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Cross Linked Acid-carrying Proppant Fracturing

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Abstract: *The Tarim carbonate reservoirs have strong heterogeneity and complicated relationship between fractures and holes, the acid fracturing doesn't work well in low-grade reservoirs with few fractures and pores. On the basis of the characteristics of the main techniques of acid - fracturing and hydraulic fracturing, the research and field trials of acid-carrying prop fracturing is proposed, in which the cross-linked acid is used as the carrying fluid, to create composite fractures with acid etching and proppant support, to increase the contact area between reservoir and fractures. The cross-linked acid, with high temperature resistance, good rheological property and good proppant - carrying capacity, can maintain high viscosity and proppant-carrying capacity during acidic rock reaction. Based on acid/rock reaction rate and conductivity experiment, the technological method of using different concentrations of acid in proppant - carrying process has been proposed to make use of acid etching and fracturing support at the end and opening of the fracture respectively, to keep the high conductivity of fractures. Cross - linked acid proppant - carrying fracturing has been applied 8 wells in Tarim Oilfield, with the success rate of 100%, providing a novel technology for the efficient development of carbonate reservoirs in Tarim Oilfield.*

Keywords: *carbonate; cross linked acid; acid proppant - carrying fracturing; conductivity; acid fracturing*

1. BACKGROUND

Natural fractures and holes are the major storage space in the Tarim carbonate reservoirs. Strong reflection areas of beads and sheet-like (representing the development of fractures and holes) in the seismic interpretation account for about 30%. Such reservoirs can give high oil and gas production after acid fracturing, while the chaotic reflection area (representing the area with few fractures and holes) accounting for about 70%, has low the success rate of acid fracturing. Besides poor properties of the reservoir, drawbacks in acid fracturing are the main reason of the poor acid fracturing post-production, for example: rock creep leading to the reduction of conductivity of etched fractures, short duration of acid fractures, closure of fractures, short distance of etched fractures, and so on. In the process of hydraulic fracturing, high conductivity can be maintained under high closure stress due to the propping effect of proppant. However, hydraulic fracturing fluid is a non-reactive fluid that does not react with carbonate rock, so the fissures in the reservoirs can't be connected. Therefore, the cross-linked acid proppant - carrying fracturing technology has been proposed. With the advantages of acid fracturing and hydraulic fracturing, it can generate longer acid etched-propping composite fractures with high-conductivity, improving the efficiency of stimulation.

2. CROSS LINKED ACID PROPPANT - CARRYING FRACTURING TECHNOLOGY

2.1 Characteristics of crosslinked acid

Cross-linked acid fluid system is mainly composed of acid viscofier and cross-linking agent, with the

supporting cross-linked acid additives: cleanup agent, corrosion inhibitors, demulsifiers, ferrous stabilizer, gel breaker, etc., forming cross-linked acid fluid system. Conditioning agent is needed for different hydrochloric acids. The basic formula of cross-linked acid is:

Base fluid: 10-28% of hydrochloric acid + 0.8% viscofier + 2% corrosion inhibitor + 1% cleanup additive + 1% ferrous stability + 1% demulsifier + 0 ~ 1% conditioning agent

Crosslinker: Crosslinker A: Crosslinker B = 1: 1

Crosslinking ratio: 100: 0.5~1.0

Breaking agent: 0.10~0.15%

Cross-linked acid base fluid has a viscosity of 30~40mPa•s, cross-linked acid and cross-linked agent are mixed in the ground in proportion to control the crosslinking time between 15s and 200s, the viscosity of cross-linked acid gel maintains at 200mPa•s at 120℃ and 170s^{-1} shearing of 60min, which can meet the requirements of proppant- carrying, as shown in Fig.1. Encapsulated gel breaker is used for the crosslinked acid, the capsule is broken under the closure pressure of the formation and releases gel breaker, helping the cross-linked acid break gel, the viscosity of gel breaking liquid is less than 5mPa•s.

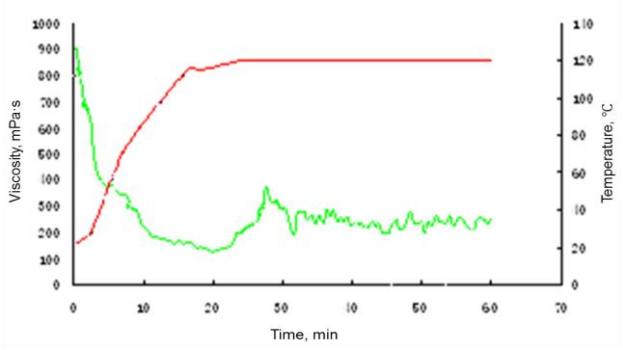

Fig 1: *Rheologic curves of cross-linked acid gel*

2.2 Experiment of acid/rock reaction

The acid/rock reaction rate determines the effective distance of live acid and the etching pattern of fracture surface, thereby affecting the proppant distribution in the fracture and the conductivity. The concentration of cross-linked acid carrying proppant was optimized through the experiments of acidic rock reaction rate. The acidic rock reaction rate of cross-linked acid at different concentrations was tested at 140℃ with Rotating Laccolite Apparatus, the results are shown in Fig.2. When the acid concentration is between 8%~16%, the acid-rock reaction rate is in the range of (5.6~10.7) × 10^{-6} mol/(cm^2•s); when acid concentration is greater than 16%, the acidic rock reaction rate significantly increases. During the process of acid proppant-carrying, the acid concentration is chosen to be 10%~15% at the stage of high proppant concentration, so the viscous acid fluid can carry the proppant, meanwhile with a certain concentration, the acid can filtrate laterally into the zone which is not reached by fracturing fractures, forming uneven etching and composite network fractures by acid etching and propping to improve conductivity.

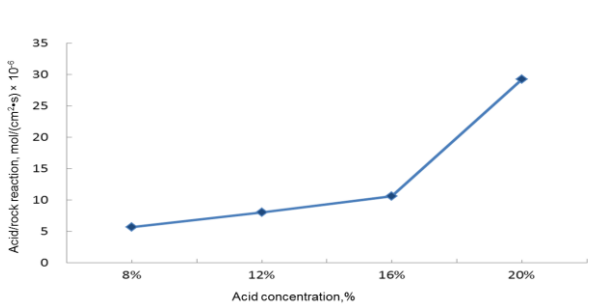

Fig 2: *Relationship between acid-rock reaction rate of cross-linked acid and acid concentration (140 ℃)*

2.3 Proppant carrying capacity of cross-linked acid

The proppant settling velocity in the cross-linked acid is 0.015mm/s under 90℃ experimental condition, meeting the sedimentation rate requirement of fracturing fluid for carbonate reservoirs in Tarim oilfield. Figure 3 shows that the cross-linked acid still has good proppant-carrying performance after 30minutes of

marble-acid reaction in the cross-linked acid containing 18% of proppant concentration under 90℃ condition. The experiment shows that the acid-rock reaction rate of cross-linked acid is slow, and the cross-linked acid can maintain high enough viscosity to carry proppant during the acid-rock reaction process.

Fig 3: *Reaction of marble and cross-linked acid carrying proppant (20 minutes)*

2.4 Conductivity experiment

The experiment was conducted with the FATSC experimental guiding device. The tests were made under two conditions: acid etched fracture and the etched core board laid with proppants. The conductivities of the acid etched fracture and acid proppant-carrying fracture are calculated by using the following formula, recommended by API.RP6,

$$WK_f = 5.63 \times 10^{-2} \frac{Q\mu}{\Delta P}$$

Where, WK_f —fracture conductivity, μm²·cm,

Q — injection rate, mL/min,

ΔP —pressure difference, MPa,

μ —liquid viscosity, mPa·s,

Figure 4 shows the conductivity test on the core board laid with proppant of 2.5kg/m² with acid etched fractures; the results are shown in Figure 5. When the effective closure pressure is greater than 30MPa, due to the proppant supporting, the conductivity variation is relatively smooth. The proppant filling can effectively improve the conductivity of the acid etched fracture, especially at the leading edge of the acid etched fracture, where the acid concentration is low, there is little or no etching conductivity formed, adding proppant helps to obtain longer effective fractures, and thus is an effective means of compensating short acid etched fractures.

Fig 4: *Results of cross linked acid-carrying proppant conductivity*

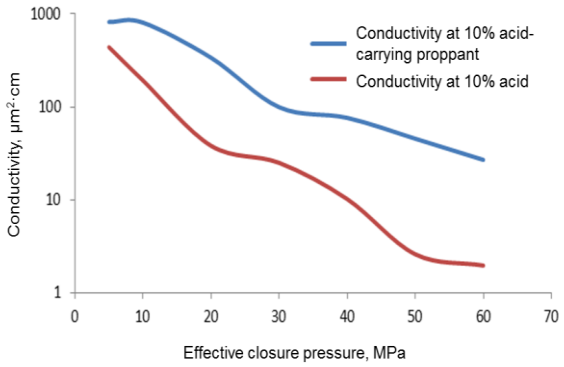

Fig 5: *Comparison of conductivity between cross linked acid carrying proppant and neat cross linked acid*

2.5 Simulation of cross-linked acid proppant-carrying fracturing

Cross-linked acid proppant-carrying fracturing process was simulated to study its advantages, the simulation results are shown in Figure 6. Fracturing fluid was injected to generate fractures and to cool the formation before acid proppant-carrying fracturing, providing more favorable conditions for cross-linked acid proppant-carrying fracturing. To reduce the influence of

acid etching on the proppant conductivity, the acid concentration was lowered at the stage of high proppant concentration. The idea of cross-linked acid proppant-carrying fracturing process is: 20% strength of cross-linked acid is used for low proppant concentration stage, mainly for acid etching and lateral communication; and 10% strength of cross-linked acid is used for high proppant concentration stage, mainly for proppant supporting.

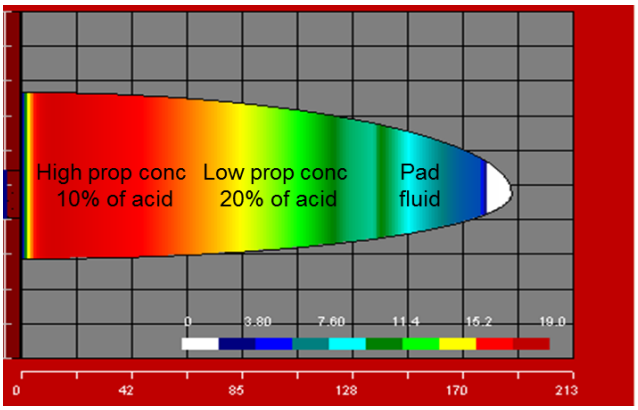

Fig.6. Simulation of cross linked acid proppant-carrying fracturing

3. FIELD APPLICATIONS

Cross-linked acid proppant-carrying fracturing technology has been tested 8 wells in Tarim Oilfield, with the process success rate of 100%, and is effective for 6 wells. The basic well condition and the main treating parameters are listed in Table 1, the deepest formation treated was 6708m, with formation temperature 160°C, the maximum proppant volume was 41.5m^3, and the maximum proppant concentration was 622kg/m^3. The reservoirs treated by cross-linked acid proppant-carrying fracturing are generally not very good, most wells didn't increase production after acid fracturing because of few fractures, pores and vugs. Under such adverse reservoir conditions, cross-linked acid proppant-carrying fracturing have achieved good stimulation effect, indicating this process has bright promotion prospects.

Table 1: *Treating parameters and effect of the cross-linked acid proppant-carrying fracturing*

No	Well Name	Interval m	Major parameters		Formation property
			Volume of sand m^3	Proppant concentration kg/m^3	
1	LN A	5502-5535	18.5	90~350	Oil and gas
2	LG C	5115-5545	14.8	90~335	Poor oil
3	TZ C	5205-5570	41.5	97~548	Poor gas
4	Ha D	6598-6745	22.7	90~576	Oil
5	Ha E	6598-6697	18.4	70~350	Oil
6	Ha F	6679-6708	28.0	87~552	Oil
7	ZG G	5917-6270	38.4	55~622	Gas-bearing
8	TZ H	5529-5550	36.2	100~463	Dry layer

4. CONCLUSIONS

(1) The cross-linked acid base fluid has viscosity of 30 to 40mPa•s, and crosslinking time controlled at 15 to 200s. The cross-linked acid gel has good rheological properties. Its viscosity can be maintained at 200mPa•s at after shearing 60 minutes at 170s^{-1} and 120°C.

(2) A new cross-linked acid proppant-carrying fracturing technology has been proposed based on acidic rock reaction rate, conductivity experiment, and cross-linked acid proppant-carrying fracturing simulation, in which prepad fluid is injected to generate fractures and cool the formation, 20% of cross-linked acid is used for low proppant concentration stage, and 10% cross-linked acid is used for high proppant concentration stage, this is more conducive to form composite acid etched-propping fractures with high-conductivity.

(3) As a novel reservoir stimulation process, crosslinked acid proppant-carrying fracturing technology has achieved good results in low-grade carbonate reservoirs with few fractures and holes, demonstrating its good prospects for promotion.

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