United States Patent [19]

Despujols

[11] **3,850,246**

[45] **Nov. 26, 1974**

[54] **GRAVEL PACKING METHOD AND APPARATUS**

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[22] Filed: **July 11, 1973**

[21] Appl. No.: **378,053**

[52] **U.S. Cl.** **166/278,** 166/51

[51] **Int. Cl.** **E21b 43/04,** E21b 43/10

[58] **Field of Search** 166/278, 51, 276, 280, 166/315

[56] **References Cited**

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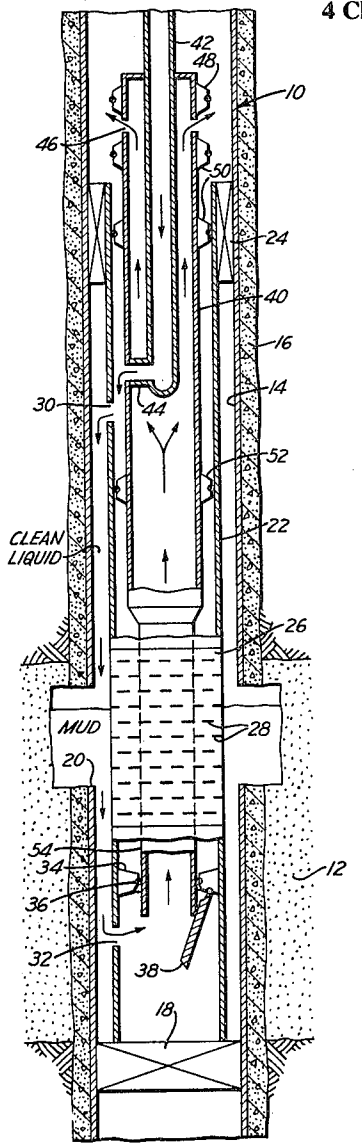
Primary Examiner—Stephen J. Novosad

[57] **ABSTRACT**

A gravel pack is formed around a liner after setting a packer closing the annulus at the upper end of the liner by circulating a clean liquid down tubing and through a crossover connection into the annulus surrounding the liner and displacing liquid containing solids suspended therein upwardly through a wash pipe while preventing flow through slots in the liner. After cleaning the annulus surrounding the liner of liquid having finely divided solids suspended therein, the gravel packing tool is moved and a clean liquid having gravel suspended therein is circulated through the crossover connection into the annulus surrounding the slotted liner. The clean carrying liquid is either displaced into the formation in which the gravel pack is formed or flows through the screen and passes upwardly through the wash pipe and annulus above the packer to the wellhead. A gravel packing tool is disclosed which permits control of flow during the gravel packing operation by movement of the tool without requiring resetting of the packer.

4 Claims, 3 Drawing Figures



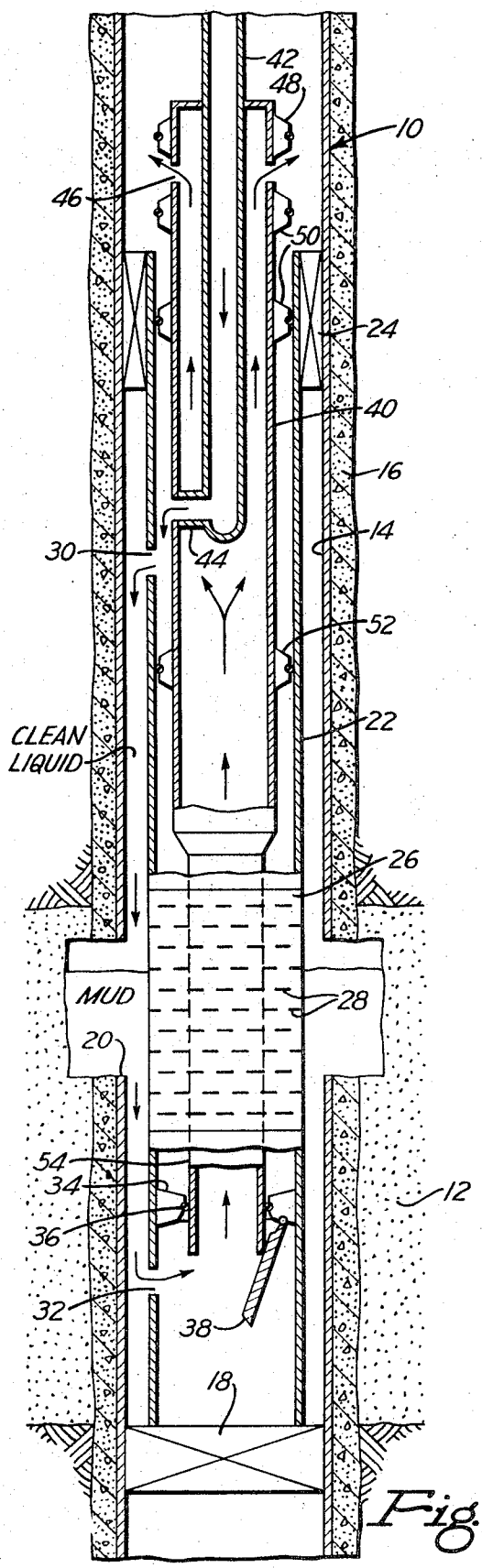

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Fig.1

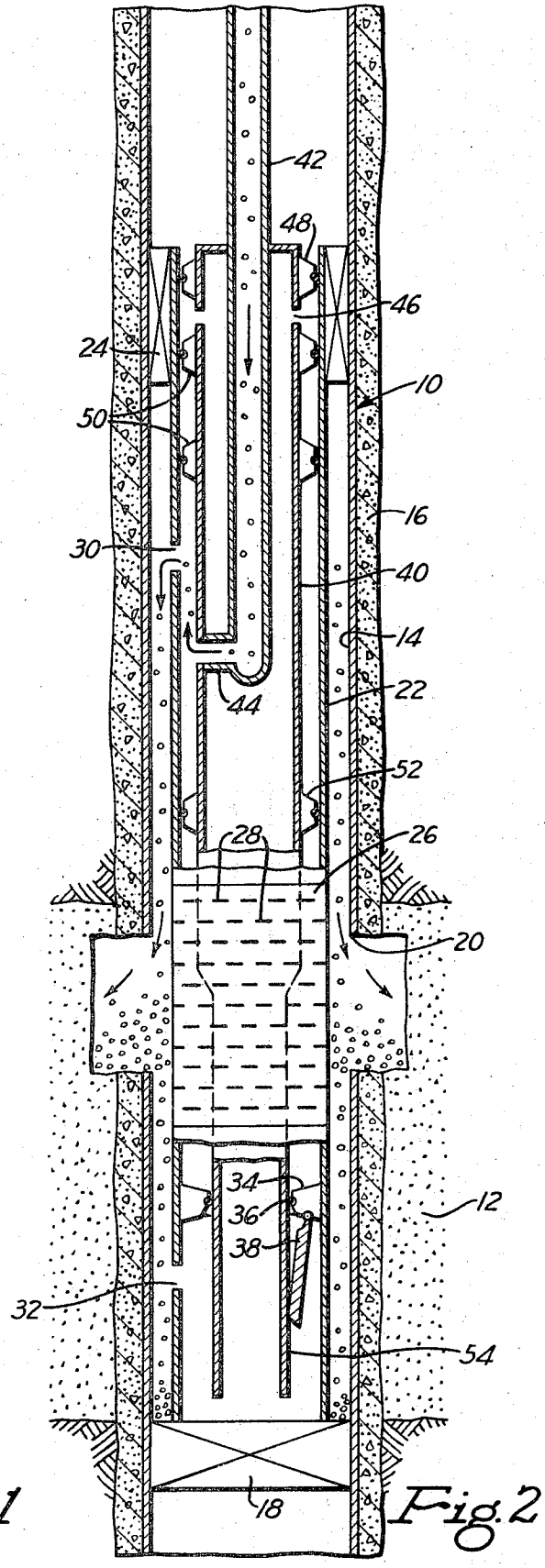
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Fig.2

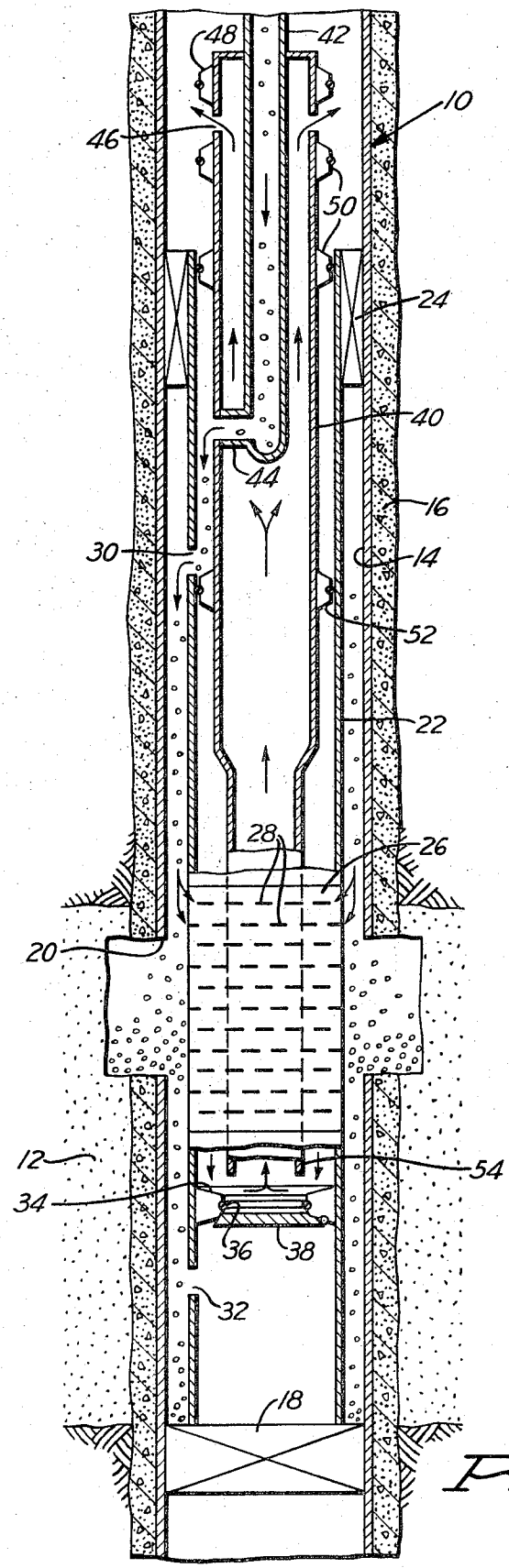

Fig.3

GRAVEL PACKING METHOD AND APPARATUS

This invention relates to the prevention of movement of sand into a well and more particularly to a method and apparatus for packing gravel around a screen through the producing interval of a well.

Many oil bearing formations do not have sufficient physical strength to maintain their integrity during production of fluids from the formation. Such formations are frequently referred to as incompetent formations. Finely divided particles move from the formation with the produced fluids into the well where the particles may settle and plug tubing and other equipment in the well. If the incompetent formation is under a high pressure, the high velocity of the particles as they flow with the produced fluids may cause severe erosion of well equipment.

One method that has been used to prevent the flow of finely divided formation particles into a well has been to pack gravel around a slotted liner or screen through at least a portion of the producing formation and produce fluids from the formation through the screen. The gravel pack supports the formation and prevents movement of finely divided particles to the screen where they may plug the openings in the screen. One method of installing a slotted liner in a gravel pack that has been used is to fill the well with gravel through the incompetent formation and then to wash the screen down through the gravel by pumping a liquid through a wash pipe extending through the screen and communicating with an opening in a shoe at the lower end of the screen. After placement of the screen at the desired level, the washing is stopped and the gravel settles around the screen, after which the wash pipe is removed.

If the formation through which the gravel pack is to be installed is under high pressure, drilling mud in the well at the conclusion of the drilling operation will contain finely divided solid particles of a weighting agent, usually barite. When the screen is washed into place, the barite is suspended but then settles with the gravel when the washing into place of the screen is completed. Barite particles in the gravel pack greatly decrease its permeability and therby interfere with production of formation fluids. Finely divided solid particles from the formation that are suspended by the liquid used in washing in the screen also may settle in the gravel pack and diminish its permeability.

Another method of forming a gravel pack, referred to as a reverse method, is to install a screen at the desired level in the well and then deliver gravel down the well into the annulus surrounding the screen. The gravel is delivered in the form of a suspension of gravel in a liquid. The liquid used to suspend the gravel passes through the screen and is returned upwardly through the well. That liquid may wash weighting agents or other finely divided particles from the annulus surrounding the screen into the screen and those particles may become lodged in the screen and reduce its fluid flow capacity.

It is important that the liner in which the screen is mounted be packed against casing or the borehole wall above the product zone to protect casing in the upper part of the well from high pressures and to prevent flow of formation fluids and solids around the upper end of the liner and into tubing for production of the fluids. A crossover arrangement in a gravel packing tool is frequently arranged to allow circulation of gravel below a packer closing the upper end of the annulus surrounding a screen. Such arrangements are disclosed in U.S. Pat. Nos. 2,896,714 of Killingsworth and 2,905,245 of DePriester. Both of those patents describe a gravel packing method in which finely divided solids that may be in the annulus around the screen are washed through the screen as the gravel pack is formed.

U.S. Pat. No. 2,652,117 of Arend et al. is of interest in disclosing the washing down method of installing a gravel pack through a productive formation. Arend avoids plugging the screen with finely divided solids by washing such solids from the well before forming the gravel pack into which the screen is subsequently washed down. The procedure used by Arend has the objectionable feature of requiring repeated setting of the packer used to close the annulus surrounding the upper end of the liner in which the screen is mounted.

This invention relates to a method and apparatus for gravel packing wells in which a liner having an intermediate portion forming a suitable screen is placed in the interval to be gravel packed while the well contains high density liquid which may have finely divided solid particles suspended in it to provide the density necessary to counteract the high pressure of the formation. A gravel packing tool having a wash pipe at its lower end and a crossover communicating with tubing at its upper end is lowered into the liner until the wash pipe protrudes from the lower end of the screen and opens a check valve mounted in the liner below the screen. Ports and sealing means are provided in the liner and on the gravel packing tool to permit successive displacement of solids-containing liquids from the well upwardly through the wash pipe and into the annulus above the packer followed by placement of gravel in the annulus surrounding the screen. The gravel can be squeezed into the formation or merely reversed into place with clean liquids which pass through the screen and into the annulus above the packer.

In the drawings:

FIG. **1** is a vertical sectional view through the interval of a well including the fluid producing incompetent formation to be packed illustrating the equipment in condition for washing solid particles-bearing liquids from that interval.

FIG. **2** is a vertical sectional view similar to FIG. **1** but showing the well as the gravel pack is being formed in the annulus surrounding the screen with the apparatus in condition for squeezing the gravel pack.

FIG. **3** is a vertical sectional view similar to FIG. **1** with the apparatus in conditions for forming the gravel pack by the reverse flow of gravel into the annulus around a screen.

Referring to FIG. **1** of the drawings, a well generally indicated by reference numeral **10** is illustrated extending through an incompetent formation **12** which is to be gravel packed to prevent flow of sand from the formation into the well. Well **10** has casing **14** cemented completely through formation **12** as indicated by the cement sheath **16** surrounding the casing **14.** In the well illustrated in FIG. **1,** the casing extends for some depth below formation **12** and a plug **18** is set in the casing at approximately the lower boundary of formation **12.** In the particular well used for the description of this invention, a window **20** is cut in casing **14** in the interval of formation **12** and the formation is underreamed adjacent the window to provide additional space for the

gravel packing. This invention is not restricted to use in a well in which casing is cemented through the formation to be gravel packed and a window milled in the casing. The casing could merely have perforations and the gravel packing accomplished through perforations. The invention can also be used in a well in which there is an open hole through the formation to be gravel packed. It is preferrred, however, because of the advantages this invention has in gravel packing formations subjected to abnormally high pressures that casing be cemented through the formation and the gravel packing accomplished through suitable openings in the casing.

A liner **22** having a packer **24** at its upper end is set in the well through the interval of the formation **12.** Liner **22** includes a screen **26** having openings **28** small enough to prevent flow of finely divided sands or the gravel used in the gravel packing through the openings into the liner **22.** The lower end of the liner **22** can rest on plug **18,** as shown, or packer **24** may be of a hanger type which when set will support the liner with screen **26** opposite the window **20** in casing **14.** Packer **24** closes the annulus between the upper end of the liner and casing **14.**

Liner **22** has upper perforations **30** above the screen **26** and lower perforations **32** below screen **26.** Between lower perforations **32** and screen **26** are sealing means **34** having a central opening provided with suitable means such as one or more O-rings **36** adapted to engage a wash pipe, as hereinafter described. A downwardly pivoting check valve **38** is biased upwardly by a spring or counterweight to close the central opening through the sealing means **34.**

A gravel packing tool used in this invention includes a sleeve **40** closed at its upper end which is run into the well on tubing **42** passing through the closure at the upper end of the sleeve. Tubing **42** is connected with a crossover **44** that opens through the wall of the sleeve to permit communication between the tubing and the annulus between the sleeve **40** and the liner **22.**

Ports **46** near the upper end of the sleeve **40** permit flow from within the sleeve to the annulus surrounding the sleeve when the ports **46** are positioned above packer **24** as shown in FIG. **1.** Top sealing means **48** extend outwardly from the sleeve above ports **46** for engagement with and sealing against the inner surface of liner **22.** Intermediate sealing means **50** below the ports **46** are also adapted to engage the inner surface of the liner and thereby seal against the liner. In the embodiment illustrated in the drawings, the intermediate sealing means **50** are shown as two spaced apart elements which provide additional flexibility in location of the gravel packing tool during the gravel packing operation. The intermediate sealing means are located above the opening of the crossover **44** through the sleeve **40.** Lower sealing means **52** extend outwardly from the outer surface of sleeve **40** below the crossover **44** and also are adapted to engage the inner surface of the liner and seal against that surface.

Sleeve **40** tapers below the level of lower sealing means **52** to form a wash pipe **54** adapted to extend downwardly through the screen **26.** The diameter of wash pipe **54** is such that the wash pipe will pass through sealing means **34** and engage the O-rings **36** to prevent flow between the outer surface of the wash pipe and the sealing means **34.**

At the beginning of the gravel packing operation of this invention, the well **10** will ordinarily be filled with a drilling mud and in the preferred use of this invention with drilling mud containing a substantial concentration of finely divided solid particles of barite or other weighting material to increase the density of the drilling mud. This invention has been found useful in gravel packing wells in which the drilling mud used to counter formation pressures had a density of **17** lbs. or more per gallon. If the well is to be completed with casing set through the producing formation and a window cut in the casing, that operation is completed and then the liner is lowered into place and the packer **24** set. It is preferred that the packer **24** and liner **22** be lowered into the well on the setting tool **40** and set by that tool to allow the setting of the packer and the gravel packing to be accomplished in a single trip into the well. Packers and gravel packing apparatus allowing setting of the packer and gravel packing through a cross-over in a single trip are commercially available and are not a part of this invention. A suitable packer and crossover tool arrangement is the Baker Retrieva-d Gravel Pack Packer described in the Composite Catalog for 1972–1973 at page 381. Details of the structure permitting the single trip operation have been omitted from the drawings to avoid cluttering the drawings with details not essential to this invention. The packer **24** and liner **22** can be run into the well and set and the gravel packing tool subsequently run into the well.

After setting the packer, the gravel packing tool is located at the position illustrated in FIG. **1** in which the intermediate sealing means **50** engage the inner surface of the liner and port **46** opens into the annulus above the packer **24.** In the position illustrated in FIG. **1,** the engagement of the intermediate sealing means with the liner is adjacent packer **24.** At this position the wash pipe **54** extends through sealing means **34** and pushes the check valve **38** downwardly to open the check valve and place the wash pipe in communication with the lower perforations **32.**

A clean liquid is pumped down tubing **42** and through crossover **44** and perforations **30** into the annulus surrounding the liner **22.** Pumping is continued to displace drilling mud in the annulus and in the underreamed formation downwardly through the annulus surrounding the screen **26** to the lower perforations **32.** The drilling mud containing the finely divided solids is displaced through perforations **32** then upwardly through the wash pipe **54,** sleeve **40** and flows through ports **46** into the annulus above the packer **24.** Pumping the clean liquid can, if desired, be continued to remove all of the drilling mud from the well; but it is only essential that the annular space surrounding the liner and in the underreamed portion of the formation be cleared of the finely divided solids.

The gravel packing tool is then lowered further to place the upper sealing means **48** in contact with the inner surface of the liner, as shown in FIG. **2.** If lowered to the position shown in FIG. **2,** flow through ports **46** is prevented by engagement of sealing means **48** and **50** with the inner surface of the liner. Gravel suspended in a liquid is then pumped downwardly through tubing **42** and crossover **44** into the annular space surrounding liner **22** and into the underreamed portion of the formation. Because ports **46** are closed by engagement of the upper and intermediate sealing means with the inner surface of the liner, liquid used to transport the

gravel is displaced into the formation in the embodiment of the invention illustrated in FIG. 2. It is preferred, therefore, that an oil be used to transport the gravel if the formation is an oil producing formation. Pumping of the liquid with the gravel suspended in it is conducted until the underreamed portion is filled. It may be desirable to squeeze the gravel pack and perhaps fracture the formation surrounding the underreamed portion and pack gravel into the fracture. That can be accomplished by increasing the pressure applied to the suspension of gravel in liquid pumped through tubing **42.**

In the gravel packing operation illustated in FIG. **3,** the gravel is reversed into place similar to the conventional gravel packing opeation. However, because of the prior removal in this invention of the drilling mud having finely divided solids suspended in it, flow of the liquid through the screen does not plug the slots in the screen. Referring to FIG. **3,** the gravel packing tool is raised to a position in which the lower end of the wash pipe is above sealing means **34,** and ports **46** are above the packer **24.** Check valve **38** pivots upwardly to the closed position shown in FIG. **3.** The intermediate sealing means **50** engage the inner surface of the liner to close the upper end of the annulus between the gravel packing tool and the liner. A suspension of gravel in a clean liquid is pumped through tubing **42,** crossover **44,** upper perforations **30,** and into the annulus surrounding the liner to fill the underreamed portion of the formation **12.** The clean liquid used to suspend the gravel flows through the screen **26** downwardly in the screen to the lower end of the wash pipe **54** and then upwardly through the wash pipe. Pumping of the suspension of gravel is continued to fill the underreamed portion of the formation and the annular space surrounding the liner. After completion of the gravel packing operation, the gravel packing tool is pulled from the well and the well is completed for production as desired.

This invention provides a method and apparatus for gravel packing around a screen set in a well penetrating a formation at an abnormally high pressure. Finely divided particles of weighting agents, or other finely divided solids, can be washed from the annulus surrounding the screen, without impairing the flow capacity of the screen, before the gravel is packed around the screen.

I claim:

1. A method of gravel packing a well containing liquid having finely divided solid particles suspended therein comprising placing a liner including a screen between the upper and lower ends thereof through the interval to be packed, setting a packer engaging the liner above the screen to close the upper end of the annulus surrounding the screen, thereafter circulating a clean liquid downwardly into and through the annulus below the packer and upwardly through wash pipe extending through the screen while preventing flow through the screen to wash finely divided solids from the annulus surrounding the screen, circulating a slurry of gravel in a liquid below the packer into the annulus surrounding the screen to fill the annulus with gravel, delivering liquid from the slurry upwardly through the wash pipe, and removing the wash pipe from the screen.

2. A method as set forth in claim **1** in which upward movement of liquid through the well is blocked while gravel is circulated into the annulus surrounding the screen and pressure is applied to the slurry circulated into the annulus to squeeze the gravel and consolidate the gravel pack.

3. Apparatus for gravel packing a well comprising a liner including a tubular screen forming a portion of the wall of the liner, a packer at the upper end of the liner above the screen adapted to close the annulus surrounding the liner, a downwardly pivoting check valve mounted in the liner below the screen adapted to prevent flow upwardly through the liner, first sealing means extending inwardly from the liner below the screen and above the check valve, upper perforations in the liner between the packer and the screen, and lower perforations in the liner below the first sealing means; a gravel packing tool comprising a sleeve closed at its upper end and adapted to extend downwardly through the liner, a tubing extending through the upper end of the sleeve, a crossover connected to the tubing and opening through the sleeve, a wash pipe extending downwardly from the lower end of the sleeve for movement downwardly through the screen to open the check valve, ports through the sleeve near its upper end, top liner sealing means extending from the sleeve above the ports and adapted to engage the liner, middle liner sealing means extending from the sleeve below the ports and adapted to engage the liner, and bottom liner sealing means extending from the sleeve below the crossover and adapted to engage the liner; said first sealing means engaging the wash pipe below the screen and above the check valve to prevent flow through the screen and into the wash pipe when the wash pipe opens the check valve.

4. A method of gravel packing a well containing a liquid having finely divided solid particles suspended therein comprising running into the well a liner having a screen forming a portion thereof between the upper and lower ends thereof, supporting the liner through the interval in which the gravel pack is desired, setting a packer around the upper end of the liner to close the annulus surrounding the liner, running wash pipe through the screen to extend through a downwardly opening check valve at the lower end of the liner, sealing the space between the liner and the wash pipe below the screen and above the check valve to prevent flow of liquid through the screen and into the lower end of the wash pipe, thereafter pumping clean liquid down tubing and crossing over below the packer into the liner and into the annulus surrounding the liner to displace liquid having finely divided solids suspended therein from the annulus surrounding the screen into the lower end of the wash pipe and upwardly through the wash pipe to the annulus above the packer, displacing gravel suspended in liquid down tubing and crossing over below the packer into the annulus surrounding the slotted liner to form a gravel pack surrounding the liner, delivering liquid separated from the gravel upwardly through the wash pipe to the annulus above the packer, and removing the wash pipe and crossover from the well.

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