

Prediction Method of Fracturing Pressure for Clean Water Sand-Carrying Fracturing in Horizontal Wells of Volcanic Reservoirs

Yue Xi

Xinjiang Oilfield Company, Karamay, Xinjiang, 834000, China

Abstract. To further reduce the operational risks of clean water sand-carrying fracturing in horizontal wells within volcanic reservoirs and better guide field operations, research on the prediction method for clean water fracturing pressure was conducted. Firstly, considering the energy dissipation caused by solid-liquid interaction, a calculation method for the frictional pressure loss of the clean water-sand two-phase flow in horizontal wellbores was established to calculate the frictional pressure loss under different working conditions. Secondly, parameters such as perforation friction and near-wellbore tortuosity friction were calculated. Consequently, a prediction method for the fracturing pressure of clean water sand-carrying fracturing in horizontal wells of volcanic reservoirs was developed. Field tests show that the calculated fracturing pressure using this method correlates well with the actual field pressure, with a calculation error $\leq 13.7\%$. The calculation accuracy is significantly improved, indicating that this method can effectively guide the design and field implementation of clean water sand-carrying fracturing.

Keywords: Clean Water Fracturing; Solid-liquid Phase Frictional Loss Ratio; Fracturing Pressure Prediction.

1. Introduction

The shallow Carboniferous volcanic reservoirs in District 9 of Xinjiang Oilfield are characterized by dense lithology, poor physical properties, and no natural productivity. Additionally, the reservoirs have shallow burial depth ($< 1000\text{m}$), high Young's modulus (28-35 GPa), and diverse natural fracture types (oblique fractures, straight cleavage fractures, network fractures, etc.), resulting in strong reservoir heterogeneity and weak water sensitivity. Previous fracturing using guar gum fracturing fluid was costly and caused post-fracturing residue damage. These reservoirs are suitable for clean water fracturing. However, due to the weak sand-carrying capacity, high fluid loss, and high operational pressure of clean water, its direct use as a fracturing fluid requires high-rate pumping conditions. To enhance the development efficiency of Carboniferous reservoirs, referencing the successful experience of clean water sand fracturing in reservoirs like shale gas, a feasibility study on clean water sand fracturing technology for horizontal wells in Carboniferous volcanic reservoirs was conducted[1-4].

Since sand-carrying capacity is improved via "velocity carrying", the solid-liquid two-phase flow regime is complex, making fracturing pressure prediction difficult. Therefore, a prediction model for clean water fracturing pressure was first established. The model calculates its component parameters to ultimately obtain the fracturing pressure. This calculated result is used to screen horizontal wells with operational feasibility, and the model's accuracy is verified against actual fracturing pressure[5-8]

2. Calculation of Clean Water Sand-Carrying Fracturing Pressure

Based on the characteristics of the fracturing process, a calculation model for fracturing pressure was established. This model can calculate the wellhead pressure P_{surf} during fracturing:

$$P_{surf} = S_h + P_{fric} + P_{net} + P_{pf} + P_{tort} - P_h \quad (1)$$

2.1 Calculation of Frictional Pressure Loss for Clean Water Sand-Carrying Flow

Commonly used formulas for clean water frictional pressure loss are mostly suitable for coarse particles or low-concentration sand-laden fluids, as shown in Table 1. However, proppants used in clean water fracturing are mostly small-sized (0.105-0.42mm), and sand ratios often exceed 30%. Therefore, existing frictional pressure loss formulas have poor applicability.

Table 1. Statistical table of common friction calculation methods

No.	Author	Principle and Applicable Conditions
1	Newitt	Semi-empirical formula, suitable for low-concentration sand-laden fluids
2	Fei Xiangjun	Derived from particle motion forms, suitable for low-concentration sand-laden fluids
3	Worster	Based on classification of bedload transport, suitable for coarse particles >2 mm
4	Babcock	Fitted from experimental data, suitable for coarse particles 0.35-0.66mm
5	Chen Guangwen	Derived by superimposing different loss scenarios; particle interference force and slurry limit concentration are hard to determine

During clean water fracturing, four working conditions exist within the tubing string, as shown in the figure below. 1) Pure Water Condition. Only liquid friction loss exists in the pipe. 2) Full Sand-Laden Fluid Condition. Both liquid friction loss and solid friction loss exist under this condition. 3) Sand-Laden Fluid Pushing Water and Displacement Conditions. These conditions are more complex, as two types of transport media coexist in the pipe: one part is water, the other is sand-laden fluid. Differences in parameters like density and concentration between water and sand-laden fluid result in significant differences in frictional losses between pipe sections carrying water and those carrying sand-laden fluid.

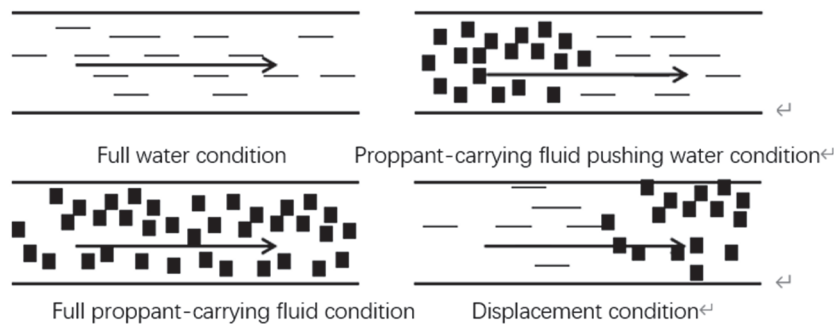


Fig 1. Schematic diagram of different fracturing stages in horizontal well

Because calculating solid phase friction loss is complex while liquid phase friction loss is relatively simple, to simplify the calculation process, Equations (2) and (6) were used to calculate the solid-liquid phase frictional loss ratio under different sand-laden fluid velocities and sand ratios. Figure 2 shows that at a constant sand concentration, as the sand-laden fluid velocity inside the pipe decreases, the relative velocity between solid and liquid phases increases. This leads to increased energy dissipation due to friction between sand particles and the liquid phase, causing the solid-liquid phase frictional loss ratio to rise. At a constant sand-laden fluid velocity, the solid-liquid phase frictional loss ratio increases with increasing sand concentration, indicating that solid phase friction loss increases as sand concentration rises.

Combining the four working conditions during fracturing operations, the proportion of sand-laden fluid volume within the pipe is determined. Equation (2) is used to calculate the liquid phase friction, Figure 2 is used to obtain the solid phase friction, and then the total frictional pressure loss along the flow path is calculated.

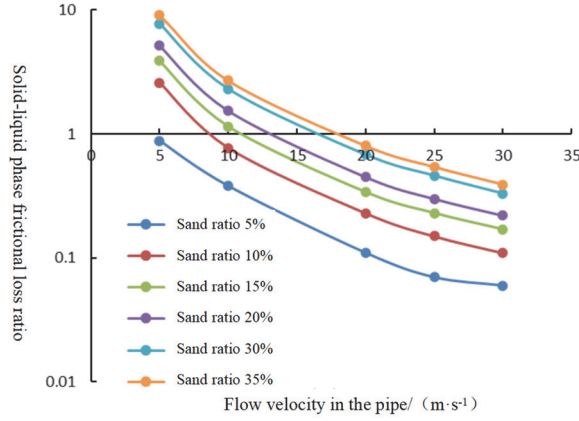


Fig 2. Friction loss ratio of sand carrying liquid-solid-liquid phase at different velocity and sand concentration

2.2 Calculation of Liquid Column Pressure

During fracturing operations, the sand concentration within the wellbore changes continuously. When calculating the hydrostatic pressure P_h , the hydrostatic pressure per unit length is calculated first, followed by the hydrostatic pressure for the entire wellbore. Due to the shallow burial depth of the target reservoir, temperature changes within the wellbore are minor, and their effect on fluid density is neglected in this calculation.

$$P_h = \sum_0^L \rho_{mix} g \Delta L \quad (2)$$

2.3 Near-Wellbore Friction and Net Pressure Calculation

During fracturing operations, near-wellbore friction includes perforation friction and near-wellbore tortuosity friction.

1) Perforation Friction Calculation

$$P_{pf} = \frac{2.2326 \times 10^{-4} Q^2 \rho_{mix}}{n^2 d^4 C^2} \quad (3)$$

2) Near-Wellbore Tortuosity Friction Calculation

$$P_{tort} = \gamma \lambda \beta \frac{4v^2 n'^{1/2}}{w_f^3} \left(\frac{E_p^3 \mu_p Q}{h_f} \right)^{0.5} \left[\frac{2}{S_H - S_h (1 - \cos 2\beta)} \right]^2 \quad (4)$$

3) Net Pressure Calculation

$$P_{net} = \left(\frac{16}{3\pi} \right)^{n'} 2^{n'+1} \left[\frac{(2n'+1)Q}{2n'h_f} \right]^{n'} \frac{KL_f}{\gamma_p w_f^{2n'+1}} \quad (5)$$

4) Fitted Calculation of Near-Wellbore Friction and Net Pressure

$$P_w = S_h + K_{pf} Q^2 + K_{nwb} Q^{0.5} + K_f Q^{n'} \quad (6)$$

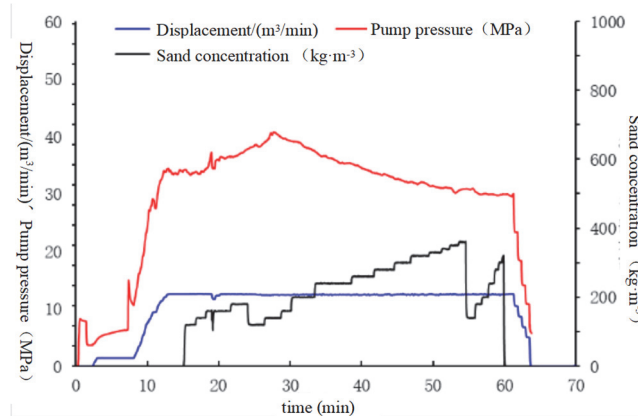


Fig 3. Construction curve of section 6 of well x1

Taking the actual operational data of Stage 6 in Well X1 as an example: This test well perforated 6 clusters per stage, using 3 holes per cluster, 120° phasing, and equal hole size. The calculation results using Equation (6) are shown in fig3 and Table 2.

Table 2. Parameter fitting results

Perforation Friction Coefficient	Near-Wellbore Bending Friction Coefficient	Fracture Geometry Coefficient
0.103	0.59	0.031

3. Validation Example

Actual operational data from clean water fracturing in horizontal wells was used to validate the fracturing pressure prediction model. The basic data for the test wells is shown in Table 3.

Table 3. Basic parameters of test well

Well	Tubing Length (m)	Tubing ID (mm)	Pump Rate (m ³ /min)	Proppant Properties (g/cm ³)	
				70/140Mesh Density/(g·cm ⁻³)	30/50Mesh Density/(g·cm ⁻³)
X1	1154	121.36	12-14	3.20	2.91
X2	1400	121.36	12-14	3.20	2.91

According to the calculation results, the predicted fracturing pressure under different working conditions correlates well with the actual pressure, with a calculation error $\leq 13.7\%$. The calculation accuracy meets the requirements for fracturing operations. The basic data for the test wells is shown in Table 4.

Table 4. Statistical table of construction pressure calculation error under different working conditions

Well	Stage	Avg. Actual Pressure /MPa	Avg. Predicted Pressure/MPa	Error/%
X1	Pure Water	21.9	22.5	2.7
	Sand-Laden Fluid Pushing Water	29.7	32.4	9.1
	Full Sand-Laden Fluid	29.4	32.3	9.9
	Displacement	26.3	29.9	13.7
X2	Pure Water	27.8	29.4	4.8
	Sand-Laden Fluid Pushing Water	33.7	36.7	8.9
	Full Sand-Laden Fluid	34.5	36.3	5.2
	Displacement	23.2	25.5	9.9
	Average Error			8.0

4. Conclusion

Combining different working conditions in horizontal well fracturing and considering energy dissipation caused by solid-liquid interaction, a calculation method for the frictional pressure loss of clean water-sand two-phase flow in horizontal wells was established. This method has no flow regime limitations and fully considers the heterogeneous flow characteristics caused by interphase slip.

At a constant sand concentration, as the sand-laden fluid velocity inside the pipe decreases, the relative velocity between solid and liquid phases increases, leading to greater energy dissipation from friction between sand particles and the liquid phase, causing the solid phase friction loss ratio to rise. On the other hand, at a constant sand-laden fluid velocity, the solid-liquid phase friction loss ratio increases with increasing sand concentration, indicating that solid phase friction loss increases as sand concentration rises, consequently increasing the total friction loss of the sand-laden fluid.

The wellhead fracturing pressure predicted using this method correlates well with the actual pressure, with a calculation error $\leq 13.7\%$. This method can be used to predict the fracturing pressure for clean water sand-carrying fracturing in horizontal wells.

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