A method of fracturing a subterranean formation includes providing a fracture field with multiple fractures. An explosive is injected into a selected fracture and detonated to increase permeability of the subterranean formation surrounding the selected fracture. The explosive is configured to detonate at a quench distance of less than a thickness of the selected fracture.
FAR FIELD FRACTURING OF SUBTERRANEAN FORMATIONS

BACKGROUND

[0001] This disclosure relates to a method of fracturing a subterranean formation. In particular, the disclosure relates to a method of providing secondary fractures from a fracture extending from a well bore.

[0002] Methods of accessing oil and gas in previously difficult to reach subterranean formations have been developed. One example method includes providing a well bore with a horizontal shaft arranged in a shale formation. Radial fractures are created using a hydraulic fracturing technique. A proppant is injected into the fractures to prevent the fractures from closing under rock consolidation stresses. Oil and gases flow from the formations surrounding the fractures into the fractures and through the well bore. Although hydraulic fracturing produces low resistance flow arteries, it doesn’t raise the permeability of the bulk rock. Hence, oil/gas still has a very hard time getting to the arteries and into the production well.

[0003] One prior art arrangement detonates explosives within the well bore to generate additional fractures extending from the well bore. The additional, small fractures are oriented at angles different from the hydraulic fracture-produced cracks.

SUMMARY

[0004] In one exemplary embodiment, a method of fracturing a subterranean formation includes the steps of providing a fracture field with multiple fractures, injecting an explosive into a selected fracture, and detonating the explosive and increasing permeability of the subterranean formation surrounding the selected fracture, wherein the explosive is configured to detonate at a quench distance of less than a thickness of the selected fracture.

[0005] In a further embodiment of any of the above, the providing step includes forming arteries from a well bore to create the fractures.

[0006] In a further embodiment of any of the above, the detonating step includes generating secondary cracks generally normal to the arteries.

[0007] In a further embodiment of any of the above, the increased permeability is provided by rubble in the arteries and the secondary cracks.

[0008] In a further embodiment of any of the above, the well bore is arranged horizontally and the arteries are generally normal to the well bore.

[0009] In a further embodiment of any of the above, the arteries extend at least 50 and up to 1200 feet (15.24 m and up to 365.8 m) from the well bore.

[0010] In a further embodiment of any of the above, the arteries are about 0.1 inch thick (2.54 mm).

[0011] In a further embodiment of any of the above, the injecting step includes injecting the explosive at least 50 feet (15.24 m) away from the well bore.

[0012] In a further embodiment of any of the above, the explosive is a liquid.

[0013] In a further embodiment of any of the above, the explosive is at least one a nitroamine or nitrocellulose dissolved in an organic solvent.

[0014] In a further embodiment of any of the above, the explosive is configured to detonate at a pressure pulse greater than the sum of the fluid reservoir pressure and the shale’s solid consolidation compressive stress.

[0015] In a further embodiment of any of the above, the explosive is a granular solid providing a proppant. The injecting step includes injecting the proppant into the fracture.

[0016] In a further embodiment of any of the above, the explosive is configured to detonate at a pressure pulse greater than the sum of the fluid reservoir pressure and the shale’s solid consolidation compressive stress.

[0017] In a further embodiment of any of the above, the detonating step includes generating a pressure pulse with a combustion device.

[0018] In a further embodiment of any of the above, the device is located within the well bore.

[0019] In a further embodiment of any of the above, the device is an acoustic generator.

[0020] In a further embodiment of any of the above, the acoustic generator is configured to provide a pressure pulse greater than the sum of the reservoir fluid pressure and the shale’s solid consolidation compressive stress.

[0021] In a further embodiment of any of the above, the increased permeability corresponds to at least one microdarcy.

[0022] In a further embodiment of any of the above, the injecting step includes leaving at least one fracture adjacent to the selected fracture free of explosive.

[0023] In a further embodiment of any of the above, the method includes the step of injecting a non-explosive proppant in the at least one fracture.

BRIEF DESCRIPTION OF THE DRAWINGS

[0024] The disclosure can be further understood by reference to the following detailed description when considered in connection with the accompanying drawings wherein:

[0025] FIG. 1 is a schematic view of a well bore having a fracture field.

[0026] FIG. 2 is a schematic view of a fracture field having fractures with explosives.

[0027] FIG. 3 is a schematic view of a fracture field following detonation of the explosives.

DETAILED DESCRIPTION

[0028] FIG. 1 schematically depicts a well bore 10 having a vertical shaft 12 connected to a horizontal shaft 14 provided in a subterranean formation 16, such as shale. “Subterranean formation” means a seam of oil or gas shale, or other oil/gas bearing rock, sandwiched between layers of overburden rock. “Subterranean formation” excludes formations accessible by conventional open mining in which workers can enter the mining area. The well bore 10 may be provided using any suitable method for the given application. The well bore 10 is less than 12 inches (30.4 cm) in diameter, and typically, less than 6 inches (15.2 cm) in diameter. In any event, the well bore 10 is of such a size that would prevent a worker from entering the well bore 10. A first tool 18 is provided in the vertical shaft 14 to create a fracture field 20 having multiple fractures 22A-22E at a spacing 24 laterally relative to one another. In one example, the fractures 22A-22E provide radial arteries extending outward from the horizontal shaft 14 up to 1,200 feet (3.43 up to 365.8 m) or more (see, for example, Economides et al., Petroleum Production Systems, Prentice Hall, New Jersey (1994)). In developing the fracture field for oil/gas production, additional cracks are usually generated at
nominal 100 ft (30.5 m) spacings by moving the well’s fracturing tool along the length of casing and repeating the above process (see, for example, *Hydraulic Fracturing*, Wikipedia (2012)).

[0029] An example (see, for example, *Hydraulic Fracturing*, Wikipedia (2012)) hydraulic fracturing method used in oil/gas shale can require up to 100 barrels/minute of incompressible water flow at supply pressures approaching 15,000 psia (105,421.36 kPa). Such a fluid supply system will generally produce a single disc-shaped radial crack having a channel thickness 36 normal to the crack direction of approximately 0.1 inch (2.54 mm) or greater (see, for example, the PKN analysis in Economides et al., *Petroleum Production Systems*, Prentice Hall, New Jersey (1994), as shown in FIG. 2. Although the oil/gas field now has 0.1-inch (2.54 mm) thick radial arteries penetrating over 1,000 ft into the formation, the shale’s permeability between these nominal 100 ft (30.5 m) spaced radial cracks is still below 1 micro-darcy.

[0030] With continuing reference to FIG. 2, a second tool 30 is arranged in the horizontal shaft 14. Once the radial crack is formed, a granular solid propellant 36, which is non-explosive, is added to the flowing water to produce a slurry for subsequent crack filling of fractures 22A, 22C, 22E. Once the slurry completely fills the crack volume, the water flow is terminated. The solid propellant within the crack now prevents the 0.1-inch (2.54 mm) thick (1,000 ft (304.8 m) radius) crack from closing at the crack’s fluid pressure returns to the nominal fluid reservoir pressure. The solid shale’s consolidation (compressive) stress is now carried through the crack’s opening by the granular propellant.

[0031] In order to achieve extensive fracturing at distances to 1,000 ft (304.8 m) from the well bore and without damage to the well’s casings and internal hardware, the disclosed method is proposed as an add-on to the current hydraulic fracturing tools. The disclosed method uses an additional means after the completion of the propped hydraulic fractures to substantially increase the shale’s permeability in the regions between the 0.1-inch (2.54 mm) radial arteries. The second tool 30 injects an explosive 32 into selected fractures, such as the fractures 22B, 22D. The adjacent fractures 22A, 22C, 22E may be injected with a non-explosive propellant 36 to keep the fractures opened, as described above. In one example, the explosive 32 is injected into the arteries a first distance 26 away from the horizontal shaft 14 to a second distance 28 from the horizontal shaft 14. In one example, the first distance 26 is about 50 feet and the second distance 28 is the remaining length of the fractures, for example 1200 feet (365.8 m).

[0032] The quenching distance of the explosive 32 must be less than the radial crack’s thickness of 0.1-inch (2.54 mm). A quenching distance greater than 0.1-inch (2.54 mm) will prevent propagation of the chemical reactions within the explosive. The explosive being liquid or granular solid phase. In one example, the liquid can be RDX (a nitromethane) or nitrocellulose dissolved in an organic solvent (for example, acetone or alcohol). If the solid phase is used, the secondary explosive 32 may be used directly as a propellant.

[0033] Referring to FIG. 3, a third tool 34, such as an acoustic generator, is provided in the horizontal shaft 14 and generally aligned with a fracture filled with the explosive (i.e. fractures 22B, 22D). The acoustic generator provides pressure pulses of a desired frequency to ignite the explosive 32 within the fractures and create secondary cracks 40 that are generally normal to the fracture. Any suitable acoustic generator may be used, such as a pulsed combustion device.

[0034] In one example, the fracturing detonation is initiated with a pulse combustion device to serve as the primary explosive. The pulse combustion device is designed to produce a pressure pulse equal to or greater than the sum of the reservoir’s fluid pressure and the shale’s solid consolidation compressive stress (for some shale formations this may be on the order of 10,000 psion). In this fashion, detonation pressures exceeding 200,000 psia (1,378,951.4 kPa) can be produced at safe distances away from the well casings while controlling the pressures of the primary combustion/explosion device below 15,000 psia (105,421.36 kPa).

[0035] In one example, a 10,000 psia (68,947.57 kPa) pulse from the casings’ primary combustion device will send a shock wave across the 50-ft (15.24 m) radial distance between the well bore 10 and the explosive 32 where it would initiate the propagating detonation through the 950-ft (289.56 m) radial length of explosive 32.

[0036] The pressure/shock sensitivity of the secondary explosive is characterized to ensure no pre-mature detonations at nominal fluid reservoir charging pressures when using liquid phase secondary explosives (or the shale’s consolidation compressive stress when using solid phase secondary explosives).

[0037] The explosive-filled fracture and secondary cracks 40 are filled with higher permeability rubble 42, increasing permeability in the subterranean formation 16 in the area of the detonated fracture. As a result, gasses/oil more easily migrates to the adjacent, undamaged fractures 22A, 22C, 22E. Oil/gas shale permeabilities are produced significantly above 1 micro-darcy at far field distances from the well bore approaching 1,000 ft (304.8 m).

[0038] Although example embodiments have been disclosed, a worker of ordinary skill in this art would recognize that certain modifications would come within the scope of the claims. For that reason, the following claims should be studied to determine their true scope and content.

What is claimed is:

1. A method of fracturing a subterranean formation comprising the steps of:
   - providing a fracture field with multiple fractures;
   - injecting an explosive into a selected fracture; and
   - detonating the explosive and increasing permeability of the subterranean formation surrounding the selected fracture, wherein the explosive is configured to detonate at a quench distance of less than a thickness of the selected fracture.

2. The method according to claim 1, wherein the providing step includes forming arteries from a well bore to create the fractures.

3. The method according to claim 2, wherein the detonating step includes generating secondary cracks generally normal to the arteries.

4. The method according to claim 3, wherein the increased permeability is provided by rubble in the arteries and the secondary cracks.

5. The method according to claim 2, wherein the well bore is arranged horizontally and the arteries are generally normal to the well bore.

6. The method according to claim 2, wherein the arteries extend at least 50 and up to 1200 feet (15.24 m and up to 365.8 m) from the well bore.
7. The method according to claim 6, wherein the arteries are about 0.1 inch thick (2.54 mm).

8. The method according to claim 6, wherein the injecting step includes injecting the explosive at least 50 feet (15.24 m) away from the well bore.

9. The method according to claim 1, wherein the explosive is a liquid.

10. The method according to claim 9, wherein the explosive is at least one a nitroamine or nitrocellulose dissolved in an organic solvent.

11. The method according to claim 9, wherein the explosive is configured to detonate at a pressure pulse greater than the sum of the fluid reservoir pressure and the shale's solid consolidation compressive stress.

12. The method according to claim 1, wherein the explosive is a granular solid providing a proppant, and the injecting step includes injecting the proppant into the fracture.

13. The method according to claim 12, wherein the explosive is configured to detonate at a pressure pulse greater than the sum of the fluid reservoir pressure and the shale's solid consolidation compressive stress.

14. The method according to claim 1, wherein the detonating step includes generating a pressure pulse with a combustion device.

15. The method according to claim 14, wherein the device is located within the well bore.

16. The method according to claim 15, wherein the device is an acoustic generator.

17. The method according to claim 16, wherein the acoustic generator is configured to provide a pressure pulse greater than the sum of the reservoir fluid pressure and the shale's solid consolidation compressive stress.

18. The method according to claim 1, wherein the increased permeability corresponds to at least one microdarcy.

19. The method according to claim 1, wherein the injecting step includes leaving at least one fracture adjacent to the selected fracture free of explosive.

20. The method according to claim 19, comprising the step of injecting a non-explosive proppant in the at least one fracture.