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Experimental Study of Pressure Waves on Transmission Speed and Energy Loss in the Fracturing Fluid

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Abstract. As a new mean to increase oil and gas production, radial well hydraulic fracturing technology has been carried out in Jiangsu, Shengli, Liaohe Oilfield and has made gratifying achievements. If there are natural fractures or cemented layers locating in distal end of radial wells, artificial fracture initiation point, which is located in natural fractures of the distal end of radial wells or near-wellbore area, can be determined by pressure wave velocity of fracturing fluid and radial borehole pressure loss. The Laws of fracturing pressure wave transmission is still unknown .To solve the problem which has been mentioned, the pressure wave's transmission speed and energy losses of hydroxypropyl guar gum fracturing fluid, clean fracturing fluid and foam fracturing fluid were measured. In addition, univariate analysis was carried out. Experimental results show that there is a big difference of pressure wave velocity in different types of fracturing fluid. The pressure wave propagation velocity in hydroxypropyl guar gum fracturing fluid is fastest (about 1539.6m/s). The propagation velocity of cleaning fracturing fluid is a little slower (about 1325.2m/s).The propagation velocity of the foam fracturing fluid reduced significantly (about 501.1m/s). The pressure wave velocity and energy loss, which are affected by viscosity, concentration, or the foam quality, also showed a different law in the same kind of fracturing fluid: The pressure wave velocity increase slightly with viscosity increasing (the average value is 7.81%). The pressure wave velocity increased significantly with concentration increasing in the guar gum fracturing fluid and clean fracturing fluid (velocity increased by 17.4% and 38.3% respectively.).There is a significant reduction with the increasing of the foam mass fraction in foam fracturing fluid (reduced by 46.3%). As the viscosity, concentration or foam mass fraction increase, energy loss of pressure wave increased. However, the patterns of pressure wave attenuation in three fracturing fluids are distinctive and there is a obvious "energy zero attenuation" segment in clean fracturing fluid. The results reveal the pressure transfer law, fill the research gaps of the pressure wave in fracturing fluid and provide a theoretical basis and numerical Simulation parameters for the analysis of fracture initiation location of radial well.

Key words: pressure wave, fracturing fluid, pressure wave velocity, energy loss; radial well, transfer law

1. Introduction

If the speed of the pressure waves on transmission in fracturing fluid is fast, distal radial wells maybe will initiate on the process of fracturing of radial wells. Otherwise, the initiation maybe will occur near the vertical well. Meanwhile, the properties of different fracturing fluid are different, and the storage capacity and the pressure wave energy loss are also different. If there are natural fractures or cemented layers located in distal radial wells, artificial fracture initiation point can be determined on natural fractures of distal radial wells or near-wellbore area by fracturing fluid pressure wave velocity and radial borehole pressure loss. According to the basic principles of fluid elasticity, Zhou Guangquan [1] gives some partial transfer law of pressure wave in water. B rown [2] puts forward the relation between the Pressure wave velocity and the frequency of viscosity of hydraulic oil. The empirical formula in the pressure wave velocity is given with the fluid density, viscosity and pressure variations of hydraulic oil by Kenji Yamaguchi [3]. Cai Yigang [4] verifies the functional relationship among Pressure wave velocity, fluid viscous resistance and transit time. He

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put forwards that there is no functional relationship between Pressure wave velocity and fluid viscous resistance. The above researches focus on the pressure wave of hydraulic oil. Guillaume Vinay [5] and other experts have done some theoretic researches on the transfer law of pressure in pipeline and have given the relations between the pressure wave velocity and pressure, wax content of hydraulic oil. They put forward that the pressure wave velocity has direct relation with the crude oil pressure distribution. Zhang Guozhong [6] has calculated the initiating velocity of compressed gelled crude oil in the pipe at isothermal condition and has given the relation between the pressure wave velocity and the distribution rule of pressure. The main object of these researches is the crude oil in the pipeline which has no reference value because it has a big difference with the property of fracturing fluid. It can be found through researches that pressure wave velocity, on one hand, is the superficial characteristics of the velocity of pressure wave propagation, and on the other hand, has relations with such factors as fluid type, viscoelasticity and concentration, etc. which determines that pressure wave velocity is very important when calculating fluid pressure distribution [7], [8]. The research on the pressure wave of the fracturing fluid is still blank nowadays, not to mention the research on the determination of the pressure wave velocity and energy loss in the transfer process. There are huge differences among the natures of different fracturing fluid, and it is difficult to reflect the rule that the influence of respective characteristics on the wave velocity and energy loss through the mathematical expression. To deal with these problems, this paper takes three kinds of fracturing fluid that are common as experimental subjects to reveal the rule for pressure transfer of the fracturing fluid to measure and analyze the velocity of pressure wave propagation and energy loss rule through experimental methods.

2. Experimental Study

2.1. Experimental installation and pressure wave

2.1.1. Experimental equipment

The mainly equipments used in this experiment are Model 5058PR type ultrasonic pulse generator, HEWLETT 54602B oscilloscope and 5.0MHz ultrasonic probe manufactured by the Pan America Company.

2.1.2. Fracturing fluid preparation

(1)Comparative Experiments of Different Types of Fracturing Fluid

To study the rule of the pressure transfer wave in different types of fracturing fluid, guar gum fracturing fluid, clean fracturing fluid and foam fracturing fluid of the same viscosity are prepared as experimental media for the linear study, all of the fracturing fluid are heated up to 30℃. The basic formula is as follows:

Table 1: The Preparation of Different Fracturing Fluid

Type	Viscosity（mPa s）	Preparation
guar gum fracturing fluid	100	water+0.3% hydroxypropyl guar powder+0.52% crosslinker
clean fracturing fluid	100	water +4.1% liquor of clean fracturing fluid
foam fracturing fluid（foamquality 40%）	110	water+0.3% hydroxypropyl guar poeder +0.52% crosslinker +1% HY-2 blowing agent

(2)The Comparative Experiment of Different Capacity Parameters of the Same Fracturing Fluid

Fracturing fluids with different viscosity, concentration and foam quality are prepared to study the influence of fracturing fluid to rule for pressure transfer.

2.2. Experimental methods and principals

The pressure wave is a kind of commotion wave generated by the fracturing equipment on the ground, which is a mechanical wave essentially and can be seen as longitudinal plane wave. The rule for pressure transfer is similar to the rule for ultrosonic transfer [9]. Considering that ultrasonic wave have the advantages of centralized direction of propagation and non-diffusion, etc. which can simulate the transfer law of straight plane wave generated by fracturing fluid on the process of infusion very well. Ultrasonic impulse is chosen as the source of the pressure wave in this research.We can figure out the wave velocity through measuring the transfer time of ultrasonic wave in certain distance, and the time equation method can be used in various media (solid, liquor, gas). We can finish the measurement of the pressure wave amplitude by using oscilloscope [10]. Time equation is adopted in this research and the Schematic diagram is below.

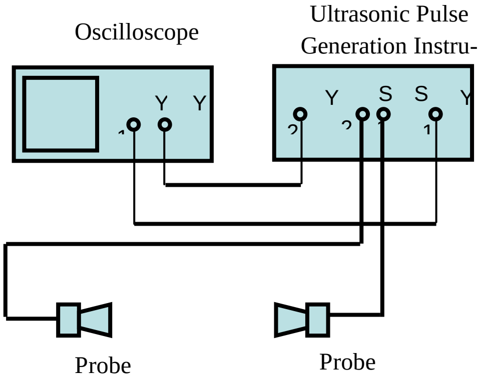

Fig. 1: The diagram of experimental apparatus of measuring pressure wave velocity using pulse method

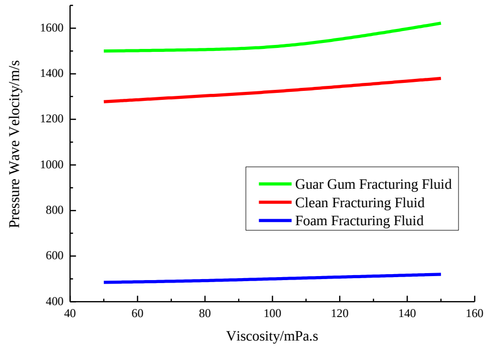

Fig. 2: Changes of the Pressure Wave Velocity in Different Types of Fracturing Fluid as Viscosity Changes

The oscilloscope outputs the electric signal which is converted by the pressure wave amplitude. According to the principle of the oscilloscope, the pressure wave attenuation index reflects the pressure wave rate, and the larger the attenuation index is, the faster the rate of the pressure wave energy losses. The energy storage capacity of the media is weaker, vice versa.

3. Analysis of Experimental Results

3.1. Determination of pressure wave in different fracturing fluid

The transfer velocity of different fracturing fluid pressure wave differs a lot when the viscosity is about 100mPa s through the determination of the pressure wave in different fracturing fluid as can be seen in table 2.

Table 2: The Determination Result of the Pressure Wave in Different Fracturing Fluid

type of fracturing fluid	wave velocity (m/s)
guar gum fracturing fluid	1545
clean fracturing fluid	1334
foam fracturing fluid(the foam quality is 40%)	550

3.2. The Influence of different performance parameter to the pressure wave

3.2.1. The law of the influence of different performance parameter to the pressure wave

(1) The Influence of Viscosity to the Pressure Wave

Analyze the changing law of transfer velocity of the pressure wave as the pressure wave viscosity changes.

Fig. 2 shows the velocity of pressure wave propagation in the guar gum fracturing fluid is about 1539.6m/s under certian velocity limit in actual operating mode, the velocity of pressure wave propagation in clean fracturing fluid is about 1325.2m/s, while the value of the wave velocity in foam fracturing fluid is the smallest which is only about 501.1m/s. Meanwhile, the pressure wave velocity increases as the viscosity of the pressure wave increases to some extent (the average value is 7.8%). There are no related researches nowadays to confirm the relation between velocity and viscosity of the pressure wave, but according to the fundamental theory of pressure wave propagation, under high viscosity circumstances, the amplitude of the pressure wave has inverse proportion to the viscosity. However, the pressure wave energy is the function of amplitude and velocity, and the pressure wave is proportional to viscosity under certain condition of the emission source energy. Therefore, the pressure wave velocity increases with viscosity to some extent [11].

(2) The Influence of the Concentration to the Wave Velocity

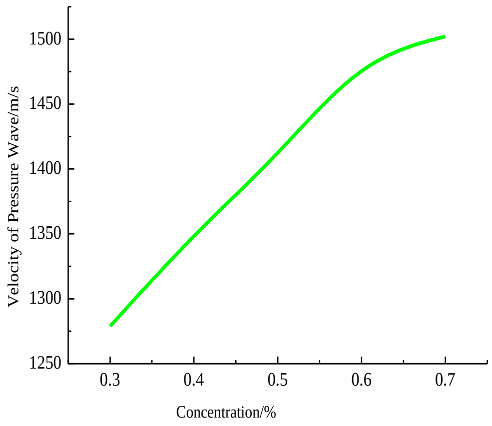

Fig. 3: The Changing Law of the Velocity of Pressure Wave in Guar Gum Fracturing Fluid with Concentration

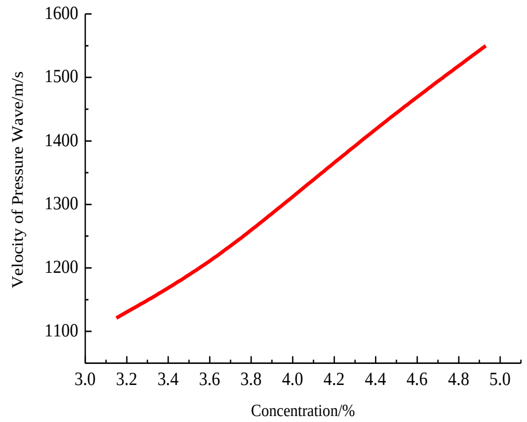

Fig. 3: The Changing Law of the Velocity of Pressure Wave in Clean Fracturing Fluid with Concentration

Fig. 3 a- Fig. 3b displays the changing law of the velocity of pressure wave in different fracturing fluid with concentration. From Fig. 3-1, the concentration of the fracturing fluid increases with the increasing of the additive amount of guar powder, the pressure wave transfer velocity increases from 1279m/s to 1503m/s (the ascensional range is 17.4%). The increase ratio of the pressure wave slows down when the concentration reaches to about 0.6%. Analysts believe that with the increasing of guar fracturing fluid concentration, guar powder gradually reaches saturation, tiny particles that can not be dissolved in water began to appear in fluid, which intensifies the exchange between energy and momentum of in the process of the pressure wave transferring, increasing the energy dissipation, slowing down the transferring velocity of the pressure wave. [12], [13] the pressure wave transfer velocity of clean fracturing fluid increases from 1121m/s to 1550m/s with the its mother liquor(the ascensional range is 38.3%), which increase in basic linear regular pattern.

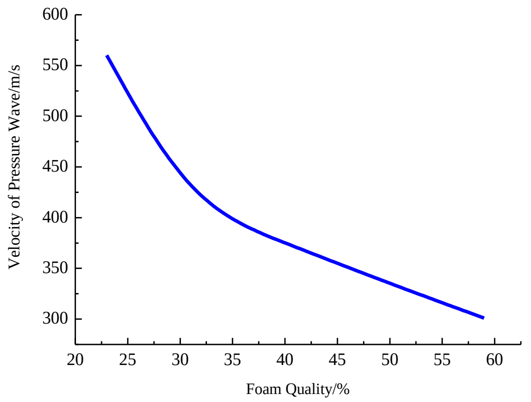

Fig. 4: Changes of the Pressure Wave Velocity in Foam Fracturing Fluid as Foam Quality changes

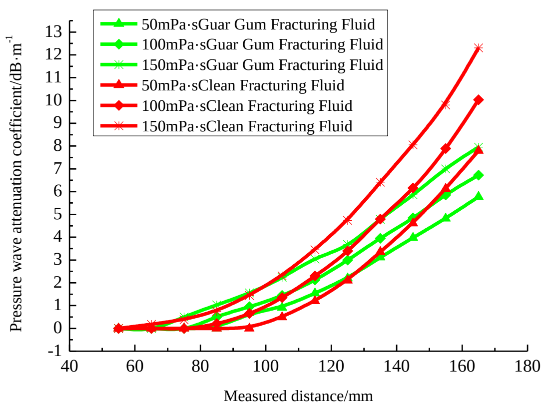

Fig. 5: Changes of Attenuation Index of Guar Gum Fracturing Fluid Pressure Wave and Clean Fracturing Fluid Pressure Wave as the Viscosity changes.

Within velocity limit of actual operating mode, concentration has a bigger influence to the pressure wave in fracturing fluid than viscosity.

(3) The Influence of the Foam Quality to the Wave Velocity

Fig. 4 shows the changes of the pressure wave in foam fracturing fluid under different foam quality. The transfer velocity of the pressure wave in fracturing fluid decreases from 560m/s to 301m/s, which has a sharp decrease of 46.3% mainly because of the different transfer velocity of the pressure wave in liquid and gas. And with the increasing of the gas content, the pressure wave needs to pass through more gas areas, causing the continuous decrease of the pressure wave. Meanwhile, with the increasing of the foam quality, the decease rate of the pressure wave slows down to some extent because as the gradually decrease of the fluid content, the influence of the fluid quality to the wave velocity becomes smaller, which tends to the wave velocity in pure gas. [14], [15] Therefore, the decease rate of the pressure wave slows down to some extent. Foam quality has a bigger influence to the wave velocity of foam fracturing fluid compared with viscosity factor.

3.2.2. The influence regularity of different performance parameter to the pressure wave energy attenuation

(1) The Influence of Viscosity to the Pressure Wave Energy Attenuation

Fig. 5 shows that the energy attenuation degree of two different types of fracturing fluid pressure wave under different viscosity. Measuring the attenuation index in certain point (the measuring distance is 120mm) with viscosity. When the viscosity of the two different kinds of fracturing fluid rises from 50mPa s to 150Pa s, the pressure wave attenuation index of guar gum fracturing fluid increases by 65.1% , while the clean fracturing fluid increases by 132.5%. With the increasing of viscosity, the attenuation index of the pressure wave increases to some extent. Viscosity has a negative influence to energy transfer. The pressure wave energy in clean fracturing fluid attenuate faster than in guar gum fracturing fluid with the increasing of viscosity. Meanwhile, guar gum fracturing fluid shows obvious energy attenuation from the starting point. While clean fracturing fluid shows certain capacity to energy, which is called “zero energy attenuation section”, and the lower the viscosity is, the further the starting point of energy attenuation is from the pressure wave source location, that is, the distance of “zero energy attenuation section” becomes longer, while the guar gum fracturing fluid and foam fracturing fluid don’t show certain capacity to energy. Clean fracturing fluid possesses both viscoelasticity and viscosity because of the micelles with rod-like structure and polymer networks. Viscoelasticity has a certain storage capacity to the pressure wave energy, and viscosity adds the resistance that the pressure wave passes through itself and energy loss, both of which determines the degree of attenuation of the pressure wave [16], [17]. This explains why the pressure wave shows energy attenuation at the starting point in guar gum fracturing fluid, while energy attenuation appears in later point in clean fracturing fluid and also why the lower the viscosity is, the further the starting point of energy attenuation is from the pressure wave source location.

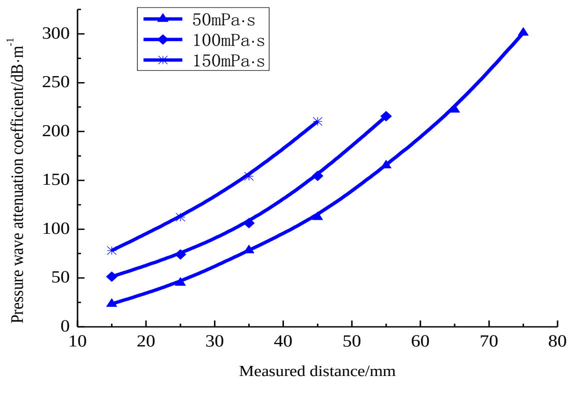

Fig. 6: Changes of Attenuation Index of Foam Fracturing Fluid Pressure Wave as the Viscosity Changes

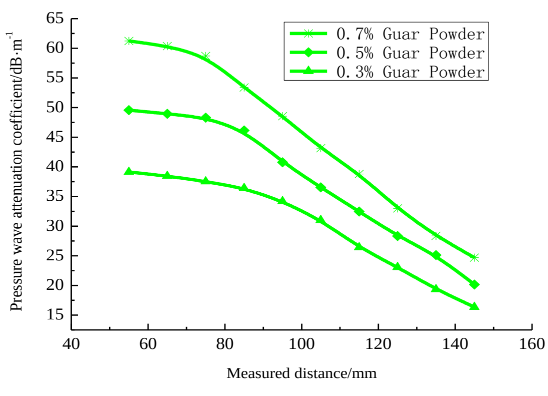

Fig. 7: The Changing Law of Pressure Wave Attenuation Coefficient in Guar Fracturing Fluids With Various Concentrations

Fig. 6: shows changes of the viscosity for energy attenuation of pressure wave in the foam fracturing fluid. The changing rule of attenuation indexes as viscosity changes was measured when the distance was

40mm. When the viscosity of foam fracturing fluid increases from 50mP s to 150mP s, the attenuation index increases by 107.4%. The pressure wave in foam fracturing fluid has a heavy energy loss compared with guar gum fracturing fluid and clean fracturing fluid. And the pressure wave energy attenuation index increases gradually with the increasing viscosity of foam fracturing fluid, and the penetration distance of the pressure wave reduces in turn (the penetrable distance of media reduces from 50mP s to 30mm Meanwhile the viscosity changes from 50mP s to 150mP s). Foam fracturing fluid has gas-liquid two-phase characteristic. Compared with single-phase medium, the gas-liquid two-phase one has more obvious dispersion characteristics of pressure waves. Frequent alternation of gas and liquid is bound to cause significant interference on the pressure wave propagation and energy loss, resulting in substantial attenuation of pressure wave energy in the foam fracturing fluid [18]-[20].

（2）Effects on Pressure Wave Energy Attenuation Made by Concentration

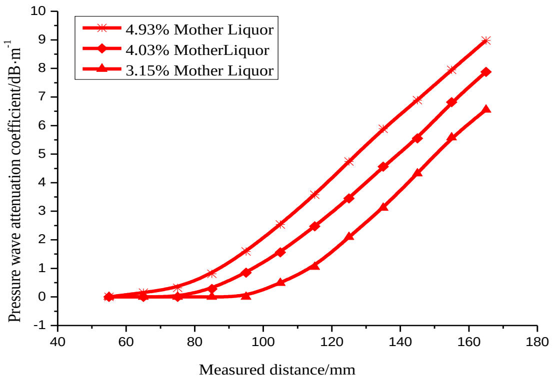

Fig. 7: The Changing Law of Pressure Wave Attenuation Coefficient in Clean Fracturing Fluids With Various Concentrations.

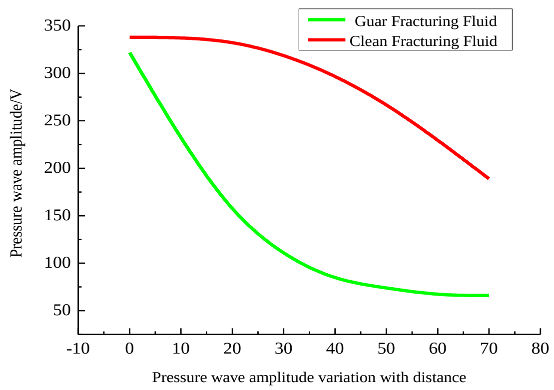

Fig. 8: Changes of Pressure Wave-Amplitudes in Fracturing Fluids as Distances Change.

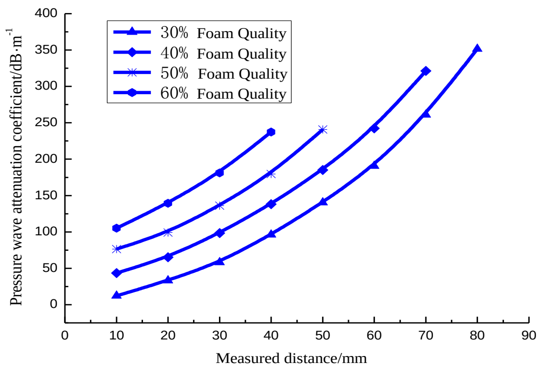

Fig. 9: Changes of Pressure Wave Attenuation Coefficient Variation in Foam Fracturing Fluids with Different Foam Weights.

Fig.7a- Fig.7b shows the law of pressure wave attenuation in various concentrations. Guar fracturing fluid and clean fracturing fluid show in different way: energy of pressure waves in the guar fracturing fluid attenuates significantly from the very beginning and amplitude decreases rapidly which shows in a diminishing law of concave function. While pressure wave energy of the latter attenuates in a contrast way, showing that energy attenuates little in the initial position. As the distance between two probes increases, energy attenuates in a fast rate, thus amplitude decreases in a convex function which is shown in Fig. 8. At the same time, The changing rule of attenuation indexes as viscosity changes was measured when the distance was 120mm. The guar gum powder in the guar fracturing fluid increases from 0.3% to 0.7% and its attenuation coefficient increases by 59.6%. While green liquor concentration in the clean fracturing fluid increases from 3.15% to 4.93%, the attenuation coefficient rises by 184.6%. The attenuation coefficient of pressure waves in the above two fracturing fluids increases with the increasing of concentrations, which is their common characteristic.

(3) Effects on Energy Attenuation of Pressure Waves by Foam Quality.

Fig.9 shows changes of pressure wave attenuation coefficient in foam fracturing fluids with various foam weights. The pressure wave attenuation coefficient with various foam qualities is measured when the distance is 40mm. The attenuation coefficient of foam fracturing fluid increases by 199.5% when the foam weight rises from 30% to 60%. When foam quality grows successively, the pressure wave energy attenuation gradually increases and distances of penetrating medium of pressure waves reduce (the distance of penetrating medium reduces from 80mm with 30% foam weight to 40mm with 60% foam weight). Compared with other fracturing fluids, the foam fracturing fluid is less effective in pressure wave propagation and energy transmission.

4. Conclusions

Magnitudes of pressure wave propagation speed in three common fracturing fluids are confirmed by the research. The result shows that pressure waves in the guar fracturing fluid propagate with proximately 1539.6m/s, which is the fastest. And the second one is the clean fracturing fluid, about 1325.2m/s. While the propagation spread in foam fracturing fluid decreases significantly to only about 501.1m/s. The effects of viscosity, concentration and foam quality on propagation velocity of pressure waves varied. The velocity of pressure waves will increase by a small margin as the viscosity grows, it increases significantly with the increasing of concentrations of guar fracturing fluid and clean fracturing fluid. While it reduces substantially as foam quality of foam fracturing fluid grows. The faster the velocity is, the easier distal fracture initiation is. The phenomenon of fracture initiation near the well bore during fracturing can be effectively avoided by controlling the viscosity, density land foam quality of the fracturing fluid

The study finds that the energy loss of pressure waves is different influenced by viscosity, density and foam quality of fracturing fluids. In general, energy losses of pressure waves increase with the growing of viscosity, concentration or foam quality of mediums. By comparing, the effect of concentration on energy loss of the pressure wave is most obvious while the effect of foam qualities in the foam fracturing fluid is the most obvious. The effects of viscosity and concentration on energy loss of pressure waves in the clean fracturing fluid are similar. The pressure loss of fracturing fluids is not only related with friction but also its own energy decay. Considering both factors can determine more accurately the pressure distribution of fracturing fluids inside the well bore, which is helpful for confirming the initiation position of fractures.

Pressure waves attenuate differently in three fracturing fluids. The attenuation of pressure waves in the guar gum fracturing fluid shows in a concave function trend. That is---energy losses substantially and the amplitude decreases rapidly in the beginning. As the measuring distance increases, the attenuation amplitude gradually decreases; The attenuation of pressure waves in the clean fracturing fluid and fracturing fluid show in a convex function that energy loss is little in the beginning, and as the measuring distance increases, the amplitude attenuation gradually increases. The clean fracturing fluid has better energy transfer properties among three.

At the start of the experiment, there is an obvious "zero energy attenuation" section of pressure waves in the clean fracturing fluid. And as the viscosity decreases, the distance of "zero energy attenuation segment" becomes longer. This phenomenon is not be found in the following two fracturing fluids, which is directly related with the viscosity of the clean fracturing fluid. In Under the experimental condition, the distance of "zero energy attenuation segment" is rather short, but it is expected to be longer during the high-pressure fracturing process, and it needs further studying.

Compared to other two fracturing fluids, being affected by dispersion characteristics of pressure waves, the attenuation coefficient of pressure wave in the foam fracturing fluid is one or two magnitude higher. And with the increasing of foam weights, the penetration distance of pressure waves gradually reduces. From the experimental point of view, the effect of foam fracturing fluid is the worst among three fracturing fluids.

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