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The application of the SRV in the development of the shale gas

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Abstract— As a kind of unconventional resource stored in the shale, shale gas has become the focus of the world because of the sustainability of its huge reserves. In recent years, the exploration technology of the shale gas has developed greatly, but the conventional Two-winged fracture technology cannot meet the needs of the production. To solve this problem, researchers proposed the concept of the Stimulated Reservoir Volume (SRV), which is to form a large fracture network to maximize well performance. Chinese researchers also give the concept of "Volume Fracturing", and make it more useful on technology to meet the requirement of production in China. This paper analyzed the applicability of fracturing techniques on the base of shale gas development case in foreign country and domestic fracturing technology. And get the conclusion that SRV is the best way to develop shale gas， otherwise, the technique of SRV needs more researches to satisfy the need of the shale gas require.

Index Terms—shale gas; stimulation fracturing; fracturing network; volume fracturing

I. INTRODUCTION

Stimulated Reservoir Volume is one of hydraulic fracturing technology to form a complex three-dimensional fracture network in the reservoir [1],[2], which can greatly increases the effective volume of the reservoir. Finally increase the production of oil and gas.

The reservoir of shale gas is a kind of dense rock, which porosity and permeability are extremely low. These characteristics determined the shale gas development is very difficult. The technology SRV proposed by the United States is one of the main stimulation techniques now. The principle of SRV is through a series of hydraulic fracturing techniques to create maximum fracture network system in the area of the oil and gas reservoirs, collecting more shale gas resources [3-5]. Chinese researchers have proposed the "Volume Fracturing", which is similar to SRV technology. It aims to increase oil and gas production by using multi-stage segment slippery water fracturing in horizontal wells [6]. During the fracturing process, a net increase pressure will create tensile fractures and shear fractures in the shale reservoirs [7]. In this situation, the conventional Two-winged fracture is no longer formed, instead of forming artificial cracks, micro-cracks and natural fracture network. These fractures communicate with each other to form a complex connection, which greatly increased the volume of fractures. The morphology distribution of crack can get through micro-seismic events mapping [8]. The author have done a lot of research, and summarized the principles and methods of SRV, which will help to optimize the performance of the oil and gas.

II. MODEL OF SRV

The description on current SRV models are still in theoretical hypothesis stage, the role of the model is only used to verify the production, but cannot be used to forecast the production. Figure 1 is a well known physical model on SRV in horizontal wells [9]:

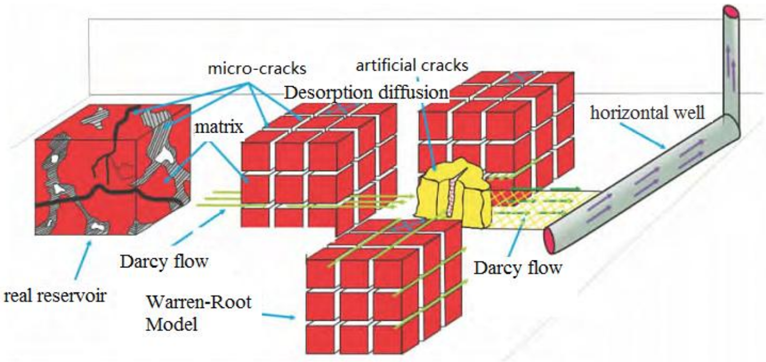

Fig.1 Physical model on SRV about shale gas

The model is obtained in an idealized station; the actual structure of the reservoir fracture network cannot be regularly arranged. The presence of natural fractures in the reservoir showed a random distribution, and therefore, the volume of fracture network is also an irregular network system. To sum up, the accuracy of the model should be discussed.

III. THEORETICAL BASIS ON SRV

The essence of the fracturing is the destroyed of the rock, there are two forms of the process of making fractures: new cracks initiation and the original cracks reopen. New crack initiation can be divided into tensile failure and shear failure, the original crack reopen divided into natural and artificial crack restart. This article assumes that the reservoir depth is deep and the well is horizontal and completed. In this situation, the in-situ stress is $\sigma_1 > \sigma_2 > \sigma_3$, which σ_1、σ_2、σ_3, represents the vertical stress, maximum horizontal stress and the minimum horizontal stress.

New cracks will produce when the net pressure in the well reaches a critical condition. The theoretical criterion ruptures criteria [10] as follows:

Tensile failure criterion only considered tangential stress at the well, usually follow the maximum tensile stress criterion:

$$
\begin{aligned}
p_{inj} &= \frac{(\sigma_2+\sigma_3)-(\sigma_2-\sigma_3)^2/8\sigma_t}{2} \qquad & \sigma_t < \frac{(\sigma_2-\sigma_3)}{4} \\
p_{inj} &= \sigma_3+\sigma_t & \sigma_t > \frac{(\sigma_2-\sigma_3)}{4}
\end{aligned} \tag{1}
$$

In this formula, P_{inj} represents the bottom of the injection pressure, σ_2 represents the maximum horizontal stress, σ_3 represents the minimum horizontal stress and σ_t represents the tensile strength of rock.

Shear fracture criterion follows Moore Coulomb:

$$
p_{inj} = \frac{[1+\sin(\theta/2)-m+m\cdot\sin(\theta/2)](L_f/2r)^{1/2}\cos(\theta/2)\sigma_3-\sigma_c}{1-m+[1+\sin(\theta/2)-m+m\cdot\sin(\theta/2)](L_f/2r)^{1/2}\cos(\theta/2)} \tag{2}
$$

Which $m=\tan^2\alpha$, $\alpha = 45^\circ + \varphi/2$, (r,θ) is the original point near the artificial fracture fracturing polar coordinates. ϕ is the angle of internal friction, σ_c is uniaxial compressive strength of the rock, L_f is the initial half-length about artificial fracture.

Cracks in the reservoir can be divided two classes, natural fractures and artificial cracks. When the inner net pressure reaches to the critical value, the original crack will reopen.

Natural fractures restart critical pressure [11]:

$$p_{nat} = \frac{\sigma_2 - \sigma_3}{1 - 2\upsilon} \tag{3}$$

υ is the Poisson's ratio of the rock.

The artificial crack restarts condition:

$$p_{hum} = \sigma_3 \tag{4}$$

During the process of the crack reopening, it is important to let the new artificial vertical fractures normal to the original fracture orientation. This can increases the fracture network greatly.

Through SRV technique, we can get a complex fracture network in the reservoir. It asks the cracks extend as possible as along the nature fractures. From the article [12-15], we can get the conclusion that, the bigger $\Delta\sigma = \sigma_H - \sigma_h$, the easier to form Two-winged fractures. Article [16] gave the concept of induced stress field, as it shows in Fig.2.

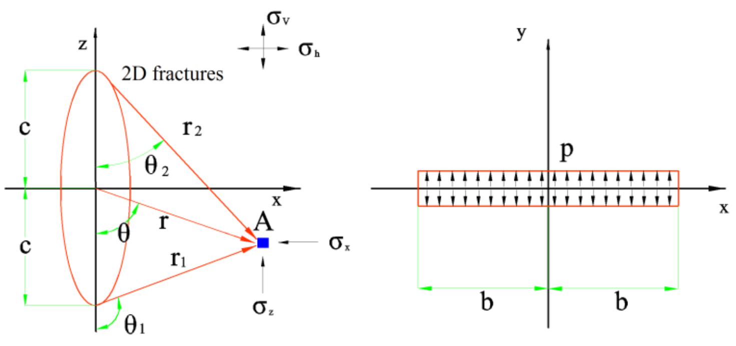

Fig.2 Sketch of 2D fractures

The induced stress caused by fractures on point A is

$$\sigma_x = p\frac{r}{c}\left(\frac{c^2}{r_1 \cdot r_2}\right)^{3/2} \sin\theta \cdot \sin\frac{3}{2}(\theta_1 + \theta_2) + p\left[\frac{r}{(r_1 \cdot r_2)^{1/2}}\cos\left(\theta - \frac{1}{2}\theta_1 - \frac{1}{2}\theta_2\right) - 1\right] \tag{5}$$

$$\sigma_z = -p\frac{r}{c}\left(\frac{c^2}{r_1 \cdot r_2}\right)^{3/2} \sin\theta \cdot \sin\frac{3}{2}(\theta_1 + \theta_2) + p\left[\frac{r}{(r_1 \cdot r_2)^{1/2}}\cos\left(\theta - \frac{1}{2}\theta_1 - \frac{1}{2}\theta_2\right) - 1\right] \tag{6}$$

$$\tau_{xz} = p\frac{r}{c}\left(\frac{c^2}{r_1 \cdot r_2}\right)^{3/2} \sin\theta \cdot \cos\frac{3}{2}(\theta_1 + \theta_2) \tag{7}$$

We can get the formula by Hooke's law:

$$\sigma_y = \upsilon(\sigma_x + \sigma_z) \tag{8}$$

p represents the pressure of the crack surface, MPa; c represents the fractures' half-height, it equals to $H/2$, m. The value of the induced stress will decrease with the increasing distance from the fracture surface. Figure 3 can prove it [17].

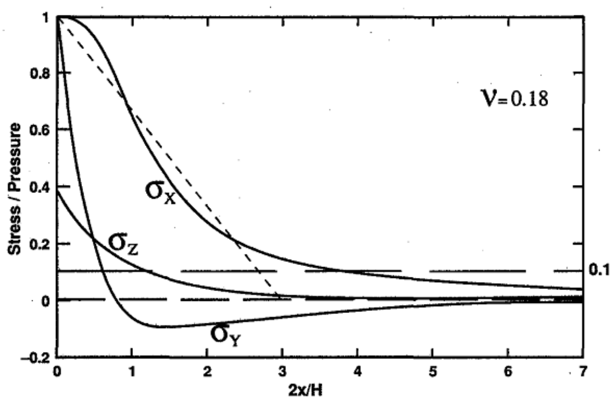

Fig.3 Induced stress decreases with increasing distance from the fracture surface

In Fig 3, $Stress/\Pr essure$ expressed by the dimensionless function, $\Pr essure$ is the net pressure in crack, the horizontal axis represents the dimensionless function $2x/H$.

We can get the approximate liner expression through the dash:

$$\frac{\sigma}{\Delta p} \approx -\frac{x}{3c} + 1 \tag{9}$$

The relationship between the initial seam maximum width ω_0 and the net pressure Δp are:

$$\omega_0 = \frac{4\left(1-\upsilon^2\right)}{E}\Delta pc \tag{10}$$

Through formula (9) and (10), we can get the conclusion that:

$$\sigma_x \approx \left(-\frac{x}{3c}+1\right)\left(\frac{\omega_0 E'}{4c}\right) \quad , \quad E' = \frac{E}{1-\upsilon^2} \tag{11}$$

So, we can get the induced stress through the form of the initial cracks.

Under the influence of the initial stress and the induced stress, we can get a synergistic stress field. The stress on the size of the two principal stress directions are $\sigma_2 + \sigma_y$ and $\sigma_3 + \sigma_x$. SRV requires of both collaborative fracturing stress difference is small enough, or equal to zero.

$$\Delta\sigma = \sigma_2 + \sigma_y - \left(\sigma_3 + \sigma_x\right) \tag{12}$$

As can be seen from Figure 3, σ_y approaches to zero, collaborative stress field mainly effected by σ_x. And through the formula (11), we know, σ_x is a function of the initial crack fracture height and width.

IV. CONSTRUCTION PROCESS

First fracturing, we can measure the magnitude and direction about in-situ stress, then use formula (12) to estimate the required maximum induced stress value. Use formula (10) and (11) to calculate the height and width of the crack. Through the date, we can optimize the size of the crack to change the stress near the well.

Second fracturing, the stress has changed. Because of the stress' anisotropy is low at this time, when the fracture crack initiation and crack extending along the near wellbore area in many different directions, and as distance increases, the impact of induced stress is reduced, the secondary cracks will slowly turn, extends in the direction of initial crack, forming a plurality of substantially parallel slits, due to crack interaction, there will be many small parallel slits between seam communication, finally to form a network structure and increase the control area of cracks. Simultaneously injecting a large amount of fracturing during high fluid loss, high elasticity, lightly gelled liquid to explore natural fractures, while using a suitable size and particle size as a proppant sand embankment medium, so that the exposed surfaces of the cracks produced more high pressure, so that the fracturing fluid and sand into the cracks of those subsequent open until the bottomhole pressure changes show cracks already overextended. Its ultimate aim is to form a network of cracks, thereby improving the formation of seepage area.

V. SUMMARY

(1) The development of shale gas is important to energy structure.

(2) It is realizable to achieve the formation of cracks in the network extends by the synergistic between inducing stress field and the initial stress field.

(3) The nature of SRV is to destroy rocks in the reservoir. This paper analyzes the basic criterion about SRV during rock destroys and gives the corresponding reference formula. In a sense, provide theoretical support for the SRV.

(4) Although the SRV technology is developing rapidly, but there are still many problems, such as the formation of cracks in the network volume, fracturing technology. The author will continue to focus on these issues in the future.

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