarbons therefrom as discussed in detail hereinabove.

Well borehole 10 is preferably cased, as at casing 13, with casing 13 cemented therein as is well known in the art. A wire-wrapped screen or liner 14 is disposed in casing 13 adjacent to interval 12, thus forming an annulus 15 between casing 13 and screen 14. Casing 13 is perforated at perforations 16, i.e., at a plurality of points extending along screen 14.

In operation, gravel 17 is pumped into the annulus 15 from an annulus outlet 18 into contact with the exterior of screen 14 until the annulus 15, at least along substantially the entire extent of interval 12, is packed with the gravel 17.

In accordance with my invention, the median size of the sand grains in interval 12 is determined. A slurry of liquid is formed containing granular particles having a relatively narrow range of grain sizes and a median grain size from about 5 to 7 times larger than that of the sands in interval 12. The screen 14 is selected so that the perforations or openings 19 in the screen 14 are sized to exclude passage of all the slurried granular particles.

Thus, the gravel 17 is slurried and pumped down annulus outlet 18 as discussed hereinabove. The liquid including the granular particles (i.e., the gravel 17) flows out of perforations 16 into interval 12 while depositing the gravel 17 in the annulus 15 and the perforations 16.

The following information, obtained from laboratory testing, shows the importance of median grain size ratio on gravel pack effectiveness and that previously recommended criteria were shown to be unsatisfactory.

TABLE I

PARTICLES SIZE RATIO VERSUS PACK EFFECTIVENESS

Test Designation	Ratio of Pack to Formation Median Grain Size	Ratio of Pack Median to Formation 10% Coarse Point	Results of Test
1411	14.7	10.7	Formation not retained
161	14.7	7.4	Formation not retained
111	5.7	4.5	Formation retained
131	5.7	3.2	Formation retained

These tests confirm that, under severe conditions of operation, the ratio of pack to formation median grain size must be less than about 6 to minimize sand production.

Although the median pack-to-formation grain size ratio of about 5 to 7 results in using finer grain particles than those in prior art gravel packs, such utilization does not result in a reduced effective pack permeability because the reduction in pack impairment by formation particles is more significant than permeability reduction due to finer gravel packs. Rounded or frac gravel is preferred to angular gravel to further reduce impairment, as will be discussed further hereinbelow.

During operation of a gravel pack, formation sand may enter a gravel pack and reduce the initial pack permeability k_{INIT} to an effective pack permeability k_{EFF}. An empirical curve was obtained of the ratio of k_{EFF}/k_{INIT} versus gravel to sand grain size ratio.

To define the ratio of effective pack permeability to formation permeability, the expression for permeability k may be taken from Krumbein, W. and Monk, G., "Permeability as a Function of Size Parameters of Unconsolidated Sand," Trans. AIME, Vol. 151, pp. 153–160, as:

$$k = Cd_m^2 e^{-1.31\sigma_\phi} \quad (1)$$

where

C is a function of particle shape, packing and skewness;

d_m = median grain size; and

σ_ϕ = standard deviation of the granular material.

If it is assumed that C for the pack and formation are the same, then the desired ratio is:

$$k_p k_f = \left(\frac{d_{mp}}{d_{mf}}\right)^2 e^{1.31(\sigma_{\phi f} - \sigma_{\phi p})} \cdot q\left(\frac{d_{mp}}{d_{mf}}\right) \quad (2)$$

where

$$q\left(\frac{d_{mp}}{d_{mf}}\right) = \begin{cases} 1 & 5 \lesssim \frac{d_{mp}}{d_{mf}} \lesssim 20 \\ \frac{k_p}{k_{INIT}} & 5 \lesssim \frac{d_{mp}}{d_{mf}} \lesssim 20 \end{cases}$$

(as obtained empirically) and

k_p = effective total permeability of the gravel;

k_f = total permeability of the formation;

d_{mp} = median pack grain size;

d_{mf} = median formation grain size;

$\sigma_{\phi f}$ = standard deviation of the granular material of the formation;

$\sigma_{\phi p}$ = standard deviation of the granular material of the gravel pack;

q = volumetric flow rate; and

k_{INIT} = initial unimpaired total permeability of the gravel.

Assuming that $\sigma_{\phi f} = 0.7$ or 0.2 and that $\sigma_{\phi p} = 0.2$, equation (2) results in the two curves shown in the graph of FIG. 2 after we have determined and plotted the values listed hereinabove. FIG. 2 thus shows that in order to maintain the highest pack-to-formation permeability ratio (that is, minimum well impairment) as well as minimizing sand production, the median grain size ratio (d_{mp}/d_{mf}) should be between 5 and 7.

EXAMPLE

For a range of typical formation sands, the following gravel packs were required under the indicated conditions:

1. 0.060 – 0.040 inch (12–18 U.S. mesh). This pack was found to be effective for formations having a median grain size between 0.168 and 0.25 mm.

2. 0.047 – 0.023 inch (16–30 U.S. mesh). This pack size was found to be effective for formations having a median grain size between 0.114 and 0.164 mm.

3. 0.033 – 0.017 inch (20–40 U.S. mesh). This pack size was found to be effective for formations having a median grain size between 0.088 and 0.124 mm.

Increasing the density and/or size of openings in the casing **13** may effect the productivity of well borehole **10**. It also makes the impairment of any single perforation **16** less critical to overall well production.

The foregoing discussions indicate that gravel pack sizing is preferably based upon a median pack-to-formation grain size ratio of 6 for operation under flow disturbances as would be induced by surges and gas evolution. The utility of particle bridging in gravel packs under disturbed flow is diminished so as to be insufficient in designing a gravel pack. To minimize the influence of formation grain size distribution the median grain size of the formation is used rather than the 10 percent coarse grain size used in prior art techniques. For an effective gravel pack, the maximum gravel pack permeability occurs for a median pack-to-formation grain size ratio between **5** and **7**. Preferably, the gravel is packed as tightly as possible in the openings **16** in the casing **13**. In flowing fluid down injection well borehole **21**, out perforations **21***a*, through formation **12** for subsequent production of formation fluids, as illustrated in FIG. **3** wherein like numerals refer to like parts of FIG. **1**, the initial flow rate is preferably increased gradually rather than rapidly. Thus, pumping, heating, heat exchanging and separating equipment may be used for circulating fluids down injection well borehole **21** and into interval **12** and out of at least a second producing well borehole **10**, similar to well borehole **10** of FIG. **1**, as is well known in the art. Fluid communication may be established between the boreholes by any means known in the art, such as by hydraulic fracturing. Hydrocarbons are then separated from the recovered formation fluids and the circulating fluid is recovered and recirculated back into well borehole **21**. Rounded pack grains (i.e., frac sands) for the gravel pack are preferred to angular particles to improve the possibility of fine particles flowing through the pack, thus reducing pack impairment tendencies. Low solids fluids are preferably used to carry the gravel **17** during gravel pack placement to preclude plugging of the pack during placement operations. Typical placement fluids may be cleaned prepared saltwater or diesel.

Thus, in the method of my invention, the size of the packing grains in the gravel pack is kept small enough to emphasize the absolute stoppage of formation grains. The median size of the packing grains is only from about 5 to 7 times larger than that of the formation median grain size. The effective permeability of such a pack is greater than that of both a conventionally designed pack in which the grains are significantly larger and a pack in which the grains are significantly smaller.

What is claimed is:

1. A method of gravel-packing a well borehole extending into an interval of a hydrocarbon-bearing subterranean earth formation comprising the steps of:

determining the median size of the sand grains in said interval;

forming a pumpable slurry of liquid containing granular particles, substantially all of said particles having a relatively narrow range of grain size with a median grain size from about 5 to 7 times larger than the median size of grains in said interval;

forming perforations in a conduit sized to exclude passage of substantially all of said slurried granular particles;

positioning said conduit in said well borehole at a depth adjacent to said interval, thereby forming an annulus between said conduit and said interval;

flowing a fluid including said pumpable slurry of liquid into said annulus into contact with the exterior of said conduit; and

maintaining said fluid in contact with said conduit until said annulus is substantially filled with said granular particles;

extending at least a second well borehole into communication with said interval;

establishing fluid communication between said first-mentioned well borehole and said second well borehole;

circulating fluid down said second-mentioned well borehole, through said interval, through the perforations in said first-mentioned well borehole, through said granular particles therein, and out the conduit disposed in said first-mentioned well borehole; and

recovering hydrocarbons from said fluid flowing out of said first-mentioned well borehole.

2. The method of claim **1** wherein the step of forming a slurry of liquid containing granular particles includes the step of forming a slurry of liquid containing rounded granular particles.

3. The method of claim **1** wherein the step of forming a slurry of liquid containing granular particles having a median grain size from about 5 to 7 times larger than the median size of grains in said interval includes the step of selecting a median grain size of approximately 6 times larger than the median size of grains in said interval.

4. The method of claim **1** including the step of tightly packing said granular particles in said annulus.

5. The method of claim **1** including the step of gradually increasing the flow rate of said circulating fluid from said first-mentioned well borehole to said second well borehole.

6. The method of claim **1** wherein the step of flowing a fluid including said pumpable slurry of liquid includes the step of flowing a low solids fluid including said pumpable slurry of liquid.

7. In a process for gravel-packing a well in which a conduit having openings sized to allow fluid to enter while excluding packing granules is installed within a well and surrounded with packing granules having sizes proportioned relative to the sizes of the granules of an unconsolidated earth formation, the improvement comprising:

proportioning the sizes of the packing granules relative to the sizes of the earth formation granules so that the packing granules have a relatively narrow range of sizes with a median size that is from about 5 to 7 times larger than the median size of the earth formation granules; and

installing said packing granules within the borehole of a well around a conduit that has openings sized to exclude substantially all of said packing granules.

8. The process of claim **7** in which the median size of said packing granules is approximately 6 times larger than the median size of the earth formation granules.

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