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Research Article

Experimental Study on Fracture Conductivity in Hydraulic Fracturing

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Abstract:

Due to high strength, ceramic is used in deep and ultra-deep reservoir, and sand is used in shallow reservoir. However, sand is cheaper than ceramic. In the field, the mixture of these two proppants have been pumped to improve the economic production. At present, there is no one to evaluate the conductivity of proppants with mixture of sand and ceramic. In this paper, the different ratio of sand and ceramic were designed to evaluate the fracture conductivity, the results were empirical formula, which could help optimize the combined proppants in field.

1. Introduction

Unconventional reservoir has been focused on the oil/gas development in recent years. As is well-known, the hydraulic fracture is the necessary method to acquire the high production from unconventional reservoir, which produces a little oil/gas with regular development means [1-3]. Proppants are the vital materials in the process of hydraulic fracturing, which keep the fracture open so that the fluid can flow into the wellbore. The effect of proppant on fracture conductivity have been studied a lot [1,4,5]. The ten deficiencies of proppant crush test has been exposed, including the liquid, temperature, human factor, the concentration of proppant and so on. In general, the crushing rate of conductivity experiment is much larger than the crush test [6]. A new equipment has been developed to study the relationship between proppant size and the degree of sand production in weekly consolidated formations. The proppant damage and huge stress attributed to the geochemical interactions [1]. The development process of API standard for Fracture Conductivity Evaluation System has been discussed [7].

Ceramic and sand are the most commonly used proppants in the process of hydraulic fracture. The hardness and sphericity of ceramic is high, whereas the price is expensive. On the contrary, the sand owns a lower hardness, sphericity as well as attractive cost. The price of ceramic is nearly 6 times larger than sand with same diameter. Therefore, a combination of ceramic and sand is pumped into the reservoir in order to reduce the cost. The conductivity is different for the various combination of ceramic and sand, which is the most important factor of production. Thus the conductivities of various combination of ceramic and sand are evaluated in the laboratory under the reservoir pressure and temperature, so as to choose an optimized combination of lower cost and better conductivity as well as provide some reference for construction in field.

2. Material and Method

2.1. Properties of proppants

The proppants used in the experiment are ceramic and sand, which have been tested by inspection agencies. Two diameters of proppants are 20/40-mesh, which are commonly used in China. The bulk density and apparent density of ceramic proppants are 1.58 g/cm^3 and 2.84 g/cm^3, respectively.

2.2. Experimental equipment

FCS-842, which is the newest Fracture Conductivity Evaluation System designed by Core Laboratories Inc. as well as owns a higher accuracy and automation, is used to conduct the experiment. The conductivity cell, as shown in figure 1, is deigned according to API standard [8]. The steel plate is used to simulate the fracture wall.

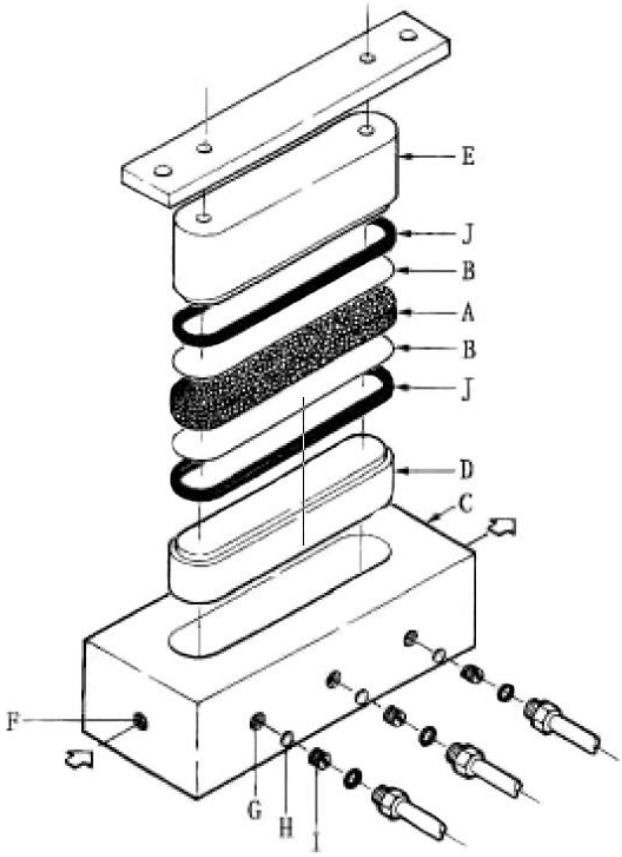

Figure 1. *API Fracture Conductivity Evaluation Unit, explode view (A: Proppants-packed Layer (17.78cm × 3.81cm × W_f), cm; B: Metal Plate; C: Body of the Conductivity Cell; D: Lower Piston; E: Upper Piston; F: Inlet/Outlet of Testing Fluid; G: Outlet of Pressure Difference; H: Mntal Screen; I: Adjustment Screw; J: Square-ring Seal.)*

2.3. Experimental principle

The permeability of proppant pack with liquid in the state of laminar flow can be calculated by the equation (1) [9].

$$\mathrm{k} = \frac{99.998\mu \cdot Q \cdot L}{A \cdot \Delta P} \qquad (1)$$

Where k is the permeability of proppant pack, μm^2, μ is the viscosity of the fluid flowing through the proppant pack, cp; Q is the flow rate of the fluid through the proppant pack, cc/sec; L is the length between pressure ports on the proppant cell, cm; A is the area of cross section, cm^2; △P is the pressure drop across proppant pack, kPa.

Assuming the cross-section shape of proppant pack is the rectangle and using the API conductivity cell (width is 3.8cm, distance is 12.7 cm between pressure ports), the conductivity of proppant pack can be calculated using equation(2)：

$$C = \frac{5.555\mu \cdot Q}{\Delta P} \qquad (2)$$

Where C is the conductivity of proppant pack, $\mu m^2 \cdot cm$; Q is the flow rate of the fluid through the proppant pack, cc/min.

2.4. Experimental program

The concentration of proppants is 5 kg/m^2 (1 lb/ft^2), and the temperature is 60 ℃ (140℉). The closure stress increased from 10 MPa to 40 MPa with an increment of 5MPa each time. The test time is 50 h for each stress point, which is according to the API standard[8] 2 wt. % KCL is the test fluid. The ratio of ceramic to sand decreases from 100 % to zero.

2.5. Experimental procedures

The detailed procedures are presented as follows:

- A certain quality of ceramic and sand is weighed according to the experimental program.
- The proppants are placed uniformly on the bottom steel plate, which is fixed in the conductivity cell. With the purpose of simulating the actual propagation in field, ceramic is put at the inlet of fluid, while sand is put at the outlet of the fluid.
- After loadding the upper steel plate, the conductivity cell is put into the hydraulic load frame. The pressure transducers and pipline of inlet/outlet are connected with the cell, and a few closure stress is applied in order to make the conductivity cell immobile.
- 2%KCl is injected into the fracture in the conductivity cell at the certain flow rate, differential closure stresses are loadded according to the experamental plan.
- Parameters, such as closure stresses and conductivities, are recorded and analyzed.

3. Results and Discussion

3.1 Results

The experimental results are are plotted in figure 2.

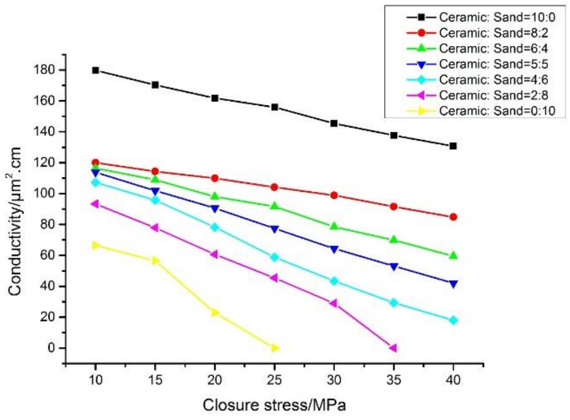

Figure 2. *The conductivities of various combined proppants under different closure stress*

The experimental results have been obtained and discussed as follows.

3.2. Discussion 1

As can be seen from the figure2, with the increasing closure stress, the conductivities gradually decrease. The highest conductivity is the proppants with 100% ceramic, in other words the proportion of ceramic to sand is 10:0. With the increasing proportion of sand, the conductivity is becoming lower at each closure stress. Thus the lowest conductivity corresponds to the proppants with 100% sand. Under the lower closure stress, the conductivity of proppants consisted of 100 % ceramic is nearly threefold to the sand. Moreover, with the increasing closure stress, the conductivity gap between ceramic and sand is gradually becoming wider. The conductivity of 100 % sand decreases to zero under a closure stress of 25 MPa, on the contrary, the conductivity of ceramic is still high above 150 $\mu m^2 \cdot cm$.

The proppants pack is gradually compacted with the increasing closure stress, which leads to a decrease of fracture width and permeability that both of these two parameters can reduce the conductivity. The roundness and sphericity are the main reason for why the conductivity of ceramic is much larger than the sand under a small closure stress. The roundness and sphericity of the ceramic are both 0.8, which are bigger than the sand with the 0.7. The higher roundness and sphericity can reduce the flow resistance and enlarge the flow space, which is helpful to enlarge the permeability and conductivity. The hardness and the strength are the main reason for why the conductivity of ceramic is much larger than the sand under a bigger closure stress. The crushing rate of ceramic under a stress of 52 MPa is 5 %, while the crushing rate of sand under a stress of 28 MPa is 9 %. In fact, due to the concentration of proppants, liquid, temperature environment and other factors, the real crushing rate in the conductivity experiment is much bigger than the test results [10].

3.3. Discussion 2

The slope of each line in the figure 2 is calculated and analyzed. Figure 3 shows the relationship between slope of conductivity with increasing closure stress and percentage of sand. The slope of curve is becoming bigger with the increasing percentage of sand, which means the conductivity decreases faster with the increasing closure stress. The experimental results are also fitted with an equation as shown in follows:

$$S = 0.0434P + 0.2781 \qquad (3)$$

Where S is the slope of conductivity with increasing closure stress, dimensionless; P is the percentage of sand, %.

The equation (3) shows that the relationship between slope of conductivity with increasing closure stress and percentage of sand is approximate linear. The correlation is verified through an experiment of 30% sand and 70% ceramic under the same condition. The result matches well. Details on verified experiment is described in later section. The reason for increasing slope is the weaker hardness of proppants pack with the increasing proportion of sand.

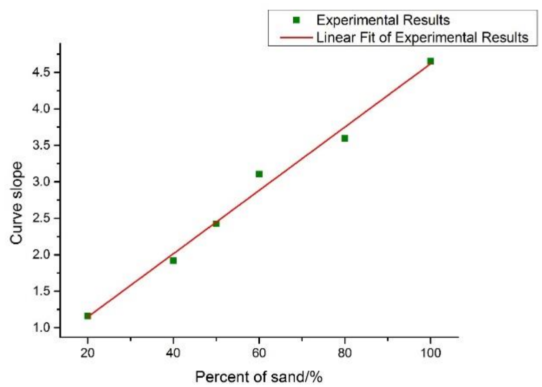

Figure 3. *The relationship between slope of conductivity with increasing closure stress and percentage of sand*

4.Conclusions

(1) With the increasing closure stress, the conductivities gradually decrease. The highest conductivity is the proppants with 100% ceramic, the lowest conductivity corresponds to the proppants with 100% sand. With the increasing proportion of sand, the conductivity is becoming lower at each closure stress. The hardness, sphericity as well as crush mechanism of sand can explain the consequence.

(2) Under the lower closure stress, the conductivity of proppants consisted of 100% ceramic is nearly

threefold to the 100% sand. Moreover, with the increasing closure stress, the conductivity gap between ceramic and sand is gradually becoming wider.

(3) An empirical equation on slope of conductivity with increasing closure stress and percentage of sand is fitted and verified.

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