PS Energy Storage Fracturing Based on a Slick-Water System in Tight Oil Reservoirs*

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Search and Discovery Article #42099 (2017)**
Posted June 26, 2017

*Adapted from poster presentation given at AAPG 2017 Annual Convention and Exhibition, Houston, Texas, United States, April 2-5, 2017

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Abstract

The difficulty in fracture extension in a plastic formation and the strong water sensitivity caused by high sensitive minerals are one of the prevalent problems in tight oil reservoirs. It is important to take into account both a fracture effect and formation protection together.

In this study, a novel horizontal well energy-storage fracturing technology is proposed to improve the fracture effect. Energy-storage SRV fracturing is forming a fracture network system by the method of multi-segment fractured horizontal wells with large displacement and injection rates, combined with a new slick-water system (slick-water + gel) and a proppant technology. Wells are shut-in after fracturing to maintain reservoir energy. Water/oil replacement can improve the well production and the ultimate recovery of tight reservoirs. The slick-water system can reduce the pump liquid friction and oil-water interfacial tension, and prevent swelling, migration and plugging of clay minerals. Based on this slick-water system, an energy-storage fracturing technique improves fracture opening and replenish formation energy effectively. To be specific, complex network fractures can be generated by means of large displacement due to an increase in static pressure in fractures; porcelain granules of different sizes support main fractures and branch fractures with the injection of a large amount of liquid, thus improving the fracture conductivity.

The results show that a stable oil production reaches 5-8 t/d by energy-storage SRV fracturing in tight oil reservoirs. Compared with conventional fracturing (1.5-2 t/d), the oil production has been improved by more than 2.5 times. Chlorine in wells is presented earlier by the new slick-water system with the energy-storage SRV fracturing, and the flowback rate once starting to produce oil is low. It is beneficial for water-oil displacement and maintaining the reservoir energy. Guar gum concentration in this slick-water system reduces from 0.4%-0.5% to 0.3%-0.4%. The amount of chemicals is reduced greatly than in conventional fracturing. In this way, the gel is formed with lower damage and costs. In general, energy-storage SRV fracturing with this slick-water system keeps good balance between SRV fracturing and formation protection, which is more applicable in increasing oil production in tight oil reservoirs.

Energy Storage Fracturing
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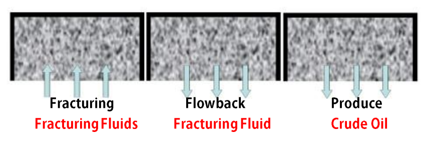
Energy-Storage SRV Fracturing Illustration

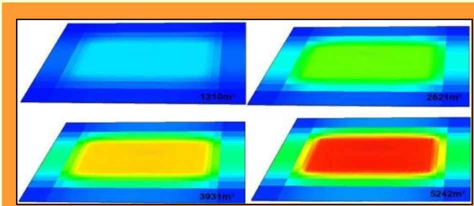


a. unflowing system of conventional fracturing

b. unflowing system of energy-storage SRV fracturing

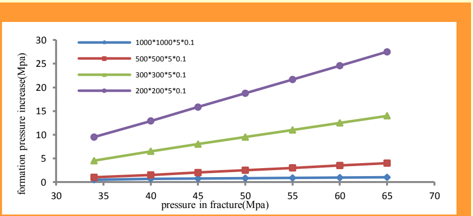
Mechanization of Energy Storage

Matrix permeability	0.5mD	Duration	120 days
Major fracture conductivity	300D·cm	Water compressibility	0.0004351
Branching fracture conductivity	30D·cm	Oil compressibility	0.0004351
Formation bulk volume	1000*1000*5*0.1	Rock compressibility	0.000145
Fracture network volume	（600+400*10）*0.34*5	Total compressibility	1.89×10^{-4}



The results of pressure distribution in the formation impacted by different amounts of fracture fluid after closing a well for 120 days

Under the simulation condition with different amounts of fracture fluid, an increasing usage of fracture fluid can improve the formation energy remarkably. Meanwhile, the increased energy will increase the well drainage area and production.



The formation pressure impacted by fracture pressure

The increment in fracture pressure will lead to the approximately linear growth of formation pressure. Therefore, improving the fracturing pressure not only contributes to the extension of a fracture network, but also increases formation pressure effectively.

Parameter Optimization

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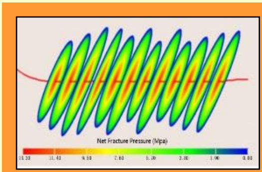
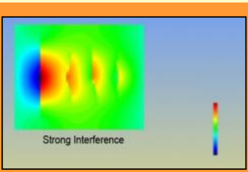
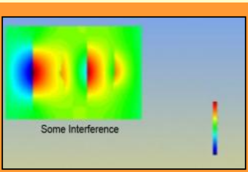
Fracture Parameter Design



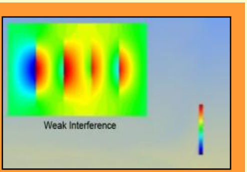
a. A schematic diagram of the disturbance between fractures



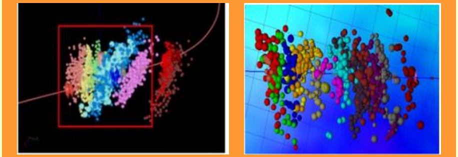
b. Fracture expanding path and displacement when a fracture interval is 60m



c. Fracture expanding path and displacement when a fracture interval is 80m



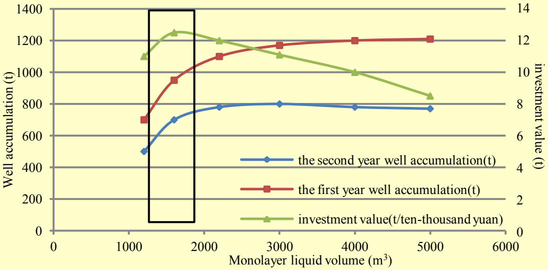
d. Fracture expanding path and displacement when a fracture interval is 100m



Downhole microseismic monitoring of Well 1 and Well 2

For Well 1 and Well 2, as examples, the well segment intervals are 62m and 70m, respectively. Some influencing areas overlapped because of fractures' mutual interference, which is against large-scale stimulation by energy-storage SRV fracturing, so the intervals should be increased to 80-100m.

Liquid Volume Optimization



Comparison of unit investment-production values under different pumping rates

Pumping Rate Optimization

The relationship between a pumping rate and static pressure in parts of a tight oil reservoir

Block name	Target formation	Permeability	Formation thickness (m)	Young modulus (Mpa)	Poisson's ratio	Reservoir pressure (Mpa)	Maximum horizontal principal stress (Mpa)	Minimum horizontal principal stress (Mpa)	Horizontal differential principal stress (Mpa)	Rock tensile strength (Mpa)	Static pressure for fracture diversion (Mpa)	Minimum pumping rate for diversion (m^3/min)
I	F	0.15	20	20000	0.21	19.4	44	36	8	3	11	12
II	F	0.2	15	22000	0.21	16.2	45	36	9	3	12	14
III	F	0.15	15	23000	0.21	18.4	39	32	7	3	10	12
IV	F	0.46	20	26000	0.21	19.8	46	38	8	3	11	12

Results of temperature measurement by coiled tubing for Well 1 and Well 2

Well No.	Well 1	Well 2
Stress difference between clusters, MPa	4-6	3-4
Cluster quantity	3	3
Pore quantity	30	48
Pore Diameter, mm	9	9
Minimum open displacement, m^3/min	10	13
Construction displacement, m^3/min	5.5	14
Anticipated result	Cannot fully open	Fully Open
Validation result	Open one cluster	Fully Open

$$P_{net} = F(Q, E, v, C, h_f, h)$$

The fracture static pressure under different construction pressure is simulated according to different formation conditions. The mechanical condition of forming fracture branches is that reservoir inner static pressure > two-direction horizontal principal stress difference + rock tensile strength, and it is the criterion to determine the minimum pumping rate. Therefore, the optimized pumping rate is 12-14m^3/min.

The results indicate that Well 1 has low displacement of 5.5m^3/min, which cannot sufficiently open fractures in the horizontal segment. Well 2 with a high displacement rate of 14m^3/min can realize fractures entirely opened effectively.

Fracturing Fluid System Optimization

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Slick Water System

Experiment temperature（20℃）	Performance index	Slick water index
Viscosity（mPa•s）	≤5	3
Surface tension（mN/m）	≤28	25.56
Interfacial tension（mN/m）	≤2	1.22
Antiswelling rate（%）	≥40	40.18
Base drag reduction rate（%）	≥50	60.12
Contact angle（°）	--	39.2

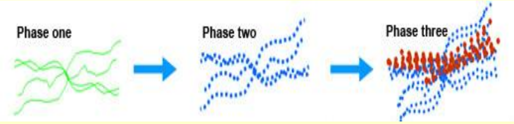
Guar Gum Fracturing System

Guar gum concentration reduces from 0.4%-0.5% to 0.3%-0.4%. The amount of chemicals in fracturing fluid reduces greatly. In this way, the fracturing fluid system is formed with lower damage and costs, which is suitable for energy-storage SRV fracturing.

Base fluid: 0.3%-0.45% guar gum.
Cross-linking agent: 15% organic borate cross-linkingagent NBG-002+2%PH conditioning agent NG-017 +10%clay stabilizing agent NGSX-36+10%demulsificate discharge aiding agentNGB-003.
Cross-linking ratio: 50:1.

Proppant Technology

Slick water	Linear gel	Jelly
Complex fractures are formed, natural fractures are linked, and micro fractures are supported by mesh number 40 – 70 proppants.	Sub-fractures and wider fractures are supported by mesh number 30 – 50 proppants.	Main fractures are supported by mesh number 20 – 40 proppants, and their conductivity is enhanced.



Well Shut-in

Well opening time

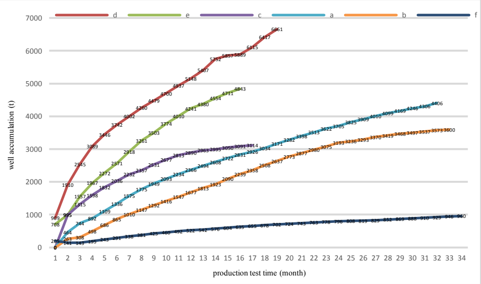
When the wellhead pressure is lower than one-third of shut-in pressure.
When reduction of wellhead pressure within 24 hours is less than 0.5Mpa.

Field Application

The chlorine appearing time and flowback rate while starting to produce oil using conventional fracturing and slip water fracturing

Well No.	Total liquid volume (m^3)	Total sand volume (m^3)	The open time for gushing	The chlorine appearing time	Flowback rate while starting to produce oil	Accumulative liquid drainage while starting to produce oil
a	4000	450	1 h after fracturing	Day 4	36.1	1444m^3 at 8th day
b	4585	407	1 h after fracturing	Day 4	18.5	846m^3 at 7th day
c	9808	385.9	12 h after fracturing	Day 1	5.4	534m^3 at 3rd day
d	9411	522.5	12 h after fracturing	Day 2	4.7	441m^3 at 8th day
e	20900	901	15 h after fracturing	Day 2	2.8	592m^3 at 4th day

Chlorine in three wells presents earlier by the new type of a slick-water system with the energy-storage SRV fracturing; the flowback rate while starting to produce oil is low and retain lots of liquid underground. It is beneficial for water-oil displacement and maintaining the reservoir energy.



The stable oil production reaches 5-8 t/d by energy-storage SRV fracturing in tight oil reservoirs (d, e, c), which can be 8-10 times higher than that from the straight wells (f) and 2-3 times higher than that from other horizontal wells (a, b) by conventional fracturing in the same well block.

Conclusions

The results show that the stable oil production reaches 5-8 t/d by energy-storage SRV fracturing in tight oil reservoirs. Compared with conventional fracturing (1.5-2 t/d), the oil production has been improved by more than 2.5 times. Chlorine in wells presents earlier by the new type of a slick-water system with the energy-storage SRV fracturing; the flowback rate while starting to produce oil is low. It is beneficial for water-oil displacement and maintaining the reservoir energy. Guar gum concentration in this slick-water system reduces from 0.4%-0.5% to 0.3%-0.4%. The amount of chemicals is reduced greatly than that of conventional fracturing. In this way, the gel is formed with lower damage and costs. In general, energy-storage SRV fracturing with this slick water system keeps good balance between SRV fracturing and formation protection, which is more applicable in increasing oil production in tight oil reservoirs.