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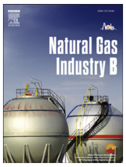

A new impulse-stage sand fracturing technology and its pilot application in the western Sichuan Basin

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Abstract

A better placement of proppants has been always the goal pursued in sand fracturing in order to get longer effective fractures and higher flow conductivity. However, it is always difficult to achieve satisfactory effects by conventional processes. On the basis of theoretical analysis and simulation with FracproPT software, basic experiments, and innovative physical modeling experiment, a new impulse-stage fracturing process has been developed by combining a special pumping process with fiber, liquid and other auxiliary engineering means. Compared with conventional fracturing, the open seepage channel created by the new fracturing process has an obvious edge in effective fracture length and flow conductivity. Moreover, the open seepage channel can also improve fracture cleanliness and reduce pressure loss in artificial fractures, thus reaching the goal of prolonging the single-well production time and maximizing productivity. After the research on principles and optimal design of this new process, on-site pilot test and detailed post-fracturing evaluation were conducted. The results indicated that (1) the new process is highly operable and feasible; (2) compared with the adjacent wells with similar geological conditions, the proppant' cost is reduced by 44%−47%, the ratio of effective fracture length to propped fracture length is increased by about 16%, the fracturing fluid recovery rate is up to 63% after 18 h in the test, and the normalized production is 1.9−2.3 times that of the adjacent wells; and (3) the new process can significantly lower the cost and enhance production. The process has a broad application prospect in shallow-middle sand gas reservoirs and shale gas reservoirs in western Sichuan Basin.

Keywords: Sichuan Basin; West; Sand fracturing; Proppant; Seepage channel; Impulse-stage sand fracturing; Flow conductivity; Cost; Efficiency

As early as the 1960s, demands on enhancing oil and gas reservoir productivity led to some practical measures taken to enhance fracture conductivity. Efforts in early stage focused on enhancing flow rate in proppant propped layers (actually, porous medium layers). Flow resistance shown in the form of pressure loss is the collective reflection of the following factors [1]: damages caused by residues left after flowback of low-quality fracturing fluid, migration of fine particles, multiphase flow, loss in fluid dynamics (β factor), resistance (throttle resistance), capillary force, crushing and embedding of proppants. To overcome these negative factors, a series of modifications have been adopted, such as application of gel breakers in fracturing fluid, wetting agents, energized fracturing fluid, clean fracturing fluid (polymer free), reduction of viscosifier concentration, enhancement of strength and sphericity of proppants, optimization of fracture parameter design to obtain larger fracture width and dozens of other measures. All these optimization measures have one objective: to make the layers propped with even proppants reach maximum theoretical flow conductivity. However, some post-fracturing assessment results show actual fractures generated have flow conductivity lower than expected, or in other words, these fractures have shorter effective fracture length than expected.

The newly developed impulse-stage sand fracturing process aims to create an open flow network within fractures to enhance flow conductivity significantly, thus making propped fracture

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layers cleaner and the pressure loss of fluid lower, and creating longer effective fracture half-length. All these would benefit the productivity of oil and gas wells in both short and long terms.

1. Principles of the new process

1.1. Theoretical foundations of the new process [2].

Is the theoretical permeability of open fracture channels higher than that of the layers propped with conventional proppant? This is the first question came to the authors' mind. In conventional hydraulic fracturing, fluid flow capacity in layers propped with proppant can be described by using the Darcy Formula, in which productivity is related to viscosity and pressure loss of the fluid, i.e.:

$$q = \frac{K_f w}{\mu} \frac{\Delta p}{L} \tag{1}$$

Where, q is volumetric flow rate in unit fracture height; K_f is permeability of the fracture, w is the width of layer propped by proppant; μ is fluid viscosity, $\Delta p/L$ is unit pressure loss.

The product of permeability and width of the fracture is commonly used to characterize flow conductivity of the fracture mentioned earlier. Under such circumstances, fracture permeability is a collective manifestation of the proppant used and the closure stress under which the proppant lives.

In the case of fluid passing thorough open channels without proppant, Navier–Stokes equations can be used to characterize the conductivity. Research results show that non-linear part of Navier–Stokes equations can be neglected under typical production conditions, so only the linear section of the equation is considered. The following flow equation can be obtained from the integration of 1D section of the Navier–Stokes equations.

$$q = \frac{w^2}{12\mu} \frac{\Delta p}{L} \tag{2}$$

Equation (2) represents the relationship between laminar flow rate and pressure loss in open channels. When Equation (1) is compared with Equation (2), effective permeability in open fracture channels can be defined as follows:

$$K_f^{\mathrm{eff}} = \frac{w^2}{12} \tag{3}$$

It can be seen from Equation (3) that even a relatively narrow seepage channel can be much higher in permeability than proppant propped layers. For example, a seepage channel of 1 mm wide has a permeability of 83,300 D, whereas layers with proppants of 20/40 meshes may provide flow conductivity of 400–500 D under closure stress of 27–35 MPa. It can be seen that effective permeability of open channels is two-order-magnitude higher.

1.2. Tests of flow conductivity in open seepage channels

1.2.1. Experimental devices and methods

Fig. 1. Experimental devices.

The experiment was performed on testing and analyzing system for fracture flow conductivity (Fig. 1), which is equipped with a conducting chamber and relevant auxiliary facilities conforming to API standards (API RP 61, 1989).

The volume of proppants required in each layer was calculated according to the area of conductor chamber. Then, the proppant was placed in two ways – conventional even placement and open seepage channel placement (Fig. 2). Flow conductivity and permeability under different closure stresses were tested.

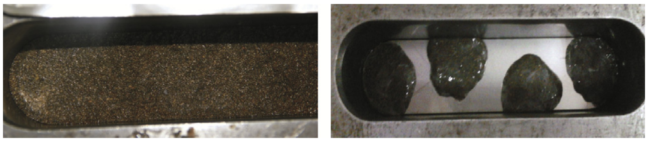

Fig. 2. Comparison of different proppant placement ways before experiment.

1.2.2. Results and discussions

If the unevenly distributed proppant masses forming the open seepage channels slip or move under closure stress, and fill up the entire free space (to make relevant results more persuasive, smooth steel plate was used in the experiment to simulate rough hydraulic fracture surfaces, in other words, the experimental condition was much harsher than real reservoir condition), flow conductivity and permeability measured under the same stress should be identical or similar. See Fig. 3 for the experimental results.

The experiment was conducted under the closure stress of 10–50 MPa. With proppant arranged in masses to form open seepage channels, the permeability and flow conductivity are 3–8 times and 4–9 times higher than that generated by evenly distributed proppant respectively. The experimental results indicate that proppant masses forming open seepage channels in a closure stress of 10–50 MPa were not pressed into a single layer, instead, the proppant maintained certain height during the closure of fractures and consequently provided favorable conditions to generate open channels with minor flow resistance. See Fig. 4 for proppant distribution after