ISSN: 2664-9640

Study on Distribution of Multi - cluster Perforating Proppant in Horizontal Well

Tao Wang [1], Yanxu Luo [2]

[1] Sulige Gas Field Branch of CNPC Great Wall Drilling Engineering Co., Ltd, China

[2]Southwest Petroleum University, China

Abstract

In order to improve the operation efficiency of horizontal well fracturing, it is usually necessary to perform multiple clusters perforation in each fracturing section, and then press multiple fractures at the same time in each section according to the limited flow fracturing method. Due to the differences of reservoir physical properties, in-situ stress and induced stress between fractures, the propagation velocity of fracturing fractures between different clusters is different. At the same time, due to the different fracture propagation velocity and fracture location, the fracturing fluid and support dose entering the fracturing fracture from different perforation clusters are different. The study on the diversion, migration and distribution of hydraulic fracturing proppant in multi-cluster fracturing fractures can provide theoretical support for the optimization of fracturing technology and fracturing materials, and the optimization of fracturing construction parameters, so as to improve the fracturing effect. Based on the liquid-solid two-phase flow model of proppant established by predecessors, the flow of proppant in fracturing fluid of tight reservoir is turbulent, and the k ~ ε turbulence model is used to deal with it. Considering the dynamic flow distribution of fracturing fluid between clusters, the finite volume method is used to solve it. The difficulties in the study of proppant distribution in horizontal well staged multi-cluster perforation are prospected and summarized.

Keywords

Segmented clusters;Invalid perforation; dynamic distribution of traffic; proppant transport;CFD; liquid-solid two-phase flow.

1. Introduction

Currently, through horizontal well drilling and completion technology and hydraulic fracturing technology, we have achieved cost-effective development of unconventional oil and gas resources that are often characterized by low porosity and low permeability. In order to improve the operation efficiency of horizontal well fracturing and reduce the construction cost, it is necessary to reduce the number of fracturing sections in the horizontal well section as much as possible. Usually, multiple clusters (2-6 clusters) of perforation are carried out in each fracturing section, and then according to the limit The flow fracturing method can simultaneously extrude multiple fractures in each section [1]. However, many field production logging data show that the production varies greatly among different perforation clusters in the staged fracturing of horizontal wells. Part of the production comes from 20% to 30% of all perforation clusters [2]. At present, it is believed that there are two main reasons for this phenomenon: one is due to the heterogeneity of the reservoir along the horizontal well axis;

At present, there are many studies on the simultaneous propagation of multiple fractures, but they all assume that the ratio of fracturing fluid and proppant entering different fractures is the same. The proppant is not easy to "turn" into the fracture from the horizontal wellbore, which

ISSN: 2664-9640

will lead to the inconsistency between the proportion of proppant accepted in different fractures and the distribution ratio of fracturing fluid. Considering that after the fracture is closed, the research on the distribution law of proppant in complex fractures is relatively difficult. It is difficult to quantitatively characterize the non-uniform distribution of proppant [3]. There are few studies on how to improve proppant entry into branched fractures, and the research on the non-uniform distribution of proppant in each fracturing cluster in horizontal well staged multi-cluster fracturing technology is still in its infancy. The migration distribution of proppant in the simultaneous propagation of multiple fractures is studied to better optimize the fracturing design.

2. Research status of proppant migration in perforated staged fracturing

At present, domestic and foreign scholars have carried out some studies on the influence of perforation parameters on proppant shunting and migration, including perforation parameters and injection displacement and other construction parameters on the perforation perforation of a single cluster of perforation at different positions and the support between perforation clusters The effect of dose shunting. In the case of single-cluster helical perforation in a horizontal well, if the flow rate at the outlet of each hole is the same, due to subsidence, the proppant is more likely to enter the fracturing fractures communicated with the perforation holes below the horizontal wellbore, while the proppant enters the upper part of the horizontal wellbore and the horizontal two Side perforations are difficult.

Daneshy[4] believed that in the process of limiting flow fracturing in horizontal wells, although the fracturing fluid flow between each perforation cluster is distributed according to the design, because the proppant is denser than the fracturing fluid, its momentum is also larger. , which makes it difficult for it to turn into the fracture at the perforation hole when it migrates in the horizontal wellbore, thus causing the non-uniform distribution of proppant among different perforation clusters.

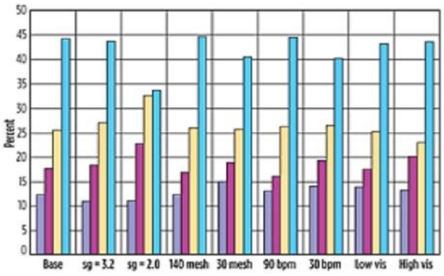

Figure 1 Numerical simulation results of Daneshy

WeiYu[5] and others believed that the uniform distribution of proppant and the maintenance of fracture conductivity are the preconditions for realizing the economic development of shale gas, but in fact, it is difficult to achieve the above two points due to the settlement, embedding and fragmentation of proppant.

Atul Bokane[6] et al. used CFD technology to study the proppant transport distribution among different perforation clusters in a single perforation section. The effects of fracturing fluid viscosity and construction displacement on proppant distribution were verified, and the numerical simulation results and physical experimental results were verified, which would help to better understand the distribution behavior of fracturing fluid and proppant between multi-perforated clusters.

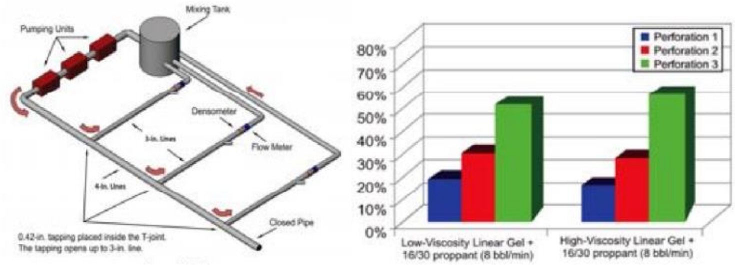

Figure 2 Crespo's experimental setup and experimental results

3. Selection of fracturing fluid flow model and sand-carrying fluid model for staged multi-cluster fractures

3.1. Fracturing Fluid Flow Model

When performing multi-cluster fracturing in a horizontal well section, the flow distribution between clusters is a dynamic process, so a dynamic distribution model of fracturing fluid needs to be established. The flow of fracturing fluid in a horizontal wellbore is shown in Figure 1, ignoring the wellbore storage effect, and the total displacement of fracturing fluid is equal to the sum of the flow rates entering each fracture[6]

$$Q_{\mathrm{T}}(t)=\sum_{i=1}^{2N}Q_i(t) \tag{1}$$

According to Kirchhoff's theorem, the pressure of fracturing fluid at the root of the wellbore is equal to the sum of fracture pressure, perforation pressure drop, and wellbore friction[22], namely:

$$p_{\mathrm{w}}=p_{\mathrm{fw},i}+p_{\mathrm{pf},i}+p_{\mathrm{f},i} \tag{2}$$

The fracture pressure pfw,i can only be obtained by solving the fluid flow equation in the fracture. Since the fracture width is extremely small relative to the fracture length, it can be assumed that the fracturing fluid in the fracture is a one-dimensional flow along the direction of the fracture length, and the flow equations of the fracturing fluid in the fracture can be expressed as:

$$\begin{gathered}\frac{\partial p(s,t)}{\partial s}=-2^{n+1}\left[\frac{(2n+1)q(s,t)}{nH}\right]^n\frac{K}{w(s,t)^{2n+1}}\\-\frac{\partial q(s,t)}{\partial s}=\frac{2Hc_{\mathrm{t}}}{\sqrt{t-\tau(s)}}+H\frac{\partial w(s,t)}{\partial t}\end{gathered} \tag{3}$$

3.2. Solid-liquid two-phase flow model and sand-carrying liquid model

3.2.1 Fluid governing equations

The continuity equation is:

$$\frac{\partial}{\partial t}(\alpha_1\rho_1)+\nabla\cdot(\alpha_1\rho_1v_1)=0 \tag{4}$$

$$\frac{\partial}{\partial t}(\alpha_s\rho_s)+\nabla\cdot(\alpha_s\rho_sv_s)=0 \tag{5}$$

The momentum conservation equation is:

$$\frac{\partial}{\partial t}(\alpha_1\rho_1v_1)+\nabla\cdot(\alpha_1\rho_1v_1v_1)=-\alpha_1\nabla p_1+\nabla\boldsymbol{\tau}_1+\alpha_1\rho_1g+\beta(v_{\mathrm{s}}-v_1) \tag{6}$$

$$\frac{\partial}{\partial t}(\alpha_{\mathrm{s}}\rho_{\mathrm{s}}v_{\mathrm{s}})+\nabla\cdot(\alpha_{\mathrm{s}}\rho_{\mathrm{s}}v_{\mathrm{s}}v_{\mathrm{s}})=-\alpha_{\mathrm{s}}\nabla p_{\mathrm{s}}+\nabla\boldsymbol{\tau}_{\mathrm{s}}+\alpha_{\mathrm{s}}\rho_{\mathrm{s}}g+\beta(v_1-v_{\mathrm{s}}) \tag{7}$$

Turbulence equation, the influence of turbulence is described by the k-ε turbulence model. The governing equations of this model include the turbulent dissipation rate ε equation and the turbulent kinetic energy k equation, namely:

$$\frac{\partial}{\partial t}(\alpha_1\rho_1 k)+\nabla\cdot(\alpha_1\rho_1 v_1 k)=\nabla\cdot\left(\alpha_1\frac{\mu_1}{\sigma_{\mathrm{k}}}\nabla k\right)+G_{\mathrm{k},1}+\Pi_{\mathrm{k}}-\alpha_1\rho_1\varepsilon \tag{8}$$

$$\frac{\partial}{\partial t}(\alpha_1\rho_1\varepsilon)+\nabla\cdot(\alpha_1\rho_1 v_1\varepsilon)=\nabla\cdot\left(\frac{\alpha_1\mu_1}{\sigma_\varepsilon}\nabla\varepsilon\right)+\alpha_1\frac{\varepsilon}{k}\left(C_{1\varepsilon}G_{\mathrm{k},1}-C_{2\varepsilon}\rho_1\varepsilon\right)+\Pi_\varepsilon \tag{9}$$

3.2.2 Interphase Force Equation

In the liquid-solid two-phase flow model, the liquid phase transmits various forces to the solid phase, including drag force, pressure gradient force, buoyancy force, etc. This paper mainly considers the large buoyancy and drag force of the fracturing fluid on the low-density proppant, and the virtual mass force generated by the particle phase on the fluid phase due to the accelerated motion.

The interphase momentum transfer term is:

$$M_{\mathrm{k}}=F_{\mathrm{D}}+F_{\mathrm{VM}}+F_{\mathrm{L}} \tag{10}$$

The drag force is based on the momentum exchange between the solid and liquid phases, using the Gi-daspow model, which is suitable for dense fluidized bed simulations and is also used in the proppant placement process. Momentum exchange coefficient β between liquid-solid two phases [7]:

$$\beta=\begin{cases}\dfrac{3}{4}C_{\mathrm{D}}\dfrac{\rho_1\alpha_1\alpha_{\mathrm{s}}\left|v_1-v_{\mathrm{s}}\right|}{d}\alpha_1^{-2.65} & \alpha_1\geqslant 0.8\\[2ex] \dfrac{150\alpha_{\mathrm{s}}(1-\alpha_1)\mu_1}{\alpha_1 d^2}+\dfrac{1.75\rho_1\alpha_{\mathrm{s}}\left|v_1-v_{\mathrm{s}}\right|}{d} & \alpha_1<0.8\end{cases} \tag{11}$$

4. Fracture model and simulation scheme

In unconventional reservoirs, volume fracturing is usually used to form complex fracture networks. This fracture physical model is based on the common 3T fracture network shape, and the analysis results of the numerical model fracture geometry based on fluid dynamics theory. Through the similarity principle The actual hydraulic pressure fracture is converted to ensure that the inlet linear velocity of the fluid in the fracture is consistent, so as to obtain the geometric size of the model fracture converted in equal proportions. Using the similarity criterion, a three-dimensional seam mesh model with a main seam length of 2m, seam height of 0.6m and seam width of 5mm was established. Three equidistant inlets are set at the left boundary of the geometric model as the inlets for fracturing fluid and low-density proppant particles, and the right end and the boundary of the branch fractures are set as the drainage outlets. The model is divided by a full hexahedral mesh. The injection boundary is set as the velocity inlet, the outflow boundary is the pressure outlet, and the no-slip boundary condition is satisfied. The finite volume method is used to solve the problem and the Simple algorithm is used to couple pressure and velocity. The discrete format is the second-order upwind style. The inlet boundary condition is used for initialization, the fracturing fluid integral in the fracture model is 100%, the control equation discrete format adopts the first-order upwind style, and the convergence standard is that each residual is less than 10-4. Combined with the dynamic distribution of flow between fractures, that is, considering the real fracturing process of one stage of multi-cluster fracturing, the proppant amount and proppant concentration entering each stage of fractures. The non-uniform distribution of proppant is studied by studying the characteristics of proppant volume concentration distribution, pressure field and flow field in fractures [8-9].

The process of sand bank formation under different conditions is simulated by numerical calculation, and the placement of proppant in complex fractures is compared and analyzed using the control variable method for fracturing fluid displacement, sand ratio, proppant density and perforation parameters. The scheme is as follows:

4.1. Effects of Fracturing Fluid Displacement

Reservoirs use low-viscosity fracturing fluids for high-displacement construction operations that increase fracture complexity. According to the research of scholars at home and abroad, the established mathematical model and the actual fracturing displacement can be processed by the Reynolds similarity principle, that is, to ensure that the linear velocity of particles entering the fracture remains the same. It is calculated by the following formula [10]:

$$v = \frac{q_f}{Hf \times wf \times 2} \tag{14}$$

Assume that the fracture height is 30m and the fracture width is 5mm; the construction displacement of the tight gas fracturing site is generally 8-16 m3/min, and the calculated linear velocity is 0.5m/s-1.2 m/s. The inlet linear velocities were selected as 0.5 m/s, 0.8 m/s, 1.2 m/s and 2 m/s respectively to analyze the influence of fracturing fluid displacement on proppant migration.

4.2. Effect of proppant density

According to the Stokes settlement equation, the proppant density directly affects its vertical force in the fracture. The greater the density, the greater the density difference with the fracturing fluid, and the more obvious the effect of gravity. The study of proppant density is of great significance to the distribution law of proppant in reservoir fractures and the selection of proppant. The model is calculated using the true density of proppant particles to analyze the density difference between the particle and the fluid, which ranges from 2650-3600 kg/m3. The distribution characteristics of proppant in fractures were studied when the true densities of proppant were 2600kg/m3, 2900 kg/m3, 3300 kg/m3 and 3600 kg/m3

4.3. Influence of perforation parameters

Horizontal wells are mainly completed with casing, and the proppant enters the horizontal wellbore and enters the fracturing fractures through perforation holes. Since the shape and size of the horizontal wellbore are relatively fixed, the factors affecting the migration of proppant in the wellbore are mainly perforation parameters, including the number of channels and pore diameter. 3 or 5 channels for simulation.

5. Summary and Outlook

The migration of proppant in the actual formation is more complicated, and there are still many aspects that need more in-depth research:

(1) The diversion, migration and distribution of proppant in fracturing fractures are comprehensively affected by multiple factors such as construction parameters, fracturing fluid performance parameters, proppant parameters, perforation parameters and fracture morphological parameters. Volume, fracturing fluid viscosity, proppant particle size and density, and fracture morphology are the main factors affecting proppant flow, migration and distribution. At present, domestic and foreign scholars have little research on the dynamic distribution of fracturing fluid flow. It is recommended to introduce this method. Considering other aspects, the situation of proppant migration in the actual fracture shape in the field is obtained by simulating different construction parameters and physical parameters;

(2) It is suggested that the subsequent physical experimental model can consider the influence of fracturing fluid filtration, rock wall roughness and confining pressure on proppant migration, so as to make the simulation closer to the real situation of the formation;

(3) The migration and placement of proppant is an extremely complex process. It is recommended to carry out more research on the microscopic mechanism of proppant migration, such as: after proppant enters fractures, the flow direction distribution of multi-particle proppant, Mutual interference between multi-particulate proppants, etc.

References

[1] Xu Dongjin, you Yanrong, Wang Shengliang, et al. Status and progress of staged fracturing technology for horizontal wells in tight reservoirs [J]. Sino foreign energy, 2013, 18 (04): 36-41

[2] Meyer B R, Bazan L W. A discrete fracture network model for hydraulically induced fractures theory, parametric and case studies. In: SPE Hydraulic Fracturing Technology Conference. The Woodlands: Society of Petroleum Engineers, 2011.

[3] PAN Linhua, ZHANG Ye, CHENG Lijun, et al. Migration and distribution of complex fracture proppant in shale reservoir volume fracturing[J]. Natural Gas Industry, 2018, 38(5): 61-70.

[4] Daneshy A. A. Numerical Solution of and Transport in Hydraulic Fracturing[J]. Journal of Petroleum Technology, 1978, 30(1):132-140.

[5] Yu W., Sepehrnoori K. Simulation of Proppant Distribution Effect on Well Performance in Shale Gas Reservoirs[C]. SPE167225. 2013.

[6] YI Liang ping. Study on initiation and propagation of multi cluster fracturing in horizontal wells of tight reservoir[Ph. D. Thesie][D]. Chengdu： Southwest Petroleum University， 2017.(in Chinese)

[7] Liu Pingli, Lei Feiyun, Li Jun, et al. CFD numerical simulation of sand laying law of single fracture under multi factor action [J]. Journal of Xi'an University of Petroleum (NATURAL SCIENCE EDITION), 2019, 34 (5): 86-90.

[8] SHI Yu. Research on the settlement and migration law of proppant in shale gas well hydraulic fracturing[D]. Xi'an: Xi'an Shiyou University, 2016

[9] KOU R, MORIDIS G J, BLASINGAME T A. Analysis and modeling of proppant transport in inclined hydraulic fractures [R]. SPE190148-MS, 2018: 25-36.

[10] XU Nuanzhu, XU Ning. Simulation of transport and sedimentation of proppant in fracture based on FLUENT[J]. Natural Gas and Oil, 2013, 31(3): 46-49.