Case study of acid fracturing of Ordovician geothermal reservoir in Taiyun area

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Abstract. The thermal reservoir in Taiyun area mainly consists of Ordovician and Cambrian carbonate formations. The target interval of example well contains more than 95% carbonate, being thick, argilliferous and have well-developed natural fissures and rich hot water. However, sometimes stimulation is necessary to achieve the designed water production rate. In this paper, multistage alternating injection acid fracturing technology is selected according to lithologic characteristics of geothermal reservoir. A gel acid, which is a composite of 20%HCl+0.8%SHY1+2% corrosion inhibitor+1.5% iron ion stabilizer+1% cleanup additive, is optimized and developed by experimental tests. Its viscosity can reach 27 mPa·s. Then, pumping schedule of multi-stage alternate injection acid fracturing is optimized by numerical simulator of acid fracturing design. It is shown from job pressure of field sample well that resistance reduction ability of gel acid needs to be further improved. Moreover, from the analysis results of pressure decline after acid fracturing, the fluid efficiency is 42.32%, net pressure is 3.3 MPa, and the dynamic fracture length is 107m, the maximum fracture width is 8.6mm by fitting treatment pressure. The water production increase factor reaches 1.2 after acid fracturing treatment. Therefore, the acid fracturing treatment is successful.
Keywords: Thermal reservoir; carbonate formations; Acid fracturing; Gel acid.

1 Introduction

The development of geothermal resources is one of the main tendencies in the future. Geothermal formation in Taiyun area mainly consists of Ordovician and Cambrian carbonate, acid treatment usually is necessary to increase water production. In fact, this technique is an important and effective method for improving the production of carbonate reservoirs in petroleum industry[1-3]. Techniques such as conventional acid fracturing, deep-penetration acid fracturing and special acid fracturing have been developed[3]. In particular, the multi-stage alternate injection technology[4-6] can significantly increase acid penetration

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distance of living acid, which has become the main technique for improving oil and gas production and recovery in carbonate reservoirs.

Ma[7] introduced geothermal well acid treatment in WR95 block, during which the average treatment pressure dropped from 20MPa to 9.53MPa instantly. After acid treatment, water temperature at wellhead rose from 53°C to 78°C, and water rate increased from 10.38m^3/h to 95.67 m^3/h. Xu[8] summarized acid treatment of HD-39B Ordovician carbonate geothermal reservoir. Logging analysis results indicated that there are multiple aquifers in target formation, and its physical properties are poor. But water rate significantly goes up by the stimulation treatment. Ji[9] reported that water production increased from less than 10m^3/h to 36m^3/h after acid fracturing in carbonate geothermal wells in southwestern Shandong. Yang[10] studied the acid fracturing technology of geothermal wells in a typical area in Beijing. The concentration and volume of acid fluid, required equipment and other parameters are designed in detail. An acid fracturing scheme is determined based on numerical simulation combining with experimental results. Water production after stimulation increased from 968m^3/d to 2163m^3/d, and the output water temperature increased from 43.5°C to 46°C.

2 Geothermal reservoir characteristics in Taiyun area

The geothermal reservoir in Taiyun area[11] is a Cambrian-Ordovician karst reservoir. The pay zone depth is about 2000m and the temperature is about 80°C.

(1) Lithological characteristics

The geothermal bedrock is mainly grey and off-white, including sandy limestone, micrite limestone, silt limestone and leopard skin limestone, etc. The fissures are mainly infilled with calcite. In general, the rocks are mainly composed of calcite and dolomite with impurities such as quartz, gypsum, and pyrite. Carbonate content is more than 95%.

(2) Reservoir space characteristics

The main types of storage space are fissures, dissolved pores, and dissolved caves.

- Pores: The pores diameter is generally 10-50μm and larger pores are rarely seen, and the distribution is relatively limited.

- Fissures: They are relatively developed, which mainly includes network fissure, high-angle cracks and micro-fractures. Network fractures consist of multiple groups of cross cracks intersecting each other and the width is usually less than 1mm. Fissures with a width larger than 1 mm are infilled. High-angle fractures consist of one or two groups of fractures.

- Cave: The dissolved cavities in the core are mainly developed in micrite limestone and crystalline ash, with a diameter of about 1-10cm.

(3) Selection of reservoir stimulation technology

Based on the adaptability of hydraulic fracturing, matrix acidizing and acid fracturing to lithology and its application experience in petroleum engineering, multistage alternating injection acid fracturing technology was selected.

3 Experimental study on gel acid system

In order to increase acid penetration fracture length, gel acid system was chosen because its low reaction rate on acid-rock. The concentration of hydrochloric acid and gelling agent are discussed emphatically.

3.1 Selection of hydrochloric acid concentration

The dissolution ratio of rock-powder with different concentrations of hydrochloric acid is shown in figure 1. The dissolution ratio is close to the limitation when its concentration is 20%. So, 20% HCl is selected based on dissolution rate with engineering experience.

3.2 Selection of gelling agent and its concentration

The experimental results of viscosity from 5 gelling agents (YS110, GHS, SHY1, CHW6 and TH2) are shown in figure 2. Viscosity of acid fluid increases with increasing concentration for gelling agents. The SHY1 is selected and its concentration is determined as 0.8% based on the influence on viscosity according to viscosity of 5 gelling agents.
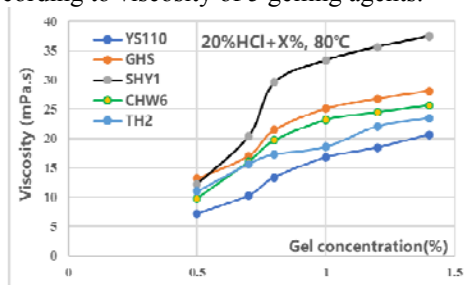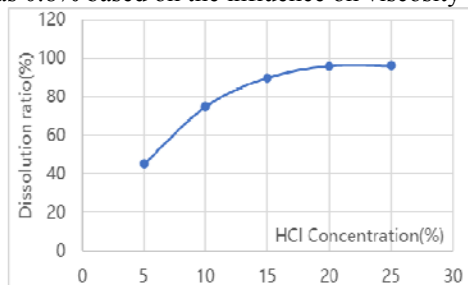

Fig. 1. Dissolution rate of HCl to rock-powder. **Fig. 2.** Acid fluid viscosity of gel concentration.

3.3 Acid and its main properties

In order to meet the requirements of acid fracturing, the acid fluid system should be compatible and anti-swelling, has low surface tension and high capacity of stabilizing colloidal iron precipitation. Acid fluid system is obtained by a lot of experiments tests and evaluations:

20%HCl+0.8%SHY1+2% corrosion inhibitor+1.5% iron ion stabilizer+1% cleanup agent

The rheological performance of the acid fluid is tested by RS600 rheometer produced from the German HAAKE company, and it is illustrated in Fig. 3.
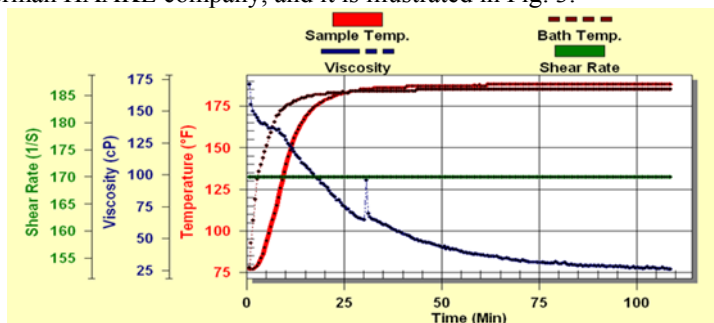

Fig. 3. Rheological performance of the acid fluid.

Fig.3 shows that the viscosity of gelling acid can reach 27 mPa.s after continuously sheared at 80°C and 170s^{-1} for 120 minutes, so the acid fluid has a good properties of temperature resistance and shear resistance, as well as retardative property.

4 Field case

According to the development situation of natural fractures, the geothermal reservoir aquifers in Taiyun area was divided into three types. Among them, the type "I" natural fracture is the most developed, which is the most concerned aquifer and the target interval of reservoir reconstruction

The logging results of example well are illustrated in Table 1. 72-82# geothermal zones have relatively pure lithology, large thickness and are argilliferous with natural fissures. But 75-80# zones (i.e. 2029.3-2045.8m) are the main water-producing interval.

Table 1. Target test layer of example well.

Zone number	Interval, m	Type of natural fissures	Rank of thermal abundance
75-80	2029.3-2045.8	I	Main thermal layer
74 82	2026.7-2027.6 2064.2-2065.1	II	Secondary thermal layer
72 73 81	2024.7 -2025.5 2062.1 -2063.0	III	Poor thermal layer

4.1 Pumping schedule of acid fracturing

Applying simulator on multi-stage alternate acid fracturing [12-13], which contains a series of models such as temperature distribution in wellbore and fracture, propagation of fracture, acid-rock reaction, the pumping schedule of acid fracturing is optimized and it is shown in Table 2.

Table 2. Pumping schedule of acid fracturing treatment.

Number	stage	Rate(m³/min)	Volume(m³)	Fluid type
1	Pre-pad fluid	2.00	30	20% Acid-Y
2	Pad fluid	5.00	45	Linear glue
3	Acid fluid	4.00	125	18%Acid-Y
4	Pad fluid	5.00	40	Linear glue
5	Acid fluid	4.00	100	18%Acid-Y
6	Pad fluid	5.00	40	Linear glue
7	Acid fluid	4.00	100	18%Acid-Y
8	Flush	4.00	200	Active water

4.2 Stimulation Job analysis and fracture evaluation

The stimulation job elapsed during 19:37-22:57 on August 8, 2016, the acid fracturing treatment curve is illustrated in Figure 4.

(1) The treatment pressure of acid injection is much higher than that of fracturing fluid injection, which indicates that the friction reduction capacity of acid fluid should be further improved.

(2) The treatment pressure converted to the same pumping rate increases first and then decreases. One of the possible reasons is that the thermal formation communicates with the nearby natural fissures zone, the other is that hydraulic fracture height is out of control to a certain extent. The real reason needs to be further verified by combining with some test methods.

(3) The pressure steeply drops after the high-pressure point displays the effective communication of hydraulic fractures with natural fissures in thermal reservoirs.
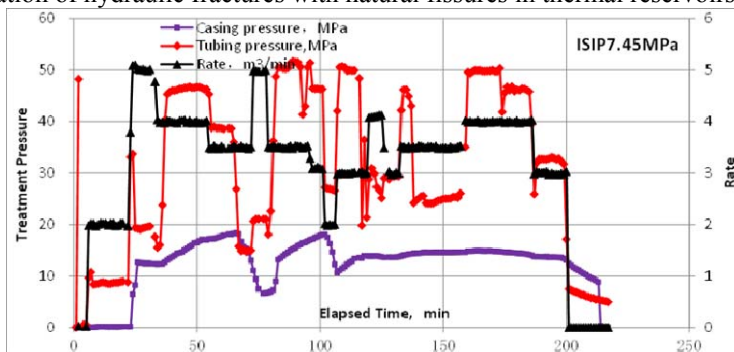

Fig. 4. Treatment pressure change curve of example well.

Applying interpretation software[14] of fracturing pressure decline according to the pressure information after stopping pump from the sample well, it was determined that the closure pressure gradient is 13.9KPa/m, the fluid efficiency is 42.32%, and the net pressure is 3.3MPa. Then, by fitting treatment pressure, fracture geometry is displayed in Figure 5, and the dynamic fracture length is 107m, the maximum fracture width is 8.6mm.
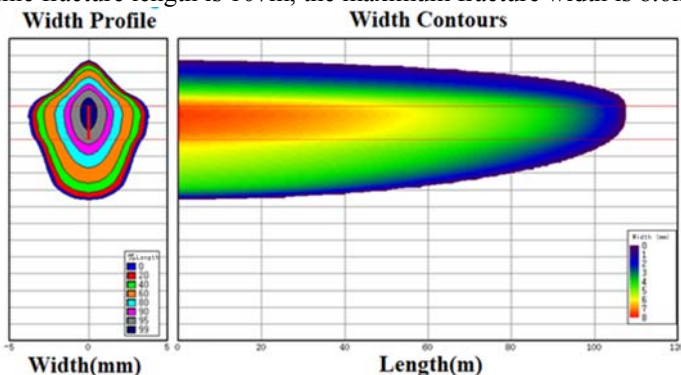

Fig. 5. Fracture geometry from acid fracturing by fitting job pressure.

4.3 Water production after acid fracturing

In order to improve the effect of stimulation treatment, gas lift technology is used to quickly flowback working fluid after acid fracturing treatment. Contrast of water production rate is shown in Table 3, water production after stimulation increased from 15.2m^3/h to 42.26m^3/h, and the water production increase factor is a about 1.2.

Table 3. Contrast of water production rate before and after stimulated.

Water production before acid fracturing			Water production after acid fracturing			Water production increase factor
Static water level(m)	Dynamic water level(m)	Flow rate (m^3/h)	Static water level(m)	Dynamic water level(m)	Flow rate (m^3/h)	
13.44	-57.6	15.2	-42	-154.29	42.26	1.2

5 Conclusions

(1) The geothermal bedrock in Taiyun area is mainly composed of limestone, and dissolved pores, caves and natural fissure are developed. The fissures in target formation are well-developed. The acid fracturing treatment was generally successful in this area.

(2) The gel acid was developed by lot of experiments; it is a composite of 20% hydrochloric acid + 0.8% thickener + 2% corrosion inhibitor + 1.5% iron ion stabilizer +1% cleanup additive. The gel acid has good compatibility with geothermal reservoirs and higher viscosity of 27mPa.s. However, its friction property needs to be further improved.

(3) According to interpretation of pressure decline after stopping pumping, the closure pressure gradient of target formation is 13.9KPa/m, the fluid efficiency is 42.32%, and the net pressure is 3.3MPa. The acid penetration fracture length is 107m, the maximum fracture width is 8.6mm in stimulation job.

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