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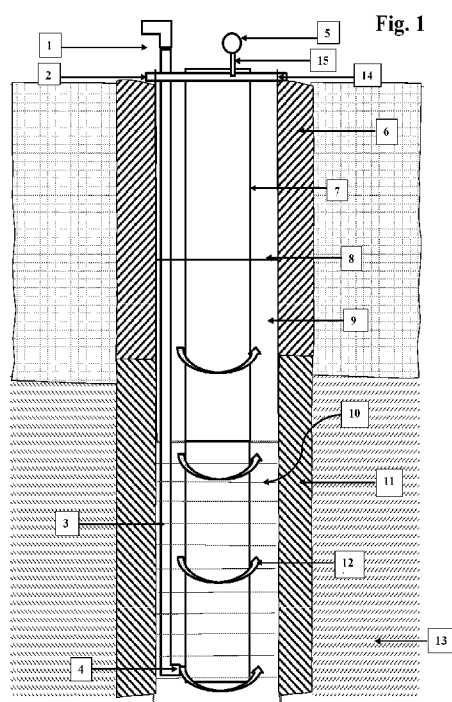
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(54) Title: METHOD OF WATER WELL MAINTENANCE-TIME BASED APPROACH



(57) Abstract: A method of preventive well maintenance with pumping equipment in the well for well rehabilitation using CO₂ with varying lengths of producing intervals utilizing varying methods to deliver cleaning energy and varying porosity of aquifers to determine varying quantities of energy over the entire well structure.

Method of Water Well Maintenance – Time Based Approach

Field of the Invention

The present invention relates to an improvement in a method of preventive well maintenance with pumping equipment in the well.

Background of the Invention

Aqua Gard® is an innovative well cleaning process that moves away from the traditional approach in the groundwater well industry of operating a well until failure. The goal of moving away from the operation until failure mentality is to target materials that build up in the near well environment (which is a natural occurrence in almost all wells) when they are soft and easy to remove. Most of the deposited material is soft until complete mineralization takes place over time. By scheduling cleaning events on a time interval approach, materials that would eventually become difficult to move are easily removed from the well, and surrounding filter pack and near aquifer.

With the installation of permanent Aqua Gard® equipment in a well, cleaning events can take place without the need to remove the pumping or injection equipment. Removal and replacement of pumping equipment during cleaning events adds a lot of downtime and cost to typical well cleaning events. The mentality of minimizing the downtime while maintaining quantity and quality of water pumped from a well is paramount to the model of protecting a well that Aqua Gard® typifies.

Aqua Gard® is a well cleaning process that utilizes natural carbon dioxide (CO₂), allowing easier compliance with regulatory discharge as well as better distribution of cleaning energy throughout the well, filter pack and the surrounding aquifer. Cleaning a well requires energy. Combination energies may be required to get the entire well structure cleaned effectively. Most of the energy utilized in the Aqua Gard® process is provided by the various phases of carbon dioxide (CO₂). The phase in which CO₂ occurs is a function of temperature and pressure, and in well environments, all three major phases of CO₂ (solid, liquid, and vapor) can occur. Aqua Gard® involves the controlled injection of liquid and vapor phases of carbon dioxide. As liquid CO₂ is injected into the well, the pressure and temperature encountered at the injection point do not initially provide a stable environment for liquid CO₂ to exist. The CO₂ therefore

undergoes a phase change to vapor. The phase change of CO₂ from a liquid to a vapor can cause a volume expansion of up to 570 times. This volume expansion is one of the sources of energy that provides the cleaning action and agitation inside the well and the near well environment.

Another source of energy is the thermodynamic cooling of the water in the well due to the controlled injection of liquid CO₂ (liquid and solid CO₂ can be very cold). When the water gets cool enough, it can freeze. Solid water (ice) has a larger volume than liquid water, and the formation of ice can break up and loosen materials that are clogging pore volume in a well.

There are many different aspects to the energy delivered into a well with the Aqua Gard® process that can be utilized. Deliver energy into the well in the form of CO₂ liquid, and vapor resulting in phase changes of liquid to vapor, liquid to solid, and solid to vapor (sublimation) occurs. This has been demonstrated to be the most effective way to deliver energy that loosens clogging materials. The Aqua Gard® process is economical and restores the pumping capacity of a well, and eliminates the need to neutralize and dispose of chemicals that can be dangerous.

Summary of the Invention

It is an object of the present invention to improve the Aqua Gard® process by providing a better distribution of effective energy into all parts of a producing interval of a well that has a long producing interval.

It is also an object of this invention to provide a challenge for distributing energy over the entire well structure. The distribution of energy into all parts of the well includes the upper casing, the producing interval of a well screen or open hole rock well, the filter pack and into the surrounding formation.

The distribution of energy can be achieved with combination energies including environmentally friendly chemicals that can be carried and distributed with the use of carbon dioxide energy in a sealed well. Carbon dioxide phase changes create agitation of the chemistries, allowing them to reach all areas of the well. Combination energies are necessary when wells have long producing intervals.

Improvements to the existing Aqua Gard® approach involve using combination energies to achieve more equal distribution of energies. The combination of chemical energy, thermal energy and mechanical energy are produced by the phase changes of liquid to vapor, liquid to solid and solid to vapor of carbon dioxide.

Chemical energy provided by National Science Foundation (NSF) approved proprietary chemicals are effective on mineral solubility, and effective on biological dispersion and disinfection, metal dispersion and clay dispersion. Placing chemistry in the well and utilizing the agitation of the carbon dioxide phase changes delivers the chemical energy to all portions of the well.

Quick release pulsing energy devices can be placed in the bottom of the well. These devices can store energy which can be released at high pressure, allowing disruptive energy to be released that can mobilize fines in the surrounding filter pack and formation. Once the energy is released, pressure rebuilds for another rapid release, and the cycle repeats until such time as energy is no longer introduced into the quick release device. If a pressure relief valve is selected as the energy delivery mechanism, it is selected based upon hydrostatic pressure. The pressure relief valve would utilize liquid and vapor phases of carbon dioxide, and would be designed to close after release to allow pressures to build up again.

Biological fouling and associated minerals on the surfaces within the water well environment can be measured with the use of low voltage resistive devices that can be permanently placed in the well. This would allow the cleaning cycle to be initiated when the surfaces are fouled or have evidence of deposited material.

A coating on a sensor in the low voltage resistive device would identify a change in the electrical voltage in the wires that are hooked up to the resistor. In many wells where low voltage resistive devices will not be able to be installed for various reasons, it is important to maintain the time interval approach. Presently, without resistive devices, there is no good indicator of when a well should be cleaned.

The method of calculating the specific capacity of a well is an industry standard and is still in use today as an indicator of the productive capacity of a well. Specific capacity is defined as the volume of water removed from a well per unit of drawdown

(GPM/FT). As the well is operated over time, and the natural well clogging processes proceed, the specific capacity of a well will go down.

Brief Description of the Drawing

Fig. 1 shows a screened well with a filter pack with pump in the well.

Fig. 2 is a figure representing the different flow regimes.

Detailed Description of the Invention

Fig. 1 represents the advantage of a variable interval injection cycle. When the well is being injected with liquid CO₂, the water becomes supersaturated with carbon dioxide. When a transition is made at the injecting valve from liquid to vapor CO₂, the water that was filled with CO₂ releases the CO₂ and the water level quickly drops. Switching from liquid back to vapor results in a very sudden surge as water flows rapidly back into the well. This sudden surge back into the well can further disrupt attached material and mobilize detached clogging material as well as bringing fines from the surrounding aquifer that have invaded the pore spaces surrounding the well.

Manipulating the injection intervals of vapor and liquid improves the efficiency and the effectiveness of the cleaning process, and the surge created by the change between liquid and vapor is maximized by lengthening the liquid time intervals and shortening the vapor injection intervals.

The surging effect is caused in the well by the change in concentration of the bubbles in the well. When liquid CO₂ is injected into the well, the concentration of bubbles in the well is very high, and the surface of the water in the well is very agitated. The high concentration of bubbles in the well results in the movement of a high concentration of vapor upwards in the well, creating a buoyancy effect. When a transition is made in the controlled injection of CO₂ from the liquid phase to the vapor phase, the high concentration of bubbles becomes much lower and the water level in the well falls quickly.

Essentially, the volume in the water column that was filled with the high concentration of vapor collapses as the high concentration of CO₂ (liquid injection) ceases. In addition to the buoyancy effect during the liquid CO₂ injection, the water

level in the well is forced downward with gases coming out of solution, and switching back to vapor results in water rushing back into the well, creating a surging effect. Maximizing the surging caused by the transition from liquid to vapor can be done by calculating the volume of liquid required to create the 'buoyancy' effect.

When the desired buoyancy effect is reached, a switch to the vapor injection can be made. With an understanding of the delivery pressure and flow of the CO₂ into the well, a timing mechanism can be used to deliver the liquid and vapor phases of CO₂. The control of the delivery with a timing mechanism will maximize this surging effect, ensuring that the delivery of the different phases creates the highest amount of water movement in the well.

In addition to maximizing the surging effect that the transition from liquid CO₂ to vapor CO₂ has on the water column, a greater control of the delivery of CO₂ to the well can maximize another form of energy delivery in the well during injection. Multiphase flow demonstrates that there are two forms of multiphase flow that the Aqua Gard® process entails.

The first form of multiphase flow is the direct delivery of CO₂ into the well. The CO₂ will travel in the delivery equipment in three different forms, vapor only, liquid only, or vapor and liquid blend, depending on how the operator controls the injection. There are a multitude of flow regimes in which a two-phase fluid will flow in a vertical water column, bubbly, slug, churn, annular, and wispy-annular. The flow regime that the fluid will flow in is based on the concentration of vapor versus liquid, as well as the velocity of the liquid in the pipe. A determination of the best way to deliver the CO₂ mixture will be made, and flow through the delivery pipe can be controlled with a flow control device to deliver the CO₂ in the method determined. The determination for the best way to deliver the CO₂ will be made based on which fluid flow regime provides the most effective way of creating 1) the surging effect caused by the transition of liquid to vapor in the injection process and 2) the vortex effect. The flow regime of CO₂ delivery would be targeted by the effect the chosen regime has on the Aqua Gard® process.

The second aspect is the multi-phase flow beyond the injection point. As the liquid and vapor phases enter the well, and the liquid phase changes to vapor, a new multi-phase regime is encountered where the liquid phase is the water in the well and

the vapor phase is the rising CO₂ vapor. The goal of this second flow regime is to remove the most amount of clogging material. An inspection of Fig. 2 shows that certain flow regimes look more disruptive than other flow regimes. Particularly, the bubbly and annular regimes do not seem to be as disruptive as the slug or churn regimes. The injection would be controlled according to the multi-phase regime, which would disrupt the near well environment the most.

Fig. 1 shows a screened well with filter pack with pumping equipment in the well.

The different types of water wells can include, e.g., water supply wells, injection wells, aquifer storage and recovery (ASR) wells, recovery wells, monitor wells, collector wells, slant wells, horizontal wells, directional wells, etc.

Fig. 1 represents a very common type of water well, but many different types of wells require time based cleaning as determined by the application of the “Mansuy Principle”.

The “Mansuy Principle” was established with the recognition that loss of specific capacity (discharge rate/drawdown) of a pumping well does not occur until significant clogging of pore space of the well screen 10, the filter pack 11 and the surrounding formation 13 has become significant, and the remaining pore space of a well begins to transition from laminar to turbulent flow. Loss of specific capacity in any well will occur at a precise moment.

The “Mansuy Principle” of time based cleaning is based on not detecting that exact moment of pore space plugging. The “Mansuy Principle” establishes time based cleaning of a well 10, 11, 13, 14 when deposited plugging material is often soft and easy to remove. The cleaning sequence is performed with the pumping or injection equipment in the well, and utilizing the pump to pump the detached deposits, thus minimizing equipment needed to clean a well. Wells have excess pore space when placed in production, and that exact moment of loss of specific capacity is after extensive plugging deposits have become established and the plugging deposits become mineralized and hardened, making their removal more difficult. Much of that excess pore space can be clogged but does not result in loss of specific capacity because extra pore space exists within the depth in a well 10 and extra pore space exists further into the surrounding formation 13.

Any other type of well, including open hole rock wells, would be cleaned with the claimed invention. Water wells are sealed with flange 2 or a packer placed inside well casing 14. Carbon dioxide or selected chemicals are introduced into the water well through injection line 1, 3 with pumping equipment 16, 17 in the well.

The chemicals, if used, must be approved to be placed into a water well. Carbon dioxide in various intervals is introduced into the well through injection line 1, 3, and regulated based upon injecting energy into a sealed well 2 at safe pressures, and monitored by pressure gauge 5 through a port 15. The non-pumping water level or static water level is represented by 8 in Fig. 1. Injecting carbon dioxide into a sealed well 2 does require a well to have some grout 6 around the well casing 14.

The intervals of carbon dioxide in both gaseous and liquid phase are introduced based upon the art of cleaning process to achieve maximum energy distribution. With very long screens or open hole intervals, chemical energy and carbon dioxide energy can be distributed over the entire well 10, 14 and penetrate the combination energies into the filter pack 11 and the surrounding formation 13. The energy release from phase changes of carbon dioxide is necessary to distribute energy over the entire well structure 10, 11, 14 and into the surrounding formation 13 in the zone of a water well that is plugged with mineral, biological and fine material from the aquifer.

A reduced amount of carbon dioxide and/or chemical energy is utilized with the volume displacement pipe or suction flow control device 7. The volume displacement pipe or suction flow control device 7 also directs the carbon dioxide or combination energies to where plugging deposits occur 10, 11, 13, 14. Carbon dioxide injected into a sealed well 2 through injection pipe 1, 3 through diversion elbow 4 creates a vortex 12 in the reduced annular space 9. The vortex 12 allows the combination energies to be distributed from the injection point represented by diversion elbow 4 and upward inside the well, allowing the entire well and near well to be cleaned more effectively.

The volume displacement pipe or suction flow control device 7 can reduce the amount of energy needed to clean the entire well 10, 11, 13, with less energy penetrating into the surrounding formation 14. With less energy penetrating into the surrounding formation 14, less time is required to return the well to ambient or pretreatment conditions. Following the injection of energy into the sealed well 2 with a

pump 16 in the well, the gases from carbon dioxide are dissipated by allowing the energy inside the well contact time, allowing effective cleaning of the well 10, 11, 13, 14.

Usually the following day, the pump 16 is operated and the well 10, 11, 13, 14 flushed of all detached and solubilized plugging deposits. The flow sleeve or suction flow control device 7 flushes the lower zones in the well by inducing flow through the extended pump suction 7. The volume displacement pipe or suction flow control device 7, in addition to reducing the volume of energy required and directing the selected energy into the well and formation, also serves the purpose of a flow sleeve to cool submersible pump motor 17.

In addition to cooling the submersible pump motor 17, the extended flow sleeve more effectively serves the purpose of flushing the well 10, 11, 14 more effectively. More effective flushing with the use of the flow sleeve 7 leaves the well in a cleaner condition, and flushes the planktonic bacteria more effectively.

Carbon dioxide induced vortex 12 creates a swirling action in the well that can be maximized. The vortex can be beneficial in the delivery of the energy provided by the carbon dioxide, and can utilize directional flow on the injection equipment to direct flow 4 in the desired direction. The use of drop pipe or a suction flow control device (SFCD) 7 to take up the space in the center of the well will focus the energy provided by the carbon dioxide phase change or combination energies towards the surfaces of the well and surrounding filter pack and aquifer. The vortex 12 will swirl upward in the annular space between the SFCD 7 and the well surfaces that are being cleaned. This vortex 12 can be utilized in the combination of carbon dioxide with chemical energy to further enhance the delivery of chemical energy. The smaller volume between the SFCD 7 or pump suction and the well/filter pack, well/aquifer interface would allow less carbon dioxide and/or chemicals to be utilized while achieving the desired cleaning effect. This will result in less impact on the surrounding aquifer 13, thus requiring less time to pump and flush the well in the impacted zone.

Fig. 1 shows a screened water well with a filter pack. Any other type of well, including open hole rock wells, would be cleaned with the same steps. Water wells are sealed with flange 2 or a packer placed inside well casing 14. Carbon dioxide or selected chemicals are introduced into the water well through injection line 1, 3. The

chemicals, if used, must be approved to be placed into a water well. Carbon dioxide in various intervals is introduced into the well through injection line 1, 3 and regulated based upon injecting energy into a sealed well 2 at safe pressures, and monitored by pressure gauge 5 through a port 15.

The non-pumping water level or static water level is represented by 8 in Fig. 1. Injecting carbon dioxide into a sealed well 2 does require a well to have some grout 6 around the well casing 14. The intervals of carbon dioxide in both gaseous and liquid phase are introduced based upon the art of cleaning process to achieve maximum energy distribution. With very long screens or open hole intervals, chemical energy and carbon dioxide energy can be distributed over the entire well 10, 14 and penetrate the combination energies into the filter pack 11 and the surrounding formation 13. The energy release from phase changes of carbon dioxide is necessary to distribute energy over the entire well structure 10, 11, 14 and into the surrounding formation 13 in the zone of a water well that is plugged with mineral, biological and fine material from the aquifer. A reduced amount of carbon dioxide and/or chemical energy is utilized with the volume displacement pipe 7.

The volume displacement pipe 7 also directs the carbon dioxide or combination energies where plugging deposits occur 10, 11, 13, 14. Carbon dioxide injected into a sealed well 2 through injection pipe 1, 3 through diversion elbow 4 creates a vortex 12 in the reduced annular space 9. The vortex 12 allows the combination energies to be distributed from the injection point represented by diversion elbow 4 and upward inside the well, allowing the entire well and near well to be cleaned more effectively. The volume displacement pipe 7 can reduce the amount of energy needed to clean the entire well 10, 11, 13 with less energy penetrating into the surrounding formation 14. With less energy penetrating into the surrounding formation 14, less time is required to return the water well to ambient or pretreatment conditions.

Improved energy distribution diagram elements list (Fig. 1):

- 1: Energy Injection port
- 2: Well sealed with flange – Can also utilize a packer
- 3: Carbon dioxide and/or chemical injection line into lower part of the well
- 4: Energy diversion port or energy quick release valve
- 5: Pressure gauge to measure internal well pressure
- 6: Grout seal
- 7: Volume displacement pipe and suction flow control pipe
- 8: Static water level
- 9: Reduced annular space between well casing and screen or open hole and volume displacement pipe or suction flow control pipe
- 10: Well screen or borehole face of rock well
- 11: Filter pack or natural pack
- 12: Vortex created by carbon dioxide injection and directional valve
- 13: Consolidated or unconsolidated aquifer
- 14: Well casing
- 15: Port through sealed well
- 16: Well pump submersible or line shaft turbine
- 17: Submersible pump motor if submersible pump is installed in well
- 18: Drop pipe or column pipe

We claim:

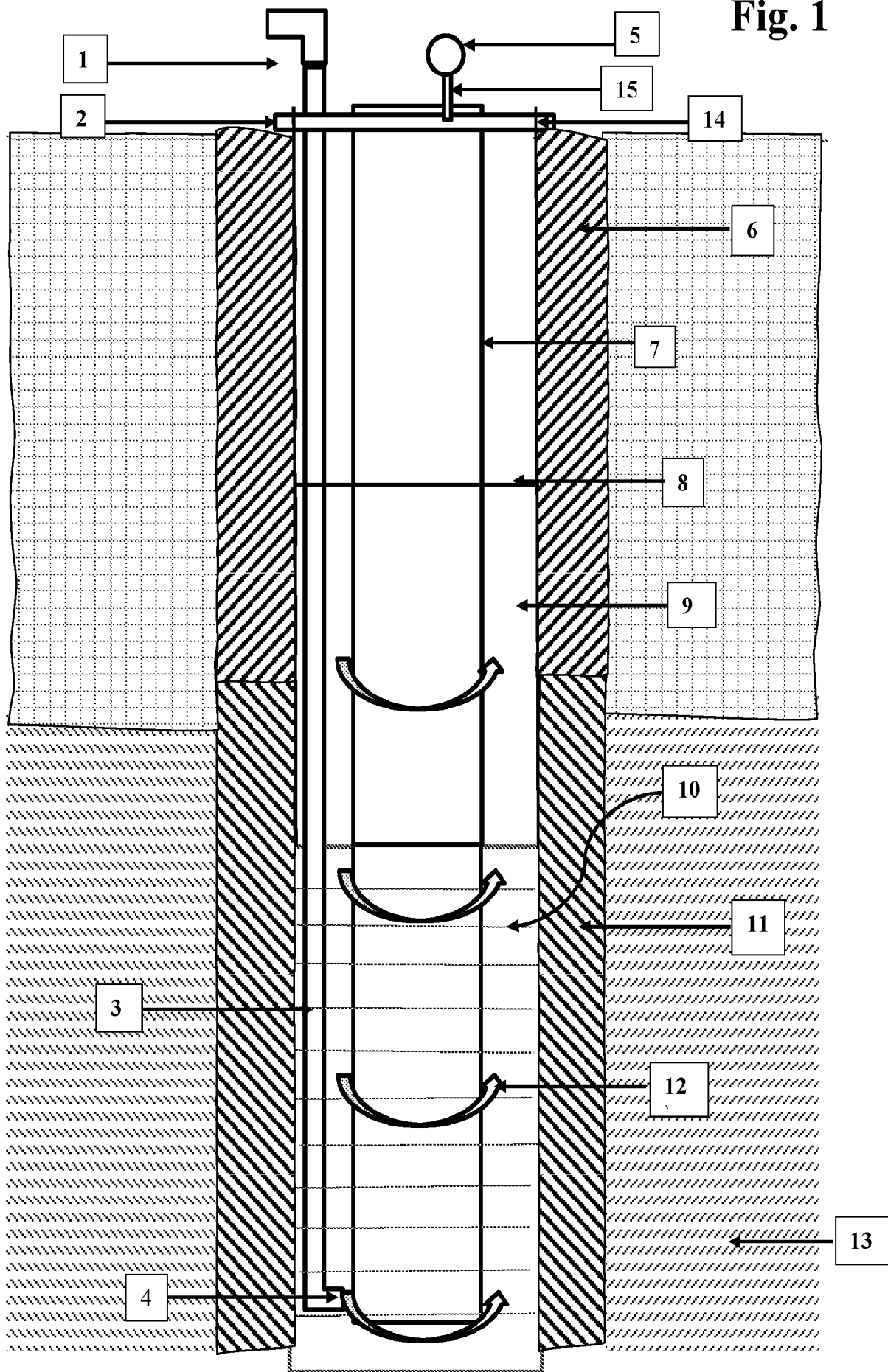
1. A method of well rehabilitation using CO₂ with varying lengths of producing intervals utilizing varying methods to deliver cleaning energy and varying porosity of aquifers to determine varying quantities of energy over the entire well structure.
2. The method of claim 1, wherein a combination of energies is utilized with chemical energy, thermal energy and mechanical energy.
3. The method of claim 2, comprising utilizing phase changes of carbon dioxide to distribute environmentally safe chemicals throughout an entire well structure.
4. The method of claim 1, further comprising setting a suction flow control device or flow sleeve at the bottom of the pump or volume displacement pipe that is smaller diameter than a well screen into the well prior to carbon dioxide injection to allow less energy required to displace water in the well and directing the cleaning combination energies to the screen or fractures of a rock well.
5. The method of claim 1, further comprising utilizing a suction flow control device or volume displacement pipe (VDP) in the well during the injection process resulting in less carbon dioxide, making it more cost effective and shortening the following development time prior to returning water quality back to pretreatment quality.
6. The method of claim 1, further comprising injecting carbon dioxide in a fashion as to create a vortex in the annular space between the suction flow control device and the well screen and casing allowing the combination energies to be delivered to all areas of the well.
7. The method of claim 1, wherein quick release valves can be placed in the lower zone of the well to release pulses of disruptive energy in repeated cycles to mobilize plugging deposits.

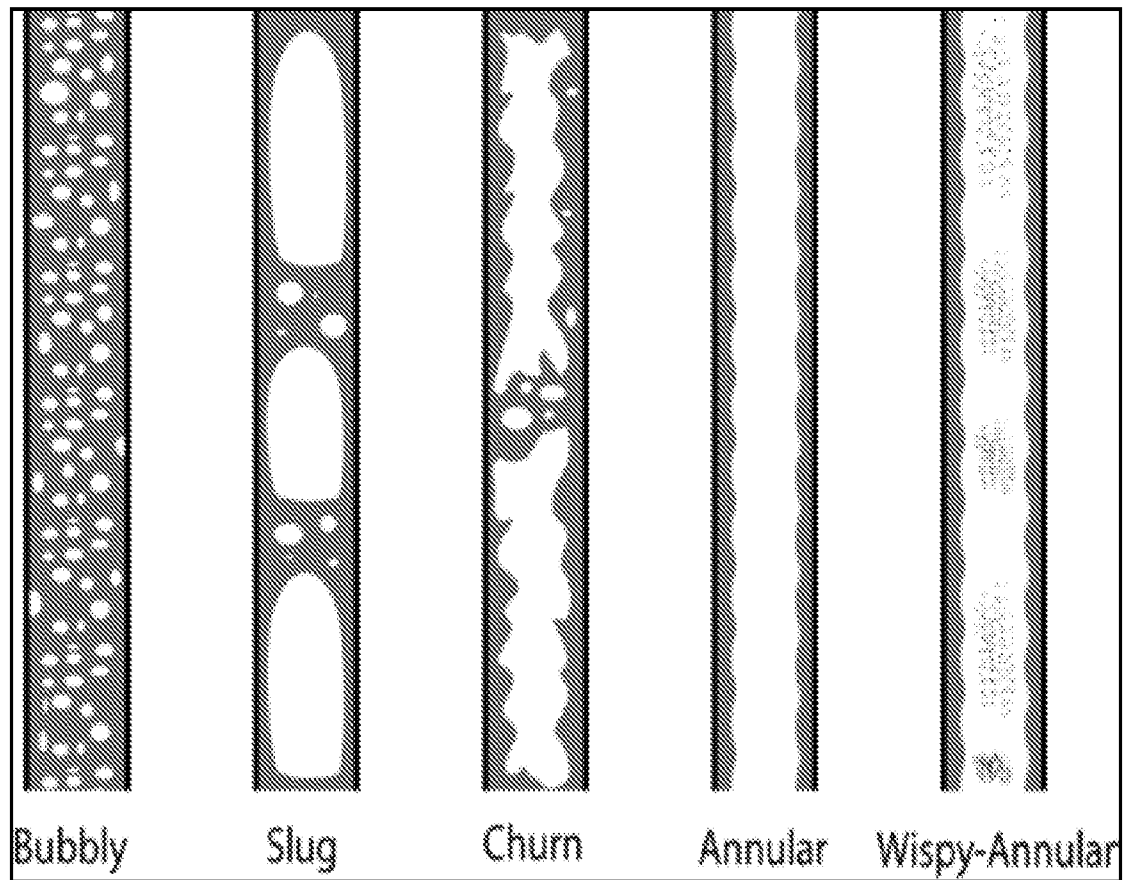
8. The method of claim 1, further comprising selecting a volume of carbon dioxide energy resulting in less penetration of solubilized carbon dioxide into surrounding formations resulting in less pump development time prior to returning the well back to ambient or pre-treatment conditions.
9. The method of claim 1, further comprising, in addition to the porosity of the aquifer, selecting the volume by evaluating the buffering capacity of the aquifer wherein the buffering capacity can be determined by assessment of the amount of carbonates in the aquifer and the total alkalinity of the water.
10. The method of claim 1, further comprising directing the injection nozzle for carbon dioxide at a desired angle to achieve a vortex in the annular space between the suction pipe on the pump or volume displacement pipe (VDP) and the well screen or borehole wall, wherein the vortex distributes energy or combination energies more efficiently throughout the well and surrounding aquifer.
11. The method of claim 1, further comprising injection of carbon dioxide into a sealed well to surge the well by switching between liquid injection and vapor injection cycles, wherein the length of cycles is calculated based upon the length of the producing interval and the flow rate of carbon dioxide.
12. The method of claim 1, further comprising shortening a vapor injection cycle and using more frequent cycles of liquid interval, creating surging of the water column, thus increasing the frequency of intervals between liquid and vapor and maximizing the surging effect.
13. The method of claim 1, further comprising using chemical energy which is NSF approved proprietary chemicals that can be effective at mineral solubility, biofilm and metal dispersion.

14. The method of claim 13, wherein the NSF approved chemistry requires the use of carbon dioxide injected into a sealed well to distribute the combination energies into the surrounding filter pack and aquifer.

1/2

Fig. 1



**Fig. 2**

INTERNATIONAL SEARCH REPORT

International application No.

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A. CLASSIFICATION OF SUBJECT MATTER

IPC - B09C 1/02; C09K 8/52; E21B 37/08, 43/16 (2017.01)

CPC - B09C 1/007; C09K 8/52; E21B 37/08, 43/164

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

See Search History document

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

See Search History document

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

See Search History document

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 2008/0128136 A1 (MANSUY, N) Jun. 5, 2008; abstract, paragraphs [0031], [0032]	1-14
A	US 2007/0144975 A1 (MILLER et al.) Jun. 28, 2007; figure 1, paragraphs [0033], [0047], [0078]	1-14
A	US 2014/0130498 A1 (RANDOLPH, J B) May 15, 2014; figures 1-6, paragraphs [0111], [0128]	1-14
A	WO 2009/007689 A1 (CLEANSORB LIMITED) Jan. 15, 2009; page 18, lines 20-29	1-14

☐ Further documents are listed in the continuation of Box C.☐ See patent family annex.

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Date of the actual completion of the international search

11 January 2018 (11.01.2018)

Date of mailing of the international search report

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