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(54) **Title**: METHOD OF TREATING A SUBTERRANEAN FORMATION WITH A MORTAR SLURRY DESIGNED TO FORM A PERMEABLE MORTAR

(57) **Abstract**: A method of treating a subterranean formation may include preparing a mortar slurry, injecting the mortar slurry into the subterranean formation at a pressure sufficient to create a fracture in the subterranean formation, allowing the mortar slurry to set, forming a mortar in the fracture, and providing a pulse of pressure sufficient to reopen the fracture and thereby provide cracks in the set mortar. The mortar slurry may be designed to form a pervious mortar, to crack under fracture closure pressure, or both.

METHOD OF TREATING A SUBTERRANEAN FORMATION WITH A MORTAR SLURRY DESIGNED TO FORM A PERMEABLE MORTAR

[0001] This patent application claims priority to US patent application 62/163768, filed on May 19, 2015, the contents of which are incorporated herein by reference, and is related to US patent application publication US20130341024, the contents of which are incorporated herein by reference.

FIELD OF THE INVENTION

[0002] The invention relates to a method of treating a subterranean formation using a mortar slurry including cementitious material, water, and aggregates and optionally admixtures and/or additives.

BACKGROUND

[0003] One method of treating a subterranean formation is fracturing. Fracturing is a process of initiating and subsequently propagating a crack or fracture in a rock layer. Fracturing enables the production of hydrocarbons from rock formations deep below the earth's surface (e.g., from 2,000 to 20,000 feet). At such depth, the formation may lack sufficient porosity and permeability (conductivity) to allow hydrocarbons to flow from the rock into a wellbore at economic rates. Manmade fractures start at a predetermined depth in a wellbore drilled into the reservoir rock formation and extend outward into a targeted area of the formation. Fracturing works by providing a conductive path connecting a larger portion of the reservoir to the wellbore, thereby increasing the volume from which hydrocarbons can be recovered from the targeted formation. Many fractures are created by hydraulic fracturing, or injecting fluid under pressure into the wellbore. A proppant introduced into the injected fluid may maintain the fracture width. Common proppants include grains of sand, ceramic or other particulates, to prevent the fractures from closing when the injection ceases. Some proppant materials are expensive and may be unsuitable for maintaining initial conductivity. Many hydraulic fracturing jobs, such as slick water or gel designs, demand the use of vast amounts of water and high hydraulic horsepower. The transport of the proppant materials can be costly, and ineffective. For example, proppant can have a tendency to settle in slick water jobs, resulting in only short preserved fracture

lengths. Hydraulic fracturing designs using gel may leave a residue that contaminates the reservoir, impairing production; they may also be unable to stay functional (preserve high viscosity) for long periods of time (5 to 24 hours) in formations that are ultra-low permeability and have long fracture closure times.

[0004] A method for providing permeability in fractures is described in U.S. 7044224. The method involves injecting a permeable cement composition, including a degradable material, into a subterranean formation. The degradation of the degradable material forms voids in a resulting proppant matrix. A problem of the method is that the degradation of the degradable material is difficult to manage. If the degradable material is not mixed uniformly into the cement composition, permeability may be limited. Furthermore, when degradation occurs too quickly, the cement composition fills the voids prior to forming a matrix resulting in decreased permeability. When degradation occurs too slowly, the voids lack connectivity to one another, also resulting in decreased permeability. In order for degradation to occur at the proper time, various conditions (such as pH, temperature, pressure, etc.) must be managed carefully, adding complexity and thus time and cost to the process. Another problem of the method is that the degradable material can be expensive and difficult to transport. Yet another problem of the method is that, even when large amounts of degradable material are used, permeability is only marginally enhanced. Furthermore, the addition of degradable material can have negative impact on flowability.

SUMMARY OF THE INVENTION

[0005] A method of treating a subterranean formation may include preparing a mortar slurry, injecting the mortar slurry into the subterranean formation, maintaining the mortar slurry at a pressure higher than a fracture closure pressure of the formation while allowing the mortar slurry to set to form mortar, reducing the pressure below the fracture closure pressure, and allowing the mortar to crack. The pressure is then increased to above the fracture opening pressure to provide additional cracks and debonding of the cement from the formation at the face of the fracture. This additional pressure pulse generates additional permeability in the fracture. The mortar slurry may be designed to set to form the mortar with a compressive strength below the fracture closure pressure of the subterranean formation. The mortar slurry may include a cementitious material and water.

[0006] Another method of treating a subterranean formation may include preparing a mortar slurry, injecting the mortar slurry into the subterranean formation at a pressure sufficient to create a fracture in the subterranean formation, allowing the mortar slurry to set, forming a pervious mortar in the fracture and then subjecting the set morar slurry to a pulse of pressure sufficient to re-open the fracture, and thereby providing additional cracks in the set morar slurry. The mortar slurry may be designed to set to form the pervious mortar with conductivity above 10 mD-ft. The mortar slurry may include a cementitious material, aggregate, and water.

DETAILED DESCRIPTION

[0007] Generally, a mortar slurry may set to form a strong, conductive, stone-like mortar after fracturing a source rock. The mortar slurry may simultaneously create and fill fractures, allowing hydrocarbons therein to escape. As the mortar slurry hardens into a mortar, the fractures may remain open, allowing the hydrocarbons to flow into a drilling pipe, so long as the mortar is permeable. Such mortar slurry may reduce or eliminate the need for proppants, which can be expensive and are sometimes unable to maintain initial conductivity. Further, enhanced conductivity through use of a mortar slurry as a fracturing agent, without large amounts of dissolvable materials, gelling agents, foaming agents, and the like may provide a safer, cheaper, more efficient treatment option as compared with conventional methods.

[0008] Treatments using the methods described herein may include stimulation, formation stabilization, and/or consolidation. Stimulation using the methods described below may involve use of a mortar slurry in place of traditional fluids such as slick water, linear gel or cross-link gel formulations carrying solid proppant material. The mortar slurry may create the fractures in a target formation zone before hardening into a permeable mortar and becoming conductive, allowing reservoir fluids to flow into the wellbore. Thus, the mortar slurry may serve as the fracturing fluid and proppant material. The mortar slurry may become conductive after hydration such that the fracture geometry created may be conductive without need for a separate proppant. Furthermore, fracture coverage may be increased, resulting in an improved fracture length as a result of more contact area, and corresponding increase in well spacing. In some instances, the well spacing may be doubled, reducing wells by 50%. Further, stimulation costs may be significantly reduced.

Additionally, the use of water may be reduced, as the mortar slurry may require up to 70%-75% less water than a traditional slick water fracturing operation.

[0009] The mortar slurry may reach and sustain high design fracture conductivity through (1) management of cracking in a mortar formed by the mortar slurry as the mortar is stressed by the closing formation; (2) management of the conductivity of the mortar slurry as it sets to form a pervious mortar; or (3) both. By managing cracking in the mortar, a conductive media may be generated via cracks due to the minimum in situ stress acting on the mortar. Such cracks may form a free path for fluid flow, thus making the cracked mortar a conductive media even if the mortar was less conductive or even relatively nonconductive prior to cracking. The conductivity of the mortar slurry may be managed during setting to form a pervious mortar by providing the mortar slurry with a sand/cementitious material ratio higher than one. Conductivity may be created by agglomeration of sand grains cemented during hydration by choosing a recipe that creates pores in the mortar. The agglomeration may occur as a result of the sand grains being precoated, or as a result of the mix of mortar slurry. Finally, in a mortar having a particular conductivity, managing cracking of a pervious mortar may allow for further enhanced conductivity. Thus, conductivity may be provided via a pervious mortar that is not cracked, via an essentially non-pervious mortar that is cracked, or via a pervious mortar that is cracked.

[0010] In one embodiment, a method of treating a subterranean formation involves the use of a mortar slurry designed to form a solid mortar designed to crack under a fracture closure pressure. In other words, the mortar slurry may have components in various ratios such that, upon setting, the resulting mortar will have a compressive strength that is less than the closure pressure of the fracture after external pressure has been removed. Thus, when external pressure is removed after the mortar slurry has set and formed the mortar, the fracture closure pressure will compress the mortar. Because the compressive strength of the mortar is less than the fracture closure pressure, such compression will result in a particular degree of cracking of the mortar, causing the permeability of the mortar to be enhanced.

[0011] Permeability in cured mortar resulting from voids within the matrix of the mortar is referred to as primary permeability. When the cured mortar is cracked, for

example, application of formation stress that exceeds the compressive strength of the mortar creates secondary permeability. Creation of secondary permeability will increase the total permeability of the cured mortar. Secondary permeability may also be created by including in the mortar slurry components that, after curing of the mortar, either shrink or expand. Components that shrink create additional voids, and also weaken the matrix, resulting in additional cracking when formation stresses are applied. Components that expand after curing of the mortar will result in the cured mortar changing dimensions within the fracture and cause cracks, resulting in secondary permeability.

[0012] The present invention may rely on primary permeability in the cured mortar, or may utilize one of the methods taught herein to additionally create secondary permeability, or may utilize a relatively impermeable mortar, and rely on secondary permeability created upon or after curing of the mortar slurry in the fracture.

[0013] The methods of treatment described herein may be useful for fracturing, re-fracturing, or any other treatment in which conductivity of a fracture or wellbore is desired. The mortar slurry (liquid phase and solid phase or both or partials of both) may be prepared (e.g., "on the fly" or by a pre-blending process) and placed into the subterranean formation at a pressure sufficient to create a fracture in the subterranean formation. The equipment and process for mixing the components of the mortar slurry (e.g., aggregate, cementitious material, and water) may be batch, semi-batch, or continuous and may include cement pumps, frac pumps, free fall mixers, jet mixers used in drilling rigs, pre-mixing of dried materials (batch mixing), or other equipment or methods. In some embodiments, the placement of the mortar slurry in the subterranean formation is accomplished by injecting the mortar slurry with pumps at pressures up to 30,000 psi. Injection can be done continuously or in separate batches. Rates of up to about 12 m^3/min may be desirable with through tube diameter of up to about 125 mm and through perforations up to about 1,202.7 mm. Once at least one fracture has been created in the subterranean formation, the pressure will desirably be maintained at a pressure higher than the fracture closure pressure, allowing the mortar slurry to set and form a stone-like mortar. Fracture closure pressure can be obtained from specialized test such micro fracs, mini fracs, leak-off test or from sonic and density log data.

[0014] So long as pressure does not drop below the fracture closure pressure between the time the fracture is created and the time the mortar slurry has set, the mortar slurry will fill and form the mortar in the fracture. Once the mortar slurry has set to form the mortar, the pressure can be reduced below the fracture closure pressure, and the mortar in the fracture may be allowed to crack, forming a cracked mortar. In order to ensure cracking of the mortar, the mortar slurry may be designed to set to form a mortar with a compressive strength at or below the fracture closure pressure of the subterranean formation. Additional design compressive strengths of the mortar may be appropriate, depending on the types and amounts of various materials used in the mortar slurry. The compressive strength may be greater than Fracture Closure – 0.5xReservoir Pressure. This is normally called effective proppant stress or effective confinement stress. In one embodiment, cracks will be induced by the effect of closure pressure but will not lose integrity as the strength of the mortar is desirably higher than the effective confinement stress. In other words, the compressive strength of the mortar may be any value between the closure pressure and the effective confinement stress, such that the mortar will crack, but not fail, when exposed to closure pressure. For example, if the fracture closure pressure of a particular formation is 8,000 psi and the reservoir pressure is 6,500 psi, the effective confined stress is 8,000-0.5x6,500= 4,750 psi, one desirable permeable mortar might have a compressive strength below 8,000 psi, and higher than 4,750 psi. Formations may exert much higher point or line loadings than anticipated on the basis of compressive strength estimates, and those loadings may induce the desired cracking as well. One having ordinary skill in the art will appreciate that the exact compressive strength of the mortar can be selected based on a number of factors, including extent of cracking or permeability desired, cost of materials, flowability, well choke policy, and the like.

[0015] After the mortar has hardened in the formation, the fracture could be exposed one more time to a pressure pulse of fluid sufficient to again open the fracture, and provide additional cracks in the mortar and/or debond the motar from the rock face of the fracture. After the pulse of pressure, the additionally cracked morar could exhibit additional permeability yet remain sufficiently agglomerated to provide the advantages of the present invention.

[0016] The length in time for the pulse of pressure provided in this embodiment of the invention could be long enough for the higher pressure to reach the full length of the

propped fracture. The pulse of pressure could be applied at any time in the life of the well, including both before hydrocarbon flow has commenced, or later after hydrocarbon flow has already been established.

[0017] The fluid utilized to provide the pressure pulse in this embodiment of the invention could be water, fracturing fluid, a hydrocarbon-based fluid, or a gas such as nitrogen or methane. Using a gas such as nitrogen or methane might avoid placement of additional solids and/or liquids within the agglomerated matrix and the formation near the face of the fractures, and thereby avoid any detrimental effects resulting from the pulse. The use of a gas would require that the well head be able to contain pressures sufficient for the fracture to be opened without the aid of the additional hydraulic head provided by a liquid in the wellbore. If a liquid is required as the fluid for the pulse, the liquid could be a proppant-containing liquid so that additional proppant is also inserted into newly formed cracks in the agglomerated matrix, or between the rock face of the fracture and the agglomerated matrix.

[0018] In some embodiments, the mortar slurry may be designed to provide a pervious mortar with a compressive strength above the expected fracture closure pressure. In such embodiments, selection of materials may ensure sufficient conductivity of the pervious mortar without reliance on cracking of the mortar to provide conductivity.

[0019] Whether the mortar slurry is designed such that the mortar cracks or not, the mortar slurry may be designed to ensure that the mortar maintains at least some integrity in the fracture. Thus, various designs of the mortar slurry result in a mortar that has a maximum compressive strength, a minimum compressive strength, or both. A particular mortar slurry provides a mortar that cracks because the maximum compressive strength is sufficiently low, yet maintains structural integrity because the minimum compressive strength is sufficiently high. Stated another way, the mortar may crack while remaining in place and serving as a proppant. The degree to which the mortar may crack may be chosen based on maximizing conductivity, such that there are enough cracks to ensure flow therethrough, but not so many cracks that the mortar breaks into small pieces and blocks or otherwise becomes a hindrance to wellbore operations.

[0020] In order to maintain the desired integrity in the fracture, the mortar may have a compressive strength above an effective confinement stress of the formation or above fracture closure if cracking of the mortar is not desired (for example, if the mortar is a

pervious mortar having sufficient permeability without cracking). Additionally, the mortar may have strength sufficient to hold on pressure cycles due to temporary well shutoffs due to maintenance or other operational reasons. In some embodiments, the mortar may have a compressive strength of about 20 MPa when the postulated fracture closure pressure is about 40 MPa, such that the fracture closure pressure will cause the mortar to crack without being destroyed.

[0021] After a permeable mortar has formed in the wellbore as a result of the use of a pervious mortar, as a result of cracking of the mortar, or as a result of both, hydrocarbons may be produced from the formation, with the permeable mortar acting to maintain the integrity of the fracture within the formation while allowing the hydrocarbons and other formation fluids to flow into the wellbore. Produced hydrocarbons may flow through the permeable mortar and/or induced cracks while formation sands may be substantially prevented from passing through the permeable mortar.

[0022] The mortar slurry includes cementitious material and water. The water may be present in an amount sufficient to form the mortar slurry with a consistency that can be pumped. More particularly, a weight ratio between the water and the cementitious material may be between 0.2 and 0.8, depending on a variety of desired characteristics of the mortar slurry. For example, more water may be used when less viscosity is desired and more cementitious material or less water may be used when strength is desired. Additionally, the ratio of water to cementitious material may be varied depending on whether other materials are used in the mortar slurry. The particular materials used in the mortar slurry may be selected based on flowability, and homogeneity.

[0023] A variety of cementitious materials may be suitable, including hydraulic cements formed of calcium, aluminum, silicon, sulfur, oxygen, iron, and/or aluminum, which set and harden by reaction with water. Hydraulic cements include, but are not limited to, Portland cements, pozzolanic cements, gypsum cements, high alumina content cements, silica cements, high alkalinity cements, micro-cement, slag cement, and fly ash cement. Some cements are classified as Class A, B, C, G, and H cements according to American Petroleum Institute, API Specification for Materials and Testing for Well Cements, API Specification 10, Fifth Ed., Jul. 1, 1990. Other cement types and compositions that may be suitable are set forth in the European standard EN 197-1, which

consists of 5 main types. Of those, Type II is divided into seven subtypes based on the type of secondary material. The American standard ASTM C150 covers different types of Portland cement and ASTM C595 covers blended hydraulic cements. The cementitious material may form about 20% to about 90% of the weight of the mortar slurry.

[0024] The water in the mortar slurry may be fresh water, salt water (e.g., water containing one or more salts dissolved therein), brine (e.g., saturated salt water), brackish water, flow-back water, produced water, recycle or waste water, lake water, river, pond, mineral, well, swamp, or seawater. Generally, the water may be from any source provided it does not contain an excess of compounds that adversely affect other components in the mortar slurry. The water may be treated to ensure appropriate composition for use in the mortar slurry.

[0025] In some embodiments, the mortar slurry may be designed to provide a pervious mortar with a minimum level of conductivity. For example, the mortar slurry may be designed to set to form a pervious mortar with conductivity from about 10 mD-ft to about 9,000 mD-ft, from about 250 mD-ft to about 1,000 mD-ft, above 100 mD-ft, or above 1,500 mD-ft using gap-graded aggregates, cracking, or both.

[0026] The mortar slurry may provide the mortar with the minimum level of conductivity without resorting to certain materials that may be expensive, harmful to the environment, difficult to transport, or otherwise undesirable. In other words, the mortar slurry may essentially exclude certain materials. For example, in some cases, gelling agents, breakers, foaming agents, surfactants, additional viscofiers, and/or degradable materials may be entirely omitted from the mortar slurry, or included in only minimal amounts. Thus, the mortar slurry may include less than 5% gelling agents, less than 5% foaming agents, less than 5% surfactants, and/or less than 5% degradable material based on the weight of the cementitious material in the mortar slurry. For example, the mortar slurry may include less than 4%, less than 3%, less than 2%, less than 1%, less than 0.5%, less than 0.1%, or trace amounts of any of these materials based on the weight of the cementitious material in the mortar slurry.

[0027] The mortar slurry may further include aggregate. Some examples of aggregates include standard sand, river sand, crushed rock (such as basalt, lava/volcanic rock, etc.) mineral fillers, and/or secondary or recycled materials such as limestone grains from

demineralization of water and fly ash. Other examples include poly-disperse, new, recycle or waste stream solid particles, ceramics, crushed concrete, spent catalyst (e.g., heavy metal leach), and glass particles. Lightweight additives such as bentonite, pozzolan, or diatomaceous earth may also be provided. The aggregate may have a grain size of 0 to 2 mm, 0 to 1 mm, possibly 0.1 to 0.8 mm. The sand/ cementitious material ratio may influence mechanical properties of the mortar, such as compressive and flexural strength, as well as the workability, porosity, and permeability of the mortar slurry. The ratio between the sand and the cementitious material may be between 1 and 8, between 1 and 6, or between 2 and 4. In some embodiments, gap-graded aggregates may be used. Thus, particular ratios of various grain sizes may be selected based on the unique characteristics of each, such that voids are intentionally created in the mortar slurry as it is pumped into the wellbore and sets to form the mortar. Thus, gap-graded aggregates may provide for a void content of the mortar of about 20%, either prior to or after the mortar has cracked to form a permeable mortar. Mixing angularities of particles may allow for better packing mixtures. For example, natural material such as sand with low or high angularity may be used either alone or in conjunction with other materials having similar or dissimilar angularities. When the designed void content is sufficiently high, the mortar may be designed to have a compressive strength higher than the fracture closure pressure. Thus, with gap-graded aggregates, a higher degree of integrity of the mortar may be obtained while allowing for sufficient conductivity. However, if additional conductivity is desired, the gap-graded aggregate may be used in conjunction with the mortar designed to crack under fracture closure pressure, creating an even higher conductivity. Sand grains in some embodiments may be coated with a cement-based mixture by means of pre-hydration to eliminate sagging and keep the mortar slurry as a single phase liquid; additionally, one may further add a thickening agent or other common solid suspension additive as well as different improvement admixtures to the mortar slurry.

[0028] The mortar slurry may include binders such as, but not limited to, Portland cement of which CEM I 52.5 R is a very rapidly hardening example, or others such as Microcem, a special cement with a very small grain size distribution (< 10 μm). The latter has very small cement particles and therefore a very high specific surface (i.e., Blaine value), as such it is possible to get very high strengths at an early time. Other cementitious

materials such as clinker, fly ash, slag, silica fume, limestone, burnt shale, possolan, and mineral binders may be used for binding.

[0029] The mortar slurry may include admixtures of plasticizers or superplasticizers and retarders. Superplasticizers may include, but are not limited to, poly-carboxylate ethers of which a commercial example is BASF Glenium ACE 352 (active component = 20 %m/m) and/or sulfonated naphthalene formaldehyde condensates of which a commercial example is Cugla PIB HR (active component = 35% m/m). Retarders may include, but are not limited to, standard retarders for cement applications known in the art of which commercial examples include CUGLA PIB MMV (active component = 25 %m/m) and/or BASF Pozzolith 130R (active component = 20 %m/m).

[0030] Optionally, a dispersant may be included in the mortar slurry in an amount effective to aid in dispersing the cementitious and other materials within the mortar slurry. For example, dispersant may be about 0.1% to about 5% by weight of the mortar slurry. Exemplary dispersants include naphthalene-sulfonic-formaldehyde condensates, acetone-formaldehyde-sulfite condensates, and flucano-delta-lactone.

[0031] A fluid loss control additive may be included in the mortar slurry to prevent fluid loss from the mortar slurry during placement. Examples of liquid or dissolvable fluid loss control additives include modified synthetic polymers and copolymers, natural gum and their derivatives and derivatized cellulose and starches. If used, the fluid loss control additive generally may be included in a resin composition in an amount sufficient to inhibit fluid loss from the mortar slurry. For example, the fluid loss additive may form about 0% to about 25% by weight of the mortar slurry.

[0032] Other additives such as accelerators (e.g., calcium chloride, sodium chloride, triethanolaminic calcium chloride, potassium chloride, calcium nitrite, calcium nitrate, calcium formate, sodium formate, sodium nitrate, triethanolamine, X-seed (BASF), nano-$CaCO_3$, and other alkali and alkaline earth metal halides, formates, nitrates, carbonates, admixtures for cement specified in ASTM C494, or others), retardants (e.g., sodium tartrate, sodium citrate, sodium gluconate, sodium itaconate, tartaric acid, citric acid, gluconic acid, lignosulfonates, and synthetic polymers and copolymers, thixotropic additives, soluble zinc or lead salts, soluble borates, soluble phosphates, calcium lignosulphonate, carbohydrate derivates, sugar based admixtures (such as lignine),

admixtures for cement specified in ASTM C494, or others), suspending agents, surfactants, hydrophobic or hydroliphic coatings, PH buffers, or the like may also be in the mortar slurry. Additional additives may include fibers for strengthening or weakening, either polymeric or natural such as cellulose fibers. Cracking additives may also be included. Some cracking additives may include expansive materials (e.g., gypsum, calcium sulfo-aluminate, free lime (CaO), aluminum particles (e.g., metallic aluminum), reactive silica (e.g., course; on long term), etc.), shrinking materials, cement contaminants (e.g., oil, diesel), weak spots (e.g., weak aggregates, volcanic aggregates, etc.), non bonding aggregates (e.g., plastics, resin coated proppant, biodegradable material).

[0033] In some embodiments, e.g., stimulation of a consolidated or semi-consolidated formation, conventional proppant material may be added to the mortar slurry. As used herein, the terms "consolidated" and "semi-consolidated" refer to formations that have some degree of relative structural stability as opposed to an "unconsolidated" formation, which has relatively low structural stability. When subjected to a fracturing procedure, such formations may exert very high fracture closure stresses. The proppant material may aid in maintaining the fractures propped open. If used, the proppant material may be of a sufficient size to aid in propping the fractures open without negatively affecting the conductivity of the mortar. The general size range may be about 10 to about 80 U.S. mesh. The proppant may have a size in the range from about 12 to about 60 U.S. mesh. Typically, this amount may be substantially less than the amount of proppant material included in a conventional fracturing fluid process.

[0034] The mortar slurry may further have glass or other fibers, which may bind or otherwise hold the mortar together as it cracks, limestone, or other filler material to improve cohesion (reduce segregation) of the mortar slurry, or any of a number of additives or materials used in downhole operations involving cementitious material.

[0035] The mortar slurry may set to form a pervious mortar in a fracture in a subterranean formation to, among other things, maintain the integrity of the fracture, and prevent the production of particulates with well fluids. The mortar slurry may be prepared on the surface (either on the fly or by a pre-blending process), and then injected into the subterranean formation and/or into fractures or fissures therein by way of a wellbore under a pressure sufficient to perform the desired function. When the fracturing or other mortar

slurry placement process is completed, the mortar slurry is allowed to set in the formation fracture(s). A sufficient amount of pressure may be required to maintain the mortar slurry during the setting period to, among other things, prevent the mortar slurry from flowing out of the formation fractures. When set, the pervious mortar may be sufficiently conductive to allow oil, gas, and/or other formation fluids to flow therethrough without allowing the migration of substantial quantities of undesirable particulates to the wellbore. Moreover, the pervious mortar may have sufficient compressive strength to maintain the integrity of the fracture(s) in the formation.

[0036] The mortar may have sufficient strength to substantially act as a propping agent, for example, to partially or wholly maintain the integrity of the fracture(s) in the formation to enhance the conductivity of the formation. Importantly, while acting as a propping agent, the mortar may also provide flow channels within the formation, which facilitate the flow of desirable formation fluids to the wellbore. The cracked mortar, while lacking sufficient strength to avoid cracking under fracture closing pressure, may also have sufficient strength to act as a propping agent. In some embodiments, the permeable mortar (i.e., pervious mortar, cracked mortar, or cracked pervious mortar) may have a permeability ranging from about 0.1 darcies to about 430 darcies; in other embodiments, the permeable mortar may have a permeability ranging from about 0.1 darcies to about 50 darcies; in still other embodiments, the permeable mortar may have a permeability of above about 10 darcies, or above about 1 darcy.

[0037] When cracking of the mortar is not specifically desired, the methods described above may optionally omit the steps of maintaining a pressure higher than the fracture closure pressure while allowing the mortar slurry to set, and allowing the mortar in the fracture to crack and form a cracked mortar. If such steps are not omitted or are only partially omitted, the mortar may still crack and form the cracked mortar, resulting in enhanced conductivity. However, if cracking is desired, such steps may ensure managed cracking occurs.

[0038] Slugs of mortar slurry and proppant laden gel may increase connectivity bewteen cracked mortar locations within the fractures using the proppant and gel sections as connectors. The sections of cracked mortar may provide support for vertical placement of high conductivity material in the fracture. The treatment may be completed at the end

with proppant and fluid for better near wellbore conductivity. Low and high frequency and ratio of cracked mortar and gel may depend on equipment capabilitity to cycle bewtween two systems.

[0039] In order to provide for efficient pumping and other working of the mortar slurry, the mortar slurry may be designed to flow in accordance with particular limitations of the worksite. Thus, taking into account variables such as temperature, depth of the wellbore and other formation characteristics, the flowability radius may be adjusted. The mortar slurry viscosity, measured by viscometers standard equipment known to the skilled person such a Fann-35 (by Fann Instrument Company of Houston Tx), may be less than 5,000 cP, or less than 3,000 cP, potentially below 1,000 cP. Likewise, the mortar slurry may be designed to set in accordance with particular limitations of the worksite. Thus, taking into account variables such as temperature, depth of the wellbore, other formation characteristics, the setting time may be adjusted. In some embodiments, the setting time of the mortar slurry may be at least 60 minutes after pump shut in. In other embodiments, the setting time of the mortar slurry may be between 2 hours and 6 hours after pump shut in, about 3 hours after pump shut in, or another setting time allowing for placement of the mortar slurry without undesirable delay after placement and before setting. When a setting time has been selected, the method of treating the subterranean formation may include allowing the mortar slurry to set by waiting the designed set time. For example, when the setting time of the mortar slurry is 60 minutes, the method may include waiting at least 60 minutes after injecting stops. A person skilled in the art will appreciate that certain retarder technologies may affect the mortar slurry strength development which may be taken into account and compensated for.

[0040] Upon setting of the mortar slurry, the mortar (e.g., a pervious mortar) may have a conductivity above 100 mD-ft, and the mortar slurry may be designed to provide such conductivity in the mortar. Prior to cracking, a pervious mortar may have a first conductivity. Such conductivity may result from a continuous open pore structure and/or cracks formed in the pervious mortar. After cracking of the pervious mortar, the cracked pervious mortar may have a higher conductivity because of the void space created by the cracks. For example, cracking may provide cracks having widths of about 0.5 mm. Thus, a second conductivity of the pervious mortar may be greater than the first conductivity of the pervious mortar prior to cracking. For example, the first conductivity may be at least 100

mD-ft, and the second conductivity may be at least 250 mD-ft. The second conductivity may be a degree or percentage greater than the first conductivity. For example, the second conductivity may be at least 25 mD-ft, 50 mD-ft, 100 mD-ft, 250 mD-ft, 500 mD-ft, or 1,000 mD-ft greater than the first conductivity. These values may apply to confinement stress of up to about 15,000 psi, with different values applicable to different applied net pressure.

[0041] Upon setting of the mortar slurry, the mortar may have a salinity tolerance above 3 % brine, and the mortar slurry may be designed to provide such salinity tolerance in the mortar. For example, the salinity tolerance may be between about 1% brine and about 25% brine. A person skilled the art may appreciate that with high salinity or alkali content, some aggregates may show unwanted alkali-silica reactivity and hence such materials are not preferred here.

[0042] The mortar slurry may be designed with a setting temperature of about 50 °C to about 330 °C, designed with a setting temperature of below 150 °C, or designed with a setting temperature of above 150 °C.

[0043] In one embodiment, the mortar slurry may be formed of 27.7 wt% Portland cement, 13.9 wt% in ground water, 55.4 wt% 0-1 mm sand, 1.7 wt% retarder, and 1.3 wt% superplasticizer.

[0044] In one particular embodiment, the mortar slurry and mortar may be designed with some or all of the following characteristics:

Property	Value
Confinement stress (at 20 hours after setting)	42-85 MPa
Conductivity	250-1,000mD-ft (with a crack width of 3 mm)
Setting time	2 hours
Setting temperature	60-200 °C
Salinity tolerance	3-10% Brine
Pumping rates	Up to 10 m^3/min
Tube diameter	127 mm
Tube perforations	12.7 mm

EXAMPLES

[0045] In one test under ambient conditions (i.e., 20 °C), a mixture using the components below with a water/cement ratio of 0.35 resulted in a mortar having the properties following.

Component	%m/m	Kg/m^3 (assuming 4% V/V air content)
CEM I 52.5 R	28.8	658
Concrete sand 0-1 mm	57.6	1,317
Water	10.1	231
Cugla MMV	0.56	12.8
BASF Glenium	0.55	12.6

Property	Value
Compressive strength (after 16 hours)	36 MPa
Compressive strength (after 24 hours)	48 MPa
Flexural strength (after 16 hours)	6 MPa
Flexural strength (after 24 hours)	7 MPa
Flowability (after 0 minutes)	>300 mm
Flowability (after 30 minutes)	>300 mm
Flowability (after 60 minutes)	>300 mm
Setting time	>120 minutes

[0046] In another test, a mixture using the materials below with a water/cement ratio of 0.35 resulted in a mortar having the properties following.

Component	%m/m	Kg/m^3 (assuming 4% V/V air content)
Microcem	29.7	667
Concrete sand 0-1 mm	59.4	1,335
Water	10.4	234
BASF Pozzolith	0.26	5.8
BASF Glenium	0.28	6.3

Property	Value
Compressive strength (after 16 hours)	64 MPa
Compressive strength (after 24 hours)	84 MPa
Flexural strength (after 16 hours)	7 MPa
Flexural strength (after 24 hours)	8 MPa
Flowability (after 0 minutes)	300 mm
Setting time	15 minutes

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[0047] In yet another test, a mixture using the materials below resulted in a mortar that met the strength requirement of at least 42 MPa at 20 °C, 50 °C, and 80 °C, and at 24 hours at 80 °C had a compressive strength in excess of 80 MPa.

[0048] In a cracked mortar test of two samples, conductivity was measured at room temperature using the falling head method, with water column height about 0.4 m. The specimen exhibited good flowability and setting behavior, with compressive strength after 16-24 hours being between 25 MPa and 30 MPa (at 80 °C). Compressive strength in this range was sufficiently weak to crack under the assumed fracture closing pressure with conductivity between 150 mD-ft and 2,200 mD-ft, as indicated below.

Cement CEM I 52.5 R	19.98 %m/m	22.46 %m/m
Water	12.91 %m/m	12.57 %m/m
Concrete sand 0-1 mm	55.33 %m/m	53.89 %m/m
Limestone filler	9.22 %m/m	8.98 %m/m
Cugla MMV	0.86 %m/m	0.84 %m/m
BASF Glenium	1.25 %m/m	1.26 %m/m
Glass fibers	0.40 %m/m	0.00 %m/m
Sand/cement ratio	2.77	2.40
Water (total)/cement ratio	0.73	0.63
Segregation	No	No
Flowability (after 0 minutes)	180 mm without vibration >300 mm with low intensity vibration of flow table	260 without vibration >300 mm with low intensity vibration of flow table
Flowability (after 60 minutes)	120 mm without vibration >300 mm with low intensity vibration of flow table	280 mm without vibration >300 mm with low intensity vibration of flow table
Setting time (min)	>75	>75
Compressive strength (after 16 hours)	26 MPa	25 MPa
Compressive strength (after 24 hours)	31 MPa	27 MPa
Conductivity – small cracks (up to 0.6 mm)	150 mD-ft	150 mD-ft
Conductivity – wide cracks (up to 3.0 mm)	2,200 mD-ft	2,200 mD-ft

[0049] In another test, conductivity was measured at room temperature using the falling head method with water column height about 0.4 m. The specimen showed proper conductivity when interpolated to 80 °C and using gas as a medium. Compressive strength was below the minimum value specified, indicating likelihood that cracking would occur, hence increasing conductivity, as indicated below.

Sand grain size	0.5-1.6 mm	1-2 mm
Cement CEM I 52.5 R	18.6 %m/m	18.4 %m/m
Water	5.6 %m/m	6.9 %m/m
Concrete sand 0-1 mm	74.4 %m/m	73.4 %m/m
Cugla MMV	0.6 %m/m	0.6 %m/m
BASF Glenium	0.9 %m/m	0.9 %m/m
Sand/cement ratio	4.0	4.0
Water (total)/cement ratio	0.36	0.43
Segregation	No	No
Flowability (after 0 minutes)	150 mm	150 mm
Setting time (minutes)	>60	>60
Compressive strength	30 MPa	12 MPa
Conductivity	26 mD-ft	75 mD-ft

[0050] In light of the various tests, it is believed that at least the following ranges (% m/m) of compositions would be suitable for a mortar slurry designed to form a substantially non-pervious mortar:

	Range	Preferred Range	Specific Example
Cement	15-40	20-29	20
Lime stone filler	15-30	20	20
Water	5-30	10-14	11
Sand	20-70	48-60	48
Superplasticizer	0-3	0.3-1.4	1.3
Retarder	0-3	0-1.8	0

Glass fibers	0-5	0.54	0
W/C ratio	0.3-0.8	0.4-0.7	0.60
S/C ratio	0.5-8	2-3	2.4

[0051] In light of the various tests, it is believed that at least the following ranges of compositions would be suitable for a mortar slurry designed to form a pervious mortar:

	Range	Preferred Range	Specific Example
Cement	10-40	14-41	14
Lime stone filler	0	0	0
Water	5-20	5-15	5
Sand	40-85	40-81	81
Superplasticizer	0-3	0.3-1.9	0.3
Retarder	0-3	0-2.5	0
Glass fibers	0	0	0
W/C ratio	0.3-0.8	0.4-0.6	0.40
S/C ratio	0.5-8	1-6	6.0

[0052] In light of the various tests, it is believed that at least the following ranges would be suitable for a mortar slurry designed with pre-hydrated precoated sand:

	Range	Preferred Range
W/C ratio (by weight)	0.05-0.50	0.15-0.30
S/C ratio (by weight)	1-10	3-6

[0053] Those of skill in the art will appreciate that many modifications and variations are possible in terms of the disclosed embodiments, configurations, materials, and methods without departing from their scope. Accordingly, the scope of the claims and their functional equivalents should not be limited by the particular embodiments described and

illustrated, as these are merely exemplary in nature and elements described separately may be optionally combined.

CLAIMS

1. A method of treating a subterranean formation, comprising:

preparing a mortar slurry designed to set to form a mortar with a compressive strength below a fracture closure pressure of the subterranean formation, the mortar slurry comprising a cementitious material and water;

injecting the mortar slurry into the subterranean formation at a pressure sufficient to create a fracture in the subterranean formation;

while maintaining a pressure higher than the fracture closure pressure, allowing the mortar slurry to set, forming the mortar in the fracture;

reducing the pressure below the fracture closure pressure;

allowing the mortar in the fracture to crack, forming a cracked mortar; and

exposing the set mortar to a pulse of pressure sufficient to reopen the fracture and provide additional cracks and permeability in the set cracked mortar.

2. The method of claim 0, wherein the pulse of pressure is provided by a compressable gas.

3. The method of claims 1 or 2 wherein the pulse of pressure is provided by pumping a liquid into the wellbore.

4. The method of any one of claims 1-3 wherein the mortar slurry is further designed to have a viscosity of less 5,000 cP.

5. The method any one of claims 1-4, wherein the mortar slurry is further designed to set to form the mortar with a setting time in excess of 60 minutes after pump shut in, and wherein allowing the mortar slurry to set comprises waiting at least 60 minutes after injecting stops.

6. The method of any one of claims 0-5, wherein the mortar slurry is further designed to set to form a pervious mortar with a compressive strength above an effective confinement stress of the formation.

7. The method of any on eof claims 0-6, wherein the mortar slurry is further designed to set to form a pervious mortar with a conductivity above 4,000 mD-ft.

8. The method of any one of claims 0-7, wherein, prior to allowing the mortar in the fracture to crack, the mortar comprises a pervious mortar having a first conductivity, and wherein the cracked mortar has a second conductivity greater than the first conductivity.

9. The method of claim 8, wherein the second conductivity is above 2,000 mD-ft.

10. The method of claim 8, wherein the second conductivity is at least 2,000 mD-ft greater than the first conductivity.

11. The method of any one of claims 0-10, wherein the mortar slurry is further designed to set and form the mortar with a salinity tolerance above 1 % brine.

12. The method of any one of claims 0-11, wherein a design ratio between the water and the cementitious material is between 0.2 and 0.8.

13. A method of treating a subterranean formation, comprising:

preparing a mortar slurry designed to set to form a pervious mortar with conductivity above 10 mD-ft, the mortar slurry comprising a cementitious material, aggregate, and water;

injecting the mortar slurry into the subterranean formation at a pressure sufficient to create a fracture in the subterranean formation;

allowing the mortar slurry to set, forming the pervious mortar in the fracture; and

after the mortar has set, providing a pulse of pressure sufficient to reopen the fracture and thereby provide cracks in the mortar.

14. The method of claim 13, wherein the mortar slurry is further designed to have a viscosity of less 5,000 cP.

15. The method of claims 13 or 14, wherein the mortar slurry is further designed to set to form the pervious mortar with a setting time in excess of 60 minutes after pump shut in, and wherein allowing the mortar slurry to set comprises waiting at least 60 minutes after injecting stops.

16. The method of any one of claims 13-15, wherein the mortar slurry is further designed to set to form the pervious mortar with a compressive strength above an effective confinement stress of the formation.

17. The method of any one of claims 13-16, wherein the mortar slurry is designed to set to form the pervious mortar with a compressive strength above 20 Mpa.

18. The method of any one of claims 13-17, wherein the mortar slurry is further designed to set and form the pervious mortar with a salinity tolerance above 1 % brine.

19. The method of any one of claims 13-18, wherein a design ratio between the water and the cementitious material is between 0.2 and 0.8.

20. The method of any one of claims 13-19, wherein the mortar slurry design further comprises sand.

21. The method of any one of claims 13-20, wherein a design ratio between the sand and the cementitious material is between 1 and 8.

22. The method of any one of claims 13-21, wherein the mortar slurry design further comprises retarder.

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2016/032858

A. CLASSIFICATION OF SUBJECT MATTER
IPC(8) - E21B 43/25; E21B 43/26 (2016.01)
CPC - E21B 43/25; E21B 43/255; E21B 43/26; E21B 43/261 (2016.05)
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)
IPC(8) - E21B 43/25, E21B 43/26 (2016.01)
CPC - E21B 43/25, E21B 43/255, E21B 43/26, E21B 43/261 (2016.05)

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
USPC -166/281; 166/307; 166/308.1; IPC(8) - E21B 43/25, E21B 43/26; CPC - E21B 43/25, E21B 43/255, E21B 43/26, E21B 43/261 (keyword delimited)

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
Orbit, Google Scholar
Search terms used: pulse, fracture, pressure, mortar, cement, cementing, slurry, subterranean formation, cracked mortar, pumping, liquid, compressible gas, reopen

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 2013/0341024 A1 (SHELL OIL COMPANY) 26 December 2013 (26.12.2013) entire document	1-3, 13-15
Y	US 3,602,311 A (WHITSITT) 31 August 1971 (31.08.1971) entire document	1-3, 13-15
Y	US 5,005,649 A (SMITH et al) 09 April 1991 (09.04.1991) entire document	2
A	US 4,530,396 A (MOHAUPT) 23 July 1985 (23.07.1985) entire document	1-3, 13-15
A	US 6,364,015 B1 (UPCHURCH) 02 April 2002 (02.04.2002) entire document	1-3, 13-15

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

* Special categories of cited documents:
"A" document defining the general state of the art which is not considered to be of particular relevance
"E" earlier application or patent but published on or after the international filing date
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed
"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
08 July 2016	18 AUG 2016
Name and mailing address of the ISA/ Mail Stop PCT, Attn: ISA/US, Commissioner for Patents P.O. Box 1450, Alexandria, VA 22313-1450 Facsimile No. 571-273-8300	Authorized officer Blaine R. Copenheaver PCT Helpdesk: 571-272-4300 PCT OSP: 571-272-7774

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2016/032858

Box No. II Observations where certain claims were found unsearchable (Continuation of item 2 of first sheet)

This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:

2. ☐ Claims Nos.:
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:

3. ☒ Claims Nos.: 4-12, 16-22
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box No. III Observations where unity of invention is lacking (Continuation of item 3 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

1. ☐ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.

2. ☐ As all searchable claims could be searched without effort justifying additional fees, this Authority did not invite payment of additional fees.

3. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:

4. ☐ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

Remark on Protest

☐ The additional search fees were accompanied by the applicant's protest and, where applicable, the payment of a protest fee.

☐ The additional search fees were accompanied by the applicant's protest but the applicable protest fee was not paid within the time limit specified in the invitation.

☐ No protest accompanied the payment of additional search fees.