IMPROVING EFFICIENCY OF ACID FRACTURING IN LOW PERMEABILITY GAS RESERVOIRS

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ABSTRACT

One of the main stimulation techniques to enhance gas production in low permeability reservoirs is acid fracturing. Controlling the leakoff of reactive fluids is the key to a successful acid fracturing. In this study, new chemicals and techniques have been developed to control the leakoff by increasing the viscosity of the fluid systems after the acid fracturing fluids were injected into formations. The initial viscosity of the acid fluids was low. The viscosity increased with the increase in the amount of acid injected. Experiments have been conducted in laboratory to prove the efficiency of leakoff control using the new chemicals. The experimental results showed that the new fluid systems reduced the leakoff significantly compared to the gelled and normal acids. The leakoff rate of the new fluid systems was close to that of non-reactive fluids. Because the targeted reservoirs had a high temperature, the thermal stability was also tested and the results showed that the new chemical fluids were stable at 120^{o}C. Because of the good experimental results, acid fracturing stimulations have been conducted using the new chemical fluid systems in 26 wells in Changqing gas field. The production performance has been evaluated after acid fracturing using the new chemicals. The field test results showed that the gas production was increased remarkably using the new chemical fluids and techniques, compared to the routine gelled acid fracturing. A plan has been embarked to apply the proposed techniques in Changqing gas field widely because of the satisfactory pilot field test results and the low cost of the chemicals.

INTRODUCTION

Changqing (Jingbian) gas field is a Paleozoic Erathem dolomite reservoir and is characteristic of low porosity, low permeability, and low productivity. The permeability ranges from 0.1 to 1.0 mD. The depth of the gas reservoir ranges from 3000 to 3700 m and the temperature from 99.6 to 113.5^{o}C. The average pressure gradient of the gas reservoir is about 0.945 MPa/100m and the average initial reservoir pressure is around 32.4MPa.

During the period of 1986 to 1990, conventional acid fracturing， gelled acid fracturing, multi-stage acid fracturing (including a closed fracture acidizing stage) were adopted as main stimulation technologies to improve reservoir production in Changqing gas field;

these technologies have played an important role for large-scale development in the Jingbian gas field. As reservoir production continues, well productivity keeps decreasing year by year, and the number of low-production wells has also increased gradually. To further improve well production and final recovery in this tight gas reservoir, it is necessary to perform deep penetrating stimulation for the carbonate gas field. To this end, new chemicals and techniques have been developed to control the leakoff by increasing the viscosity of the fluid systems. Experiments have been conducted in laboratory to prove the efficiency of leakoff control using the new chemicals. Pilot acid fracturing tests were also conducted and the results were evaluated.

DEVELOPMENT AND EVALUATION OF CHEMICALS

Development of Leak-off Control Acid

There have been reports to study and use leakoff control fluids[1-7]. Coulter *et al*.[1] reported that the leakoff might be controlled by using viscous, non-reactive fluids. Shumaker *et al*.[2] demonstrated that the leakoff of the reactive fluids in carbonate reservoirs could be controlled to the extent that actual productivity increased closely approximate those predicted by computer design program. Welton *et al*.[7] developed a unique in-situ crosslinkable acid system that uses a blend of HCl/formic acid as the base acid and a synthetic polymer gelling agent.

The main purpose of this study was to develop leakoff control acid (LCA) systems with a satisfactory function to reduce leakoff significantly and with a low cost. The difference between LCA and gelled acid is shown in Fig. 1. Initially the viscosity of gelled acid is high and is then reduced with the increase in the pH value. In contrast, initially the viscosity of LCA is low and then increased with the increase in the value of pH (2-4) as LCA fluids react with rock; finally the viscosity of LCA decreases as the value of pH is greater than a specific value (pH>4).

A novel LCA fluid system with a low leakoff and a low cost was developed. The additives with specific function are listed in Table 1. Some of the functional components are iron ion stabilizer, chemicals for reducing leakoff, corrosion inhibitor, and surfactant.

Evaluation of Leakoff Control Acid

Crosslink reaction is expected to happen when the pH value in LCA fluids increases, which causes the increase in viscosity of LCA. The further increase in the pH value will reduce the viscosity of LCA, however. To test whether the LCA fluids developed in this study behave as supposed, experiments were conducted to measure the viscosity of LCA at different values of pH. The results are shown in Fig. 2. One can see that the viscosity of the developed LCA fluid increases first and then decreases with the pH value, as expected. The initial viscosity of the LCA was about 40 cP. The maximum viscosity was about 150 cP; the corresponding pH value was around 2.5. Such a high viscosity can reduce the leakoff rate significantly. The final viscosity was 20 cP approximately.

The property of low viscosity at the high pH value can facilitate and improve the liquid return rate, which can help to enhance the stimulation efficiency. Also shown in Fig. 2 is the effect of pH value on the viscosity of gelled acid. The results show that the viscosity of gelled acid almost does not change (slightly decrease) with the pH value ranging from 0 to about 6.0. No viscosity peak was observed. So it may not reduce the leakoff significantly.

Note that the actual maximum viscosity of LCA may be much greater than the maximum value shown in Fig. 2. This was because the chemical reaction between acid and rock was fast and it was difficult to control the pH value at a specific value or in a narrow range because of the limitation of experimental conditions. According to our visual observation, the status of the LCA varied from low viscosity liquid to high viscosity gel-like liquid.

Evaluation of the Dynamic Leakoff

Actual reservoir rock from Changqing gas field was used to conduct the dynamic leakoff tests to evaluate the function of the novel LCA in controlling leakoff. The reservoir depth of sampling was 3663.5 m. The core samples looked tight and the values of permeability measured using brine were listed in Table 2. The sizes of all the core samples (cubic) were 2×2×2 cm. Microfractures were also observed in these core samples. Experiments were conducted at a temperature of 90^{o}C, close to reservoir temperatures. Three different types of acids, normal acid, gelled acid, and LCA, were used to conduct the comparison of leakoff. The procedure was similar to those reported by Vitthal and McGowen[4]. The experimental results of dynamic leakoff are shown in Fig. 3 and also listed in Table 2. One can see from Table 2 that LCA had the lowest value of leak off. Compared with the normal acid, the leakoff of LCA was reduced by about 75%; compared with the gelled acid, the leakoff of LCA was reduced about 36%.

Fig. 4 demonstrates the relationship between leakoff and time for different acid-fracturing fluids. One can see from Fig. 4 that the LCA had the smallest volume of leakoff at a specific time. The normal acid fluid had the greatest leakoff.

McGowen and Vitthal[5] reported that the leakoff volume (linear gel, etc.) from dynamic leakoff tests was proportional to the square root of time. To test this, the relationship between leakoff and the square root of time is plotted in Fig. 5. The data from LCA fluids show an approximately linear relationship between leakoff and the square root of time but the other two fluids do not demonstrate such a linear relationship.

Acid-rock reaction rate mainly depends on the transportation speed of H^+. The increase in viscosity of LCA can reduce the transportation speed of H^+. Therefore the acid-rock reaction rate in LCA can be decreased so as to increase the penetrating distance of the acid. To test this, three different acid fluids were used and experiments of acid-rock reaction were conducted. The results are shown in Fig. 6. The solid squares represent the results of the residual acid concentration after the reaction between acid fluid and rock was completed; the solid triangles represent the gelled acid and the solid diamonds represent the normal acid (see Fig. 6). One can see from Fig. 6 that LCA has the highest residual acid concentration, which represents that the acid-rock reaction in LCA is the lowest. A lower acid-rock reaction rate is helpful to penetrate deeper formation during acid-fracturing.

Results of Field Tests

26 wells have been acid-fractured using the new LCA fluid systems because of the low leakoff and other satisfactory properties. One example was chosen here to show the results of the field tests. Two nearby wells with similar rock and fluid properties were acid-fractured using different blend of acid fluid systems. As shown in Table 3, the values of the porosity of the formations in two wells were 8.6 and 9.0% respectively; the values of the permeability were 0.899 and 1.057 mD; the initial gas saturations were 84.4 and 85.7% respectively. One can see from Table 3 that the rock properties and the fluid saturation of the formations in the two wells were very close. Well 3 was acid-fractured using a blend of LCA/normal acid and Well 3A was acid-fractured using a blend of gelled/normal acid. The reason to use normal acid was to increase the conductivity of the fracture; the use of LCA could increase the length of the fracture. The volume of used LCA was about 50 m^3 and the volume of normal acid was about 25 m^3. The well test results after the acid-fracturing showed that the use of the blend of LCA/normal acid increased the gas production over six times compared to the use of the blend of gelled acid/normal acid (see Table 3).

Over 26 wells have been acid-fractured using the new LCA fluid system in Jingbian gas field because of the remarkable increase in gas production from the pilot tests. Most of the wells resulted in satisfied gas production after acid-fracturing by using the new LCA fluid system.

CONCLUSIONS

The following conclusions may be drawn from the present study:

1. A novel LCA fluid system was developed to reduce the leakoff of acid-fracturing fluid significantly at a temperature as high as 120^{o}C.
2. Compared with the normal acid, the leakoff of LCA was reduced by about 75%; compared with the gelled acid, the leakoff of LCA was reduced about 36%.
3. The pilot test results showed that the use of the blend of LCA/normal acid could increase the gas production over six times compared to the use of the combination of gelled acid/normal acid.

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Table 1: Functional Components of the New LCA

Items	Code Name	Function
Corrosion Inhibitor	HSJ－1	Protect the oil pipe from being eroded
Corrosion Inhibiting supporter	ZJ－1	Work as an assistant agent in the component of the corrosion inhibitor
Fe^{3+} Stabilizer	LS1－1	Stabilize Fe in the acid fluid
Leakoff Reducer	LS1－2	Increase the viscosity of the tired-acid
Gelled Acid	DSGA、	Increase the viscosity of the acid fluid
surfactant	YQ－1	Reduce the surface tension of the acid

Table 2: Experimental Results of Dynamic Leakoff Tests

Serial Number	Acid fluid style	Permeability of brine （mD）	Velocity of the acid injection （ml/min）	Leakoff coefficient （$m/min^{1/2}$）
1	Normal acid	0.2285	2	1.323×10^{-3}
2	Gelled Acid	0.1268	5	5.146×10^{-4}
3	LCA	0.0965	5	2.594×10^{-4}

Table 3: Results of Field Tests of Acid-Fracturing

Well Number	Blend of Acid	Formation Thickness (m)	Porosity (%)	Permeability (mD)	Gas Saturation (%)	Gas Production ($\times10^4$ m^3/day)
3	LCA/Normal acid	3.6	8.6	0.899	84.4	39.8
3A	LCA/Gelled acid	2.8	9.0	1.057	85.7	6.0

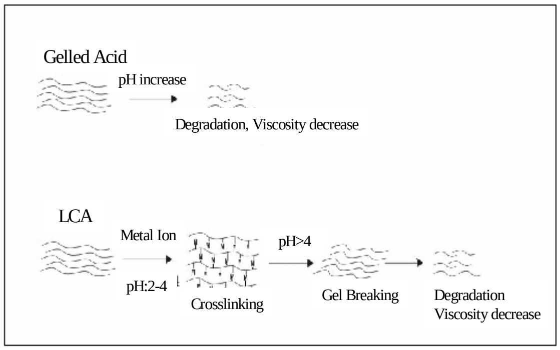

Fig. 1: Difference between LCA and gelled acid

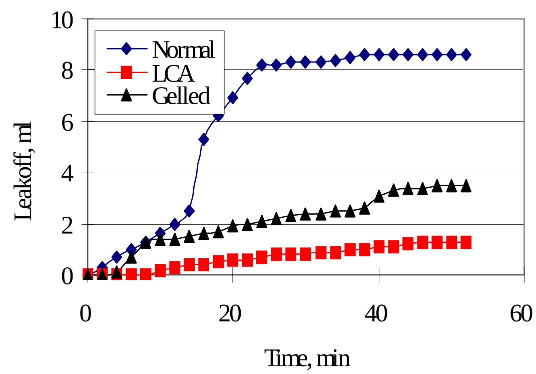

Fig. 4: Relationship between leakoff and time in different acid-fracturing fluids

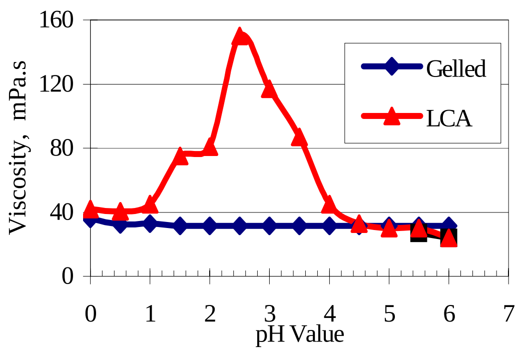

Fig. 2: Change in viscosity of different acid fluids with pH value

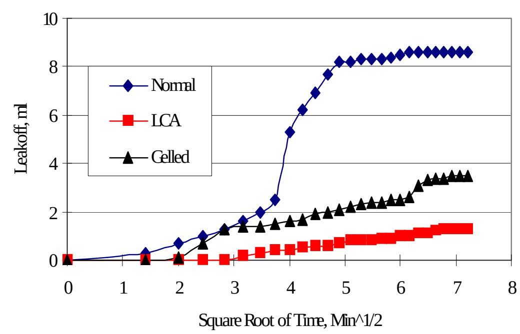

Fig. 5: Relationship between leakoff and the square root of time in different acid fracturing fluids

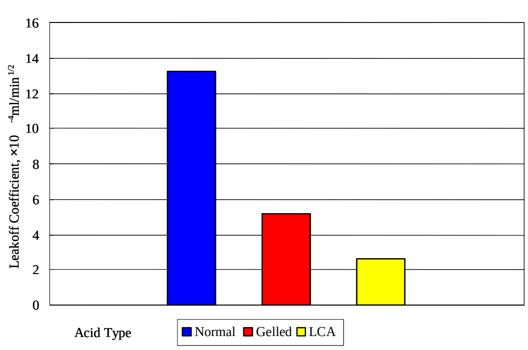

Fig. 3: Comparison of leakoff between different acid-fracturing fluids

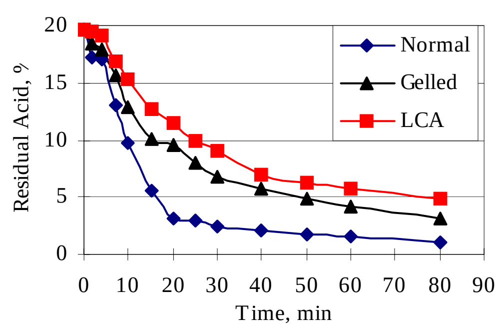

Fig. 6: Residual acid concentrations in rock by different acid-fracturing fluids