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(54) **SYSTEM AND METHODS FOR TREATING SUBSURFACE FORMATIONS CONTAINING FRACTURES**

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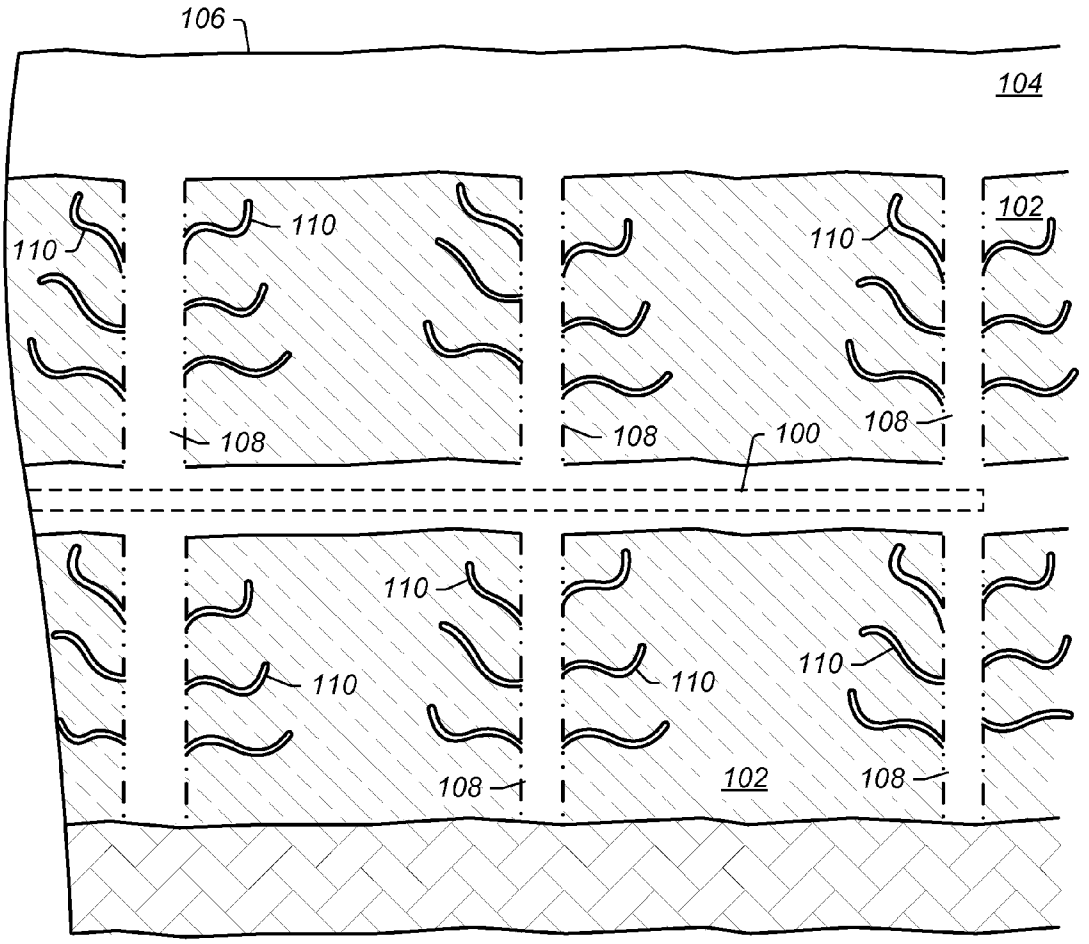
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(57) **ABSTRACT**

Methods of treating hydrocarbon containing formations are described herein. A method for treating a mudstone formation includes providing a substantially horizontal or inclined wellbore to mudstone formation; providing acid to the portion of mudstone formation such that a size of the fractures is increased; and allowing hydrocarbons to flow through the fractures.



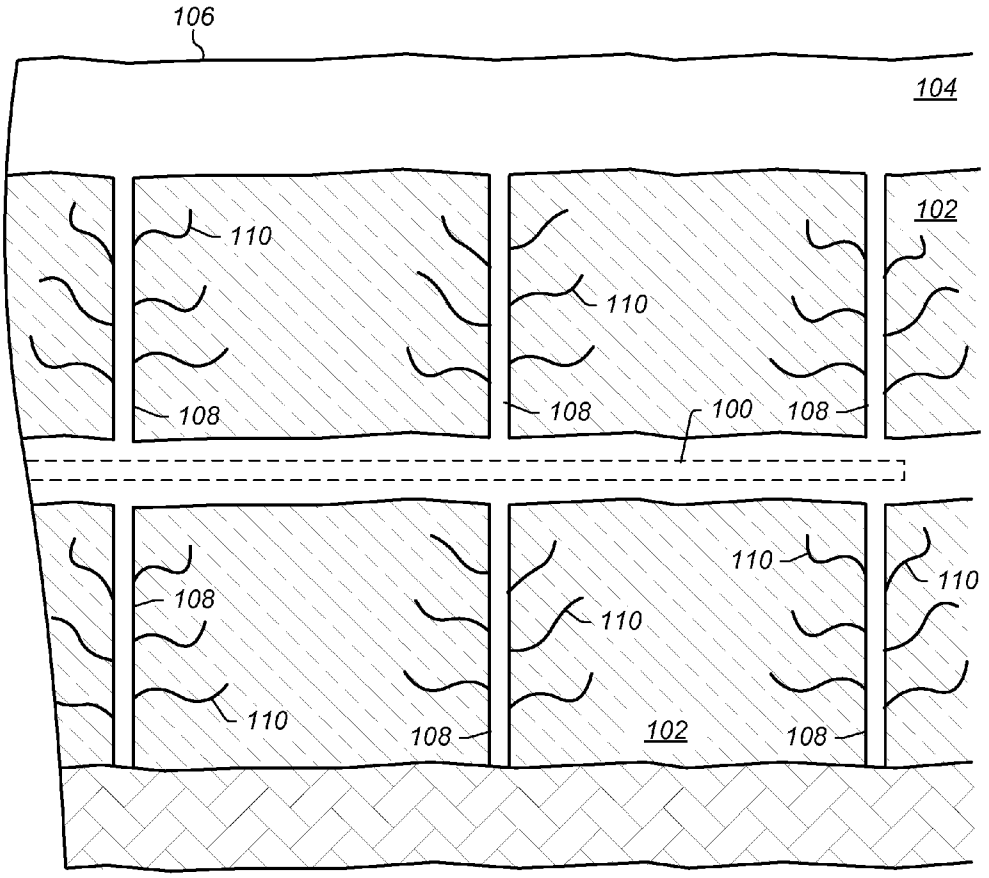

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FIG. 1

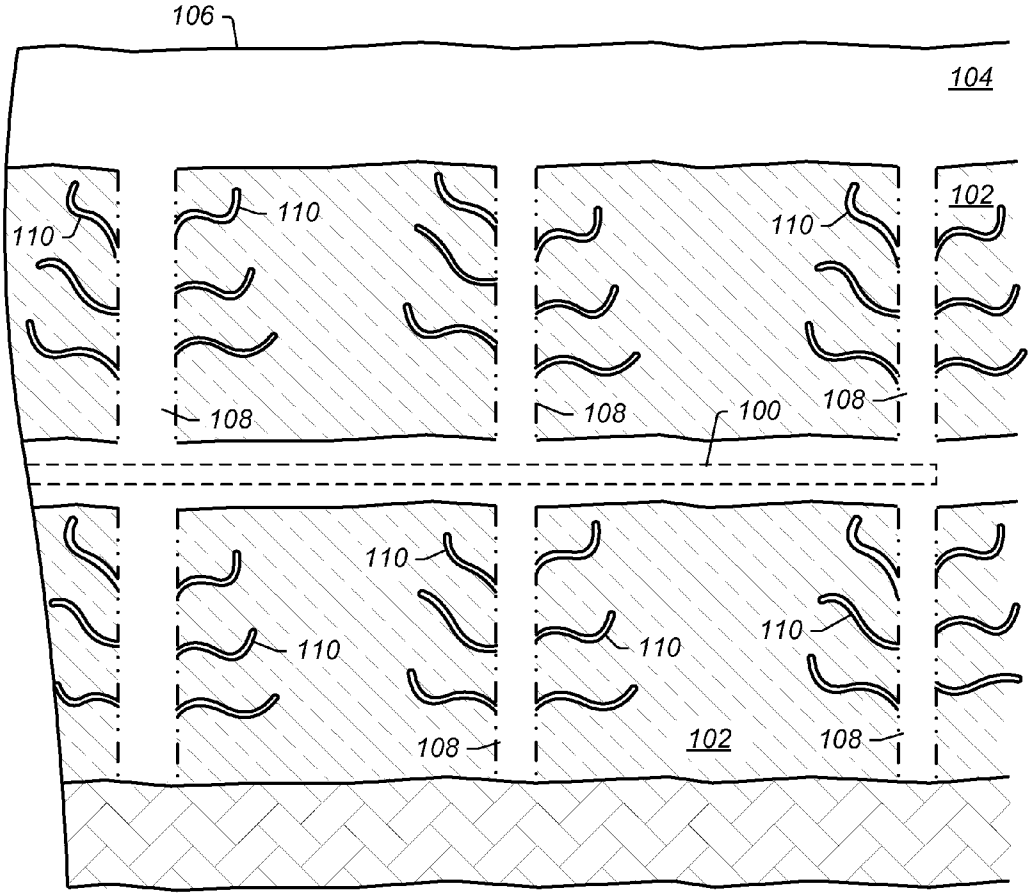

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FIG. 2

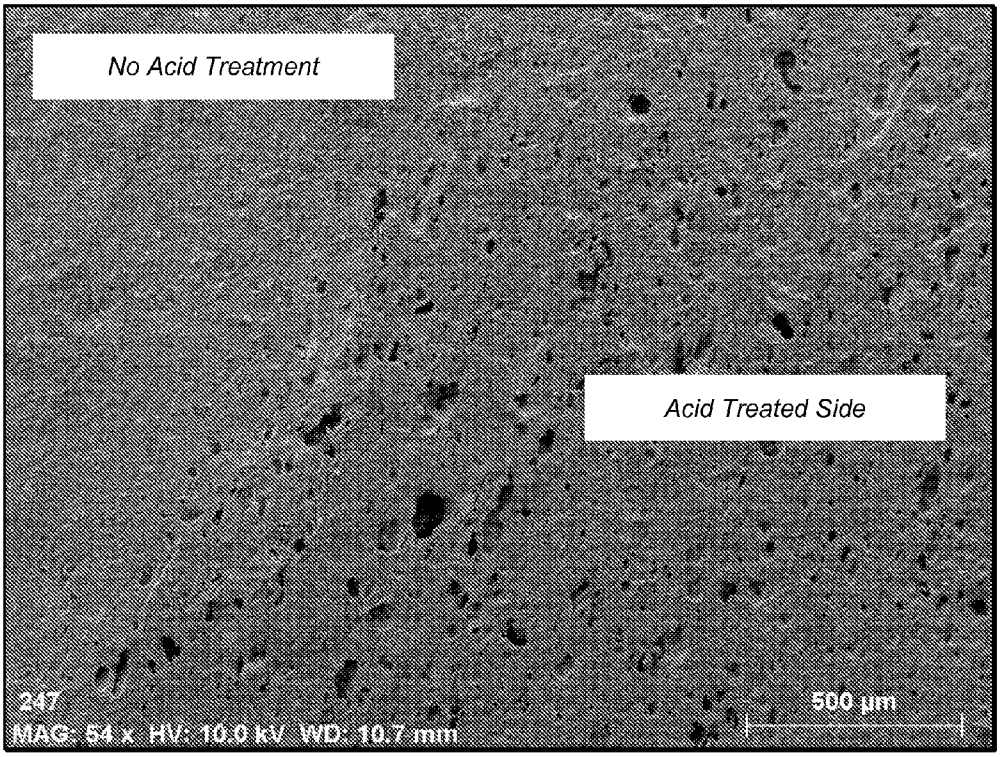

No Acid Treatment
Acid Treated Side
247
MAG: 54 x HV: 10.0 kV WD: 10.7 mm
500 µm

FIG. 3

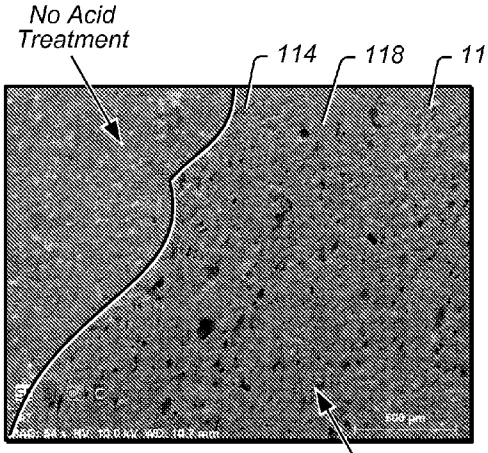


FIG. 4A

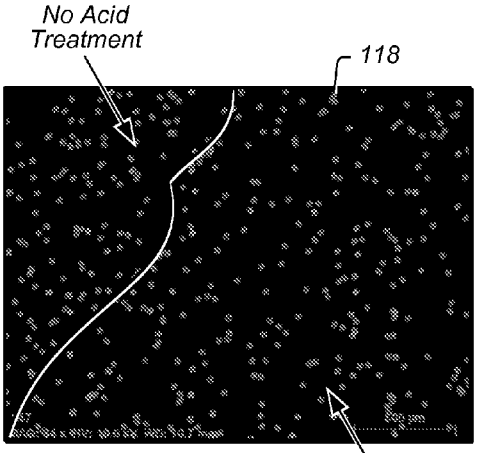


FIG. 4B

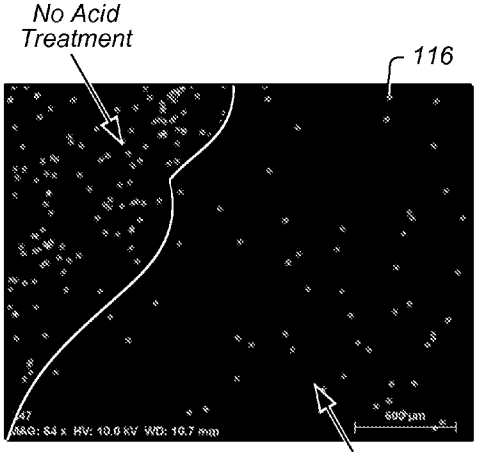


FIG. 4C

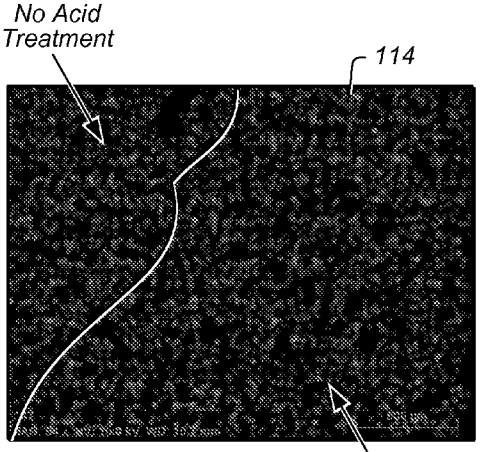


FIG. 4D

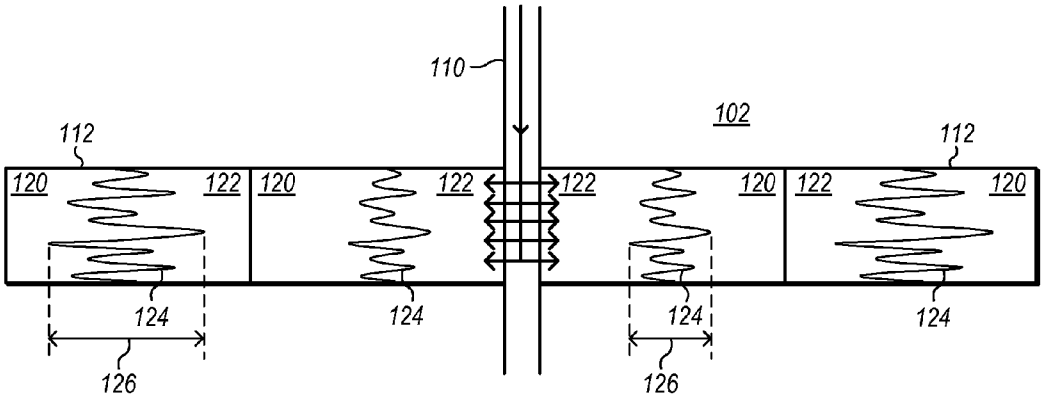

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FIG. 5

SYSTEM AND METHODS FOR TREATING SUBSURFACE FORMATIONS CONTAINING FRACTURES

BACKGROUND

[0001] 1. Field of the Invention

[0002] The present invention relates generally to methods and systems for production of hydrocarbons and/or other products from various subsurface formations such as hydrocarbon containing formations containing fractures.

[0003] 2. Description of Related Art

[0004] Hydrocarbons obtained from subterranean formations are often used as energy resources, as feedstocks, and as consumer products. Concerns over depletion of available hydrocarbon resources and concerns over declining overall quality of produced hydrocarbons have led to development of processes for recovery that is more efficient, processing and/or use of available hydrocarbon resources. In situ processes may be used to remove hydrocarbon materials from subterranean formations that were previously inaccessible and/or too expensive to extract using available methods.

[0005] Substantial reserves of hydrocarbons are known to exist in formations that have relatively low permeability. Examples of such formations include the Eagle Ford shale, the Barnett shale, the Travis Peak and Cotton Valley formations and the Bakken shale. Several methods have been proposed and/or used for producing heavy hydrocarbons from relatively low permeability formations. Recovery of hydrocarbons from low permeability subterranean formations is difficult because of the low mobility of fluids in the pore space in the subterranean formation (ultra-low permeability rocks). This makes the production and injection of fluids from such reservoirs very difficult. Similar problems are encountered in heavy oil reservoirs (reservoirs containing crude oil with a viscosity larger than about 100 centipoise). Here too, the mobility of the fluids is small and it is difficult to inject and produce from the hydrocarbon bearing rock.

[0006] It is a common practice to acidize subterranean formations in order to increase the permeability of the formation. For example, an acidizing fluid is injected into a well in order to increase the permeability of a surrounding hydrocarbon-bearing formation, and thus, facilitate the flow of hydrocarbon fluids into the well from the formation or the injection of fluids such as gas or water, from the well into the formation. Such acidizing techniques may be carried out as "matrix acidizing" procedures or as "acid-fracturing" procedures.

[0007] In acid fracturing, the acidizing fluid is disposed within the well opposite the formation to be fractured. Thereafter, sufficient pressure is applied to the acidizing fluid to cause the formation to break down with the resultant production of one or more fractures therein. An increase in permeability thus is affected by the fractures formed as well as by the chemical reaction of the acid within the formation.

[0008] In matrix acidizing, the acidizing fluid is passed into the formation from the well at a pressure below the breakdown pressure of the formation. In this case, increase in permeability is affected primarily by the chemical reaction of the acid within the formation with little or no permeability increase being due to mechanical disruptions within the formation as in fracturing.

[0009] In yet another technique involving acidizing, the formation is fractured. Thereafter, an acidizing fluid is injected into the formation at fracturing pressures to extend the created fracture. The acid functions to dissolve formation materials forming the walls of the fracture, thus increasing the width and permeability thereof. Grieser et al. describes in "Surface Reactive Fluid's Effect on Shale," Presented at the 2007 SPE Production and Operations Symposium, Mar. 31, 2007 to Apr. 3, 2007 describes injecting acidizing fluid into the formation at fracturing pressures.

[0010] In most cases, acidizing procedures are carried out in calcareous formations such as dolomites, limestones, dolomitic sandstones, etc. For example, U.S. Pat. No. 5,238,067 to Jennings, Jr. describes methods to improve fracture acidizing in a carbonate containing formation. Initially, the formation is hydraulically fractured to form a fracture in the formation in a preferred direction. Thereafter, an acid is directed into the fracture to etch the fracture's face and create channels therein. Afterwards, a viscous fluid is directed into the fracture which fluid contains a material sufficient to serve as a diverter and prevent growth in the existing fracture. Once the diverting material is in place, hydraulic fracturing is again conducted within the existing fracture whereupon fracturing forces are directed away from the diverter to form a branched fracture to contact hydrocarbonaceous vugs in the formation. The steps of fracturing acidizing, and diverting are continued until a vuggy area in the formation has been interconnected with the fracture system.

[0011] Although, there has been a significant amount of effort to develop methods and systems to produce hydrocarbons and/or other products from relatively high permeability formations, there is still a need for improved methods and systems for production of hydrocarbons from very low permeability formations such as shales and tight sands.

SUMMARY

[0012] Methods and systems of treating subsurface hydrocarbon formations containing fractures are described herein. In some embodiments, a method for treating a mudstone formation includes, providing a substantially horizontal or inclined wellbore to the mudstone formation; forming a plurality of fractures in a portion of the mudstone formation, wherein the fractures include one or more microfractures having an original width of less than 0.5 mm; providing acid to the portion of mudstone formation such that a width of some of the microfractures increases to greater than the original width of the fracture; and allowing hydrocarbons to flow through the widened fractures.

[0013] In some embodiments, a method for treating a mudstone formation, includes providing a substantially horizontal or inclined wellbore to mudstone formation; providing acid to a portion of the mudstone formation that includes microfractures; allowing the acid to flow through the microfractures; and increasing a size of the microfractures such that hydrocarbons flow through the fractures, wherein the acid, inhibits softening of the mudstone formation.

[0014] In some embodiments, a method for treating a mudstone formation, includes providing a substantially horizontal or inclined wellbore to mudstone formation; providing acid to a portion of the mudstone formation that includes microfractures; allowing the acid to flow through the microfractures; and increasing a size of the microfractures to allow placement of proppant inside of the microfractures.

[0015] In some embodiments, a method for treating a shale formation, includes providing a substantially horizontal or inclined wellbore to the shale formation; forming a plurality of fractures in a portion of the shale formation, wherein the fractures include one or more microfractures having a width

of less than 0.5 mm; providing acid to the portion of shale formation such that a width of some of the microfractures increases to a width greater than the original width of the fracture; allowing hydrocarbons to flow through the widened fractures; and producing hydrocarbons from the formation.

[0016] In some embodiments, a method for treating a mudstone formation, includes providing a substantially horizontal or inclined wellbore to the shale formation; providing a first fluid to a portion of the mudstone formation such that one or more fractures are formed in the formation; providing a second fluid to the portion of the mudstone formation, the second fluid including acid and having a viscosity less than the viscosity of the first fluid, wherein addition of the second fluid increases a width of one or more formed fractures; and producing hydrocarbons from the formation.

[0017] In further embodiments, features from specific embodiments may be combined with features from other embodiments. For example, features from one embodiment may be combined with features from any of the other embodiments.

[0018] In further embodiments, additional features may be added to the specific embodiments described herein.

BRIEF DESCRIPTION OF THE DRAWINGS

[0019] Advantages of the present invention may become apparent to those skilled in the art with the benefit of the following detailed description and upon reference to the accompanying drawings in which:

[0020] FIG. **1** depicts a schematic side view of treating a mudstone formation with acid.

[0021] FIG. **2** depicts hydrocarbon formation in FIG. **1** after treatment with acid.

[0022] FIG. **3** is a scanning electron microscope picture of a portion a calcareous mudstone or shale formation of an embodiment of an acid treated mudstone or shale formation.

[0023] FIG. **4**A depicts the elemental composition of different portions of an embodiment of an acid treated mudstone or shale formation.

[0024] FIG. **4**B depicts the carbon composition of the acid treated mudstone or shale formation depicted in FIG. **4**A.

[0025] FIG. **4**C depicts the calcium composition of the acid treated mudstone or shale formation depicted in FIG. **4**A.

[0026] FIG. **4**D depicts the silicon composition of the acid treated mudstone or shale formation depicted in FIG. **4**A.

[0027] FIG. **5** depicts a schematic of alternate injection of fluids having different viscosities in a mudstone or shale formation.

[0028] While the invention is susceptible to various modifications and alternative forms, specific embodiments thereof are shown by way of example in the drawings and may herein be described in detail. The drawings may not be to scale. It should be understood, however, that the drawings and detailed description thereto are not intended to limit the invention to the particular form disclosed, but on the contrary, the intention is to cover all modifications, equivalents, and alternatives falling within the spirit and scope of the present invention as defined by the appended claims.

DETAILED DESCRIPTION

[0029] The following description generally relates to systems and methods for treating hydrocarbons in the formations. Such formations may be treated to yield hydrocarbon products and other products.

[0030] "API gravity" refers to API gravity at 15.5° C. (60° F.). API gravity is as determined by ASTM Method D6822 or ASTM Method D1298.

[0031] "Acid" refers to any inorganic or organic fluid that ionizes to provide high concentrations of protons (low pH) in solution with water. Examples of acids include hydrochloric acid, acetic acid, formic acid, hydrofluoric acid, and fluoboric acid.

[0032] A "fluid" may be, but is not limited to, a gas, a liquid, an emulsion, a slurry, and/or a stream of solid particles that has flow characteristics similar to liquid flow.

[0033] A "formation" includes one or more hydrocarbon containing layers, one or more non-hydrocarbon layers, an overburden, and/or an underburden. "Hydrocarbon layers" refer to layers in the formation that contain hydrocarbons. The hydrocarbon layers may contain non-hydrocarbon material and hydrocarbon material. The "overburden" and/or the "underburden" include one or more different types of impermeable materials. For example, the overburden and/or underburden may include rock, shale, mudstone, or wet/tight carbonate.

[0034] "Formation fluids" refer to fluids present in a formation and may include gases and liquids produced from a formation. Formation fluids may include hydrocarbon fluids as well as non-hydrocarbon fluids. Examples of formation fluids include inert gases, hydrocarbon gases, carbon oxides, mobilized hydrocarbons, water (steam), and mixtures thereof. The term "mobilized fluid" refers to fluids in a hydrocarbon containing formation that are able to flow as a result of thermal treatment of the formation. "Produced fluids" refer to fluids removed from the formation.

[0035] "Fracture" refers to a crack or surface of breakage within rock not related to foliation or cleavage in metamorphic rock along which there has been minimal movement. A fracture along which there has been lateral displacement may be termed a fault. When walls of a fracture have moved only normal to each other, the fracture may be termed a joint. Fractures may enhance permeability of rocks greatly by connecting pores together, and for that reason, joints and faults may be induced mechanically in some reservoirs in order to increase fluid flow. "Microfracture" refers to a fracture in a formation that is less than about 0.5 mm in width and/or is too small to accept a proppant.

[0036] "Hydrocarbons" are generally defined as molecules formed primarily by carbon and hydrogen atoms. Hydrocarbons may also include other elements such as, but not limited to, halogens, metallic elements, nitrogen, oxygen, and/or sulfur. Hydrocarbons may be, but are not limited to, kerogen, bitumen, pyrobitumen, oils, natural mineral waxes, and asphaltites. Hydrocarbons may be located in or adjacent to mineral matrices in the earth. Matrices may include, but are not limited to, sedimentary rock, sands, silicilytes, carbonates, diatomites, and other porous media. "Hydrocarbon fluids" are fluids that include hydrocarbons. Hydrocarbon fluids may include, entrain, or be entrained in non-hydrocarbon fluids such as hydrogen, nitrogen, carbon monoxide, carbon dioxide, hydrogen sulfide, water, and ammonia.

[0037] "Hydraulic fracturing" refers to creating or opening fractures that extend from the wellbore into formations. A fracturing fluid, typically viscous, is injected into the formation with sufficient hydraulic pressure (for example, at a pressure greater than the lithostatic pressure of the formation) to create and extend fractures, open preexisting natural fractures, or cause slippage of faults. In the formations discussed

herein, natural fractures and faults may be opened by the pressure. A proppant may be used to "prop" or hold open the fractures after the hydraulic pressure has been released. The fractures may be useful for allowing fluid flow, for example, through a shale formation, or a geothermal energy source, such as a hot dry rock layer, among others.

[0038] "Perforations" include openings, slits, apertures, or holes in a wall of a conduit, tubular, pipe or other flow pathway that allow flow into or out of the conduit, tubular, pipe or other flow pathway.

[0039] "Mudstone" refers to a fine grained sedimentary rock that consists of compacted silica and clay minerals. "Calcareous Mudstone" refers to a fine grained sedimentary rock that consists of compacted silica, carbonate minerals and clay minerals.

[0040] "Relatively permeable" is defined, with respect to formations or portions thereof, as an average permeability of 10 millidarcy or more (for example, 10 or 100 millidarcy).

[0041] "Relatively low permeability" is defined, with respect to formations or portions thereof, as an average permeability of less than about 10 millidarcy. One darcy is equal to about 0.99 square micrometers. A low permeability layer generally has a permeability of less than about 0.1 millidarcy.

[0042] "Shale" refers to a fine grained sedimentary rock that consist of silica, clay, and carbonaceous minerals such as calcite and dolomite.

[0043] Hydrocarbon fluid production using conventional techniques from mudstone and calcareous hydrocarbon formations is difficult due to the very low permeability (for example, less than 0.1 millidarcy) of the hydrocarbon containing formations.

[0044] The term "wellbore" refers to a hole in a formation made by drilling or insertion of a conduit into the formation. A wellbore may have a substantially circular cross section, or another cross-sectional shape. As used herein, the terms "well" and "opening," when referring to an opening in the formation may be used interchangeably with the term "wellbore." "Horizontal wellbore" refers to a portion of a wellbore in a subterranean hydrocarbon containing formation to be completed that is substantially horizontal or at an angle from horizontal in the range of from about 0° to about 15°.

[0045] Fracturing in low permeability formations has been developed in recent years using horizontal wellbores, however, production of hydrocarbons from these formations has proved difficult. Fracturing of the low-permeability formations may allow efficient production of hydrocarbons from the formation. Acid fracturing may allow the low-permeability formation to be more easily fractured, however, the acid may dissipate into the formation and not reach the end of the formation and/or dissolve more of the formation than is desired.

[0046] Once a fracture forms in the formation, the fracture may close under stress unless the fracture size is increased or propped open. The formed fractures, however, are generally not of sufficient width to allow conventional proppants (for example, sand or ceramic materials) to enter the fracture because the proppant particles are too large. Fractures or microfractures that do not have any proppant in the fracture tend to close when the well starts production and may not contribute to hydrocarbon production. Microfractures, however, are wide enough to allow acid to enter the microfracture.

[0047] Furthermore, in very low permeability hydrocarbon formations (for example, mudstone) natural barriers may contain a fracture so that is does not generate a size (height or width).

[0048] Acidizing of low permeability formations after fracturing has not proved successful. In the acidizing low permeability formations the rapid reaction rate of the acidizing fluid with those portions of the formation with which it first comes into contact and does not penetrate into the formation. Thus, the acid becomes spent before it penetrates into the formation a significant distance from the fracture.

[0049] It has been unexpectedly found that permeability of a mudstone hydrocarbon formation or a calcareous shale formation that includes at least about 5 wt. %, about 10 wt. %, about 20 wt. % about 50 wt. %, about 70 wt. %, or more of carbonate minerals is enhanced using fracturing in combination with acid. In some embodiments, an amount of carbonate materials in the low permeability formation ranges from about 1% by weight to about 70% by weight, from about 5% by weight to about 50% by weight or from about 10% by weight to about 30% by weight. Examples of such mudstone and calcareous shale formations are Bakken shale and the Eagle Ford shale. In carbonaceous mudstones, treatment of a fractured formation with acid may dissolve the carbonate minerals after leaving behind the silica, clay minerals and organic material to potentially prop open the fractures even if the fracture does not contain any proppant.

[0050] The use of acid in the very low permeability formations increases the open surface area of microfractures and the main fracture and increase connectivity between the fractures. Thus, production of hydrocarbons from the formation may be increased by at least 20%, at least 30%, or at least 50% as compared to production using conventional techniques.

[0051] In some embodiments, a portion of a very low permeable formation that includes at least ten percent carbonate compounds (for example, calcite or dolomite) is selectively treated with acid. The acid may be an inorganic acid or an organic acid. For example, the solution of acid may be an aqueous solution of hydrochloric acid. Commonly, the aqueous solution of hydrochloric acid employed for acidizing subterranean calcareous formations contain between 5 and 28% by weight, between 7 and 20% by weight, or between 10 and 15% by weight of hydrogen chloride. An aqueous solution of acetic acid or formic acid may be used. In some embodiments, the acid solution has a pH of less than about 6, less than about 5, less than about 3, less than about 1, or less than about 0.5.

[0052] The acid may be injected in the hydrocarbon containing formation. Contact of the acid with carbonate mineral in the formation may consume the carbonate minerals (for example, generate carbon oxides) and leave behind siliciclastic minerals and organic material. Asperities may be formed during acid treatment and the formed asperities may allow the fracture to remain conductive. This is in contrast to carbonate formations where all or substantially all of the rock matrix is dissolved. Leaving behind siliciclastic minerals and organic material and or formation of asperities may provide topographic relief to the fracture surface or microfracture surface leading to the creation of open fracture and/or microfracture pathways through which hydrocarbons may flow. Treating the hydrocarbon containing formation with acid may increase conductivity in the formation by creating a connectivity between fractures and/or associated microfractures. In some embodiments, treatment of the hydrocarbon containing for-

mation with acid may increase the conductivity of the main fracture by non-uniform etching of its surface, which creates rough fracture surfaces with asperities that do not allow the fracture to close under stress.

[0053] In some embodiments, the acid is injected with shale stabilizing chemicals. Shale stabilizing materials include, but are not limited to, quaternary ammonium salts, inorganic salts such as sodium chloride and potassium chloride and/or potassium acetate. Examples of shale stabilization fluids are described in U.S. Patent Application No. 20010259588 to Ali et al. For example, a solution of acid, quaternary ammonium salt and/or water may be injected into a mudstone formation. Injection of acid and/or shale stabilizing chemicals may stabilize the shale, and thus, make the shale less susceptible to softening and/or reduce proppant embedment as compared to conventional methods (for example, water based fracturing). Softening of the shale may result in a loss in conductivity of the fracture.

[0054] In some embodiments, an acid solution is injected as an emulsion or a foam. Injecting the acid as a foam or an emulsion may reduce the reactivity of the acid.

[0055] In some embodiments, the dissolution and/or selective dissolution of carbonate compounds may change the mechanical properties of the rock. For example, the rock may be weakened. A change in mechanical properties may allow a change in the amount of pressure (for example, less pressure) needed to propagate the fracture and/or associated fractures. Thus, allowing different fracture patterns to be formed in the formation as compared to conventional fracturing methods.

[0056] In some embodiments, a fracture and/or associated microfractures are formed in the hydrocarbon formation using conventional fracturing and well stimulating methods (for example, hydraulic fracturing, pneumatic fracturing, alternating fracturing ("Texas-Two Step"), zipper fracturing, forced tip screen out, or the like) in conjunction with acid. For example, a horizontal wellbore may be provided to a wellbore, a first section of the formation may be fractured, the well may be plugged at the first formation and a second fracture may be formed at a second location along the well. In some embodiments, the fracturing is performed using solutions that have a pH of greater than about 6, great than about 7 or greater than about 7.5. After one or more fractures have been formed, acid may injected into the wellbore and the fractures acidized and etched as desired. The acid may be placed in any or all of the fracturing fluid stages, the pad, the main proppant stages, etc., or before or after the fracture is placed. The acid may have a pH of less than about 6, less than about 5 or less than about 1.

[0057] Acidizing the fractures removes the carbonate from the formation and increases the size of the fracture and microfractures. Increasing the size of the fracture, may inhibit the fractures from closing. Seismic and/or microseismic technology may be used to assess the size and/or shape of fractures formed in the formation. Acid may injected until a desired fracture size (for example, width) is obtained. In some embodiments, a fracture has a width of greater than 1 mm, greater than 10 mm or greater than 1 cm. Due to the increased size of the fractures, proppants may not be necessary or the amount proppants is reduced. In some embodiments, a surface of the main fracture may be etched. In some embodiments, acid increases the width of some the microfractures to enhance insertion of proppant into the microfracture network.

[0058] In some embodiments, hydraulic fractures are created in a particular sequence to enhance microfracturing (or microcracking) of the formation (for example, zipper fracturing and alternate fracturing). In zipper fracturing, two parallel horizontal wells are fractured sequentially one fracture at a time while alternating between wells. Treatment of zipper fractures with acid may open the microfractures to create conductive fractures and thus, allow hydrocarbons to flow through the formation. For example, in the "Texas Two Step" method (alternate fracturing method), fracturing fluid (for example, fluid having a pH of greater than 5) is pumped into fractures in a sequence of 1, 3, 5, 7, 9, 2, 4, 6, 8 rather than the sequence 1, 3, 2, 5, 4 with the numbers representing the sequence of the fractures along a well starting at the toe. These types of fracturing in conjunction with the acid may lead to conductive microfractures. In some embodiments, acid is used in conjunction with and fracturing sequence to promote formation of microfractures and secondary fractures.

[0059] In some embodiments, injection of acid into a fractured formation may stabilize the formation (for example, a mudstone or shale formation) and inhibit softening of the formation. For example, the formation may harden due to the acid treatment. Hardening the formation may reduce proppant embedment as compared to conventional methods and/or prevent a loss of conductivity of the fracture.

[0060] FIG. **1** depicts a schematic representation of an embodiment of a low permeability formation being treated with acid after forming a fracture in the formation. In some embodiments, fracturing is not performed and the acid is injected directly into the low permeability formation. FIG. **2** depicts a schematic representation of the formation in FIG. **1** (nonacid treated fractured formation) after treatment with acid. FIG. **3** is a scanning electron microscope picture of a portion of a calcareous mudstone or shale formation before and after treatment with acid. FIGS. **4**A-D depict the elemental composition of different portions of an embodiment of an acid treated mudstone or shale formation. FIG. **4**A depicts the total elemental composition of silicon (data **114**, red dots), calcium (data **116**, green dots) and carbon (data **118**, blue dots), an embodiment of an acid treated mudstone or shale formation. FIG. **4**B depicts the carbon composition of the mudstone or shale formation of FIG. **4**A (i.e., FIG. **4**A with the silicon and calcium removed). FIG. **4**C depicts the calcium composition of the mudstone or shale formation of FIG. **4**A (i.e., FIG. **4**A with the silicon and carbon removed). FIG. **4**D depicts the silicon composition of the mudstone or shale formation of FIG. **4**A (i.e., FIG. **4**A with the calcium and carbon removed).

[0061] In some embodiments, a size and location of the fractures in a low permeability formation may be determined prior to or after providing acid to the hydrocarbon containing formation. Wellbore **100** may be located in a layer **102** under the overburden **104** of a hydrocarbon containing layer **106** (for example, a mudstone or calcareous formation). Wellbore **100** may be horizontal or substantially horizontal. In some embodiments, wellbore **100** in provided to a natural fracture or a formed fracture in the formation. In some embodiments, a size and location of the fractures **108** and/or microfractures **110** in a low permeability formation may be determined prior to, during, or after treatment of the hydrocarbon containing formation **102**. In some embodiments, microfractures **110** are adjacent or proximate to fractures **108**.

[0062] Acid may be introduced into formation **110** through injection wellbore **100**. Injection wellbore **110** may include packers and/or other plugs that allow the acid to follow into

selected portions of the formation. Acid may contact carbonate near or proximate the wellbores and dissolve a portion of the formation near or proximate fractures **108** or microfractures **110** to increase the size (for example, length and/or width) of the fracture as shown in FIGS. **2** and **3**. Referring to FIGS. **4**B through **4**D, the calcium concentration (data **116** green dots) is much less in than in the acid treated portion of the mudstone or shale formation. The concentration of silicon (red dots, data **114**, FIG. **4**D) and carbon (blue, dots, data **118**) remains the same. Such increased permeability may allow connectivity between fractures and allow hydrocarbons to be mobilized through the fractures. Thus, a conductivity of the hydrocarbon layer is increased as compared to conventional acid fracturing techniques. In certain embodiments, the microfractures open and interconnect.

[0063] In some embodiments, a fracturing fluid is injected under high pressure through the wellbore to create fractures **108** and/or microfractures **110**. Creation of fractures **108** and microfractures **110** may be done prior to or after injection of acid into the formation. Microfractures **110** may extend from fracture **108**.

[0064] The process may be repeated to create additional fractures in the formation. In some embodiments, the newly created fractures connect with the fractures formed with acid. In some embodiments, acid is injected in one portion of the low permeability formation. The acid may increase the size of microfractures and allow the acid to flow into the microfractures or fractures in a second portion of the hydrocarbon formation. The acid may etch a surface of fractures and microfractures. Etching the surface may increase the conductivity of the fracture. In some embodiments, the width of the microfractures and/or the fractures **108** in the second portion may increases after contact with acid. Opening of the microfractures in the second portion of the hydrocarbon layer may increase conductivity between the first and second portions of the hydrocarbon layers.

[0065] Mobilized hydrocarbons (for example, gas and liquids) may be produced from the treated formation. For example, fluids may flow from the microfractures into a production wellbore and be produced from the formation. In some embodiments, fluids are injected into the formation after formation of the fractures to mobilize hydrocarbons. Fluids may include steam, water, gas, or compound known in the art to for drive processes. Fluids may flow into wellbore **100** and be produced from the formation. In some embodiments, injection wellbore **108** is a production wellbore. In certain embodiments, hydrocarbon fluids are produced from different portion of the formation.

[0066] In some embodiments, a hydrocarbon formation (for example, a mudstone or shale formation) is treated with fluids having different viscosities and/or elasticity. Malhotra et al., in "Proppant Placement Using Alternate-Slug Formation," SPE 16385, Presented at the SPE Hydraulic Fracturing Technology Conference, TX Feb. 4-6, 2013, describes treatment of hydrocarbon formations having different viscosities and/or elasticity.

[0067] In some embodiments, the fluids injected into the formation include proppants. At least one of the fluids is a mixture of acid and water. High viscosity and low viscosity fluids may be alternately pumped into the formation. In some embodiments, proppants are carried by the low viscosity fluid. A high viscosity fluid (for example, a linear or cross-linked gel) is pumped into the formation. After a period of injection, a second fluid having a lower viscosity than the first fluid (for example, a water based acid solution) may be injected into the formation. The low viscosity fluid may disperse (e.g., finger) through the more viscous fluid, placing the acid deeper into fracture in a non-uniform manner

[0068] FIG. **5** depicts a schematic of an embodiment of injecting high and low viscosity fluids in a hydrocarbon formation. First fluid **120** is injected into microfracture **112** of formation **102** through vertical wellbore **100**. In some embodiments, wellbore **100** is a substantially horizontal or deviated wellbore in formation **102**. In some embodiments, first fluid **120** is injected into fracture **108** and then disperses into microfracture **112**. First fluid **120** is a high viscosity fluid that disperses through formation **102**. After injection of the first fluid **120**, low viscosity second fluid **122** is injected into fracture **108**. In some embodiments, second fluid **122** is an acidic solution. Second fluid **122** disperses through the more viscous first fluid **120** in microfracture **112** in a non-uniform manner represented by fingers **124**. The mixing of the two fluids may be governed by the mixing zone velocity and finger velocity. A mixing zone refers to the length over which the local concentration varies from 0 (concentration of first fluid) to 1 (concentration of second fluid). For example, length **126** in FIG. **5** represents a mixing zone. A mixing zone velocity is the rate of change of mixing zone length. A finger velocity refers to the ratio of finger-tip velocity to the injection velocity (injection rate dived by the cross-sectional area).

[0069] After a second injection, a third fluid having a higher viscosity fluid than the second fluid may be injected into the formation. The third fluid may have the same viscosity or a different viscosity than the viscosity of the first fluid. The higher viscosity fluid may move the acidic fluid deeper into the fracture and into the microfractures. The injection of the alternating fluids, therefore, leads to a deeper and, in some embodiments, a non-uniform distribution of acid into the formation, (for example, as shown by fingers **124** in FIG. **5**). Contact of the acid with the microfractures may widen the fractures to allow hydrocarbons to flow from the fractures. Thus, microfractures deep in the formation may be widened to allow production of hydrocarbon from the formation. In some embodiments, microfractures are widened sufficiently to allow proppants to be placed in the widened fractures. In some embodiments, softening of the formation at deeper depths in the formation is inhibited.

[0070] In some embodiments, when the acid solution (low viscosity fluid) contains proppants, a proppant bed may form near the injection point due to higher settling rate of proppants in the low viscosity fluid. Injecting a higher viscosity fluid may displace the proppant bed deeper into the fracture and into the microfractures. The injection of the alternating fluids, therefore, leads to a deeper and non-uniform distribution of acid and/or proppants in the fracture.

[0071] In some embodiments, dissolution of carbonate minerals from the rock results in a softening of the rock leading to closure of propped and un-propped fractures by softer organic material (such as kerogen and bitumen) and clays. In some embodiments, the acid solution may contain an organic solvent (such as methanol, ethanol or iso-propyl alcohol) that will solubilize and remove this organic material. Removal of a portion of the softer organic material may result in a higher propped or un-propped fracture permeability after dissolution of the carbonate minerals. In some embodiments, the organic solvent is injected with the non-acidic fluid.

[0072] Further modifications and alternative embodiments of various aspects of the invention will be apparent to those

skilled in the art in view of this description. Accordingly, this description is to be construed as illustrative only and is for the purpose of teaching those skilled in the art the general manner of carrying out the invention. It is to be understood that the forms of the invention shown and described herein are to be taken as the presently preferred embodiments. Elements and materials may be substituted for those illustrated and described herein, parts and processes may be reversed, and certain features of the invention may be utilized independently, all as would be apparent to one skilled in the art after having the benefit of this description of the invention. Changes may be made in the elements described herein without departing from the spirit and scope of the invention as described in the following claims.

What is claimed is:

1. A method for treating a mudstone formation, comprising:

providing a substantially horizontal or inclined wellbore to the mudstone formation;

forming a plurality of fractures in a portion of the mudstone formation, wherein the fractures comprise one or more microfractures having a width of less than 0.5 mm;

providing acid to the portion of mudstone formation such that a width of some of the microfractures increases to a width greater than the original width of the fracture; and

allowing hydrocarbons to flow through the widened fractures.

2. The method as claimed in claim **1**, assessing a size and location of fractures in the portion of the mudstone formation.

3. The method as claimed in any one of claim **1** or **2**, wherein mudstone formation contains about 10% carbonate minerals.

4. The method as claimed in any one of claims **1-3**, wherein forming fractures comprises hydraulic fracturing, pneumatic fracturing, alternate fracturing, or combinations thereof.

5. The method as claimed in any one of claims **1-4**, wherein providing acid etches a surface of the fracture.

6. The method as claimed in any one of claims **1-5**, further comprising producing hydrocarbons from the mudstone formation.

7. The method as claimed in any one of claims **1-6**, wherein the mudstone formation comprises from about 5% carbonate compounds to about 70% carbonate compounds.

8. The method as claimed in any one of claims **1-7**, wherein a majority of the fractures are microfractures.

9. The method as claimed in any one of claims **1-8**, wherein the acid is provided as an emulsion and/or a foam.

10. The method as claimed in any one of claims **1-9**, further comprising providing stabilizing chemicals to the mudstone formation.

11. The method as claimed in any one of claims **1-10**, wherein the acid is provided as a solution of acid and quaternary ammonium salts.

12. The method as claimed in any one of claims **1-11**, wherein the acid is provided as a solution of inorganic salts.

13. The method as claimed in any one of claims **1-12**, further comprising applying pressure to the acid, wherein the application of pressure forms additional fractures in the mudstone formation.

14. The method as claimed in any one of claims **1-13**, wherein providing acid enhances conductivity one or more fractures.

15. A method for treating a mudstone formation, comprising:

providing a substantially horizontal or inclined wellbore to the mudstone formation;

providing acid to a portion of the mudstone formation comprising microfractures; and

allowing the acid to flow through the microfractures; and

increasing a size of the microfractures such that hydrocarbons flow through the fractures, wherein the acid inhibits softening of the mudstone formation.

16. The method as claimed in claim **15**, assessing a size and location of fractures in the portion of the mudstone formation.

17. The method as claimed in any one of claim **15** or **16**, wherein mudstone formation contains about 50% carbonate compounds.

18. The method as claimed in any one of claims **15-17**, wherein providing acid etches surfaces of the microfractures.

19. The method as claimed in any one of claims **15-18**, further comprising producing hydrocarbons from the mudstone formation.

20. The method as claimed in any one of claims **15-19**, wherein the mudstone formation comprises from about 5% carbonate materials to about 70% carbonate materials.

21. The method as claimed in any one of claims **15-20**, further comprising forming fractures in the portion of the mudstone formation prior to providing acid to the mudstone formation.

22. The method as claimed in any one of claims **15-21**, wherein the acid is providing as an emulsion and/or a foam.

23. The method as claimed in any one of claims **15-22**, further comprising providing shale stabilizing chemicals to the mudstone formation.

24. The method as claimed in any one of claims **15-23**, wherein the acid is provided as a solution of acid and quaternary ammonium salts.

25. The method as claimed in any one of claims **15-24**, further comprising applying pressure to the acid, wherein the application of pressure forms additional fractures in the mudstone formation.

26. A method for treating a mudstone formation, comprises:

providing a substantially horizontal or inclined wellbore to the mudstone formation that has undergone a fracturing process;

providing acid to a portion of the mudstone formation comprising microfractures; and

allowing the acid to flow through the microfractures; and

increasing a size of the microfractures to allow placement of proppant inside of the microfractures.

27. A method for treating a shale formation, comprising:

providing a substantially horizontal or inclined wellbore to the shale formation;

forming a plurality of fractures in a portion of the shale formation, wherein the fractures comprise one or more microfractures having a width of less than 0.5 mm;

providing acid to the portion of shale formation such that a width of some of the microfractures increases to a width greater than the original width of the fracture;

allowing hydrocarbons to flow through the widened fractures; and

producing hydrocarbons from the formation.

28. A method for treating a mudstone formation, comprising:

providing a substantially horizontal or inclined wellbore to the shale formation;

providing a first fluid to a portion of the mudstone formation such that one or more fractures are formed in the formation;

providing a second fluid to the portion of the mudstone formation, the second fluid comprising acid and having a viscosity less than the viscosity of the first fluid, wherein addition of the second fluid increases a width of one or more formed fractures; and

producing hydrocarbons from the formation.

29. The method as claimed in claim **28**, wherein at least one of the widened fractures has a width of less than 0.5 mm.

30. The method as claimed in any one of claim **28** or **29**, wherein the second fluid comprises proppants.

31. The method as claimed in any one of claims **28-31**, further comprising providing a third fluid to the formation after providing the second fluid, wherein the third fluid has a higher viscosity than the second fluid.

32. A method of treating a hydrocarbon formation comprising:

forming a plurality of fractures in a portion of the hydrocarbon formation; and

providing acid to the portion of the hydrocarbon formation such that a width of some of the fractures increases to a width greater than the original width of the fracture.

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