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Research Article

Technical difficulties in the cementing of horizontal shale gas wells in Weiyuan block and the countermeasures☆

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Abstract

When well cementing is conducted in horizontal shale gas wells in Weiyuan block of the Weiyuan–Changning State Shale Demonstration Area, Sichuan Basin, the oil-based drilling fluid is not compatible with cement slurry, is difficult to be displaced because of its high density, and cement sheath tends to be broken in the situations of large-scale stimulated reservoir volume fracturing. In view of these problems, a series of studies were carried out specifically on the theoretical basis of cement sheath sealing mechanical parameters, oil-displacement preflush improving the interface cementation quality, toughness set cement satisfying large-scale fracturing requirements and cementing technology conducive to the wellbore integrity. The following achievements were made. First, the theoretical model of cement sheath mechanical integrity taking into account the plastic characteristics and interface cementation strength of cement sheath is instructive to the mechanical design of set cement for horizontal shale gas wells, avoiding the micro-annulus as much as possible. Second, oil-displacement preflush is developed and it is well compatible with oil-based drilling fluids and cement slurry with the flushing efficiency on oil-based drilling fluids higher than 90%. Third, the tough set cement which is developed based on the theoretical model of cement sheath sealing integrity not only guarantees higher compressive strength, but decreases Young's modulus by 30%. Forth, it is confirmed that water displacement cementing technology suitable for shale gas wells is conducive to improving the wellbore seal integrity. These research findings were applied in 12 horizontal wells. It is indicated that the quality cementing ratio of horizontal segment reaches 92% and the post fracturing effect is very good, which guarantees the sealing integrity of wellbores and provides a technical support for the highly efficient development of shale gas reservoirs.

Keywords: Sichuan Basin; Weiyuan–Changning State Shale Demonstration area; Weiyuan block; Horizontal shale gas wells; Wellbore integrity; Oil-displacement preflush; Toughening set cement; Theoretical model; Cementing

China has abundant shale gas resources. Compared with the United States, however, China encounters more difficulties in shale gas development, since shale gas reservoirs in China are significantly different from those in the United States in terms of geologic times, burial depth, preservation conditions, drilling difficulties and fracturing pressures. In view of geologic times, shale gas reservoirs in the United States are younger (predominantly marine formations formed in Upper Paleozoic and Mesozoic, with relatively stable geologic structures), whereas those in China are older (with relatively more active geologic structures and more complicated accumulation patterns). Moreover, shale gas reservoirs reflect a burial depth of 1000–3500 m, smaller drilling difficulties and fracturing pressure of 50–70 MPa in the United States, and a burial depth of 1500–5000 m, greater drilling difficulties and fracturing pressure of 60–100 MPa in China. With large well depth, high temperature & pressure and high fracturing

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pressure, shale gas wells in China may present higher requirements for cementing operations, and higher challenges to ensure wellbore integrity [1]. As to cementing techniques for shale gas wells abroad, conventional surfactants, emulsification, nanometer emulsification, multiple emulsification and other preflush systems have been developed and extensively deployed in fields as high-efficiency preflush for oil-based drilling fluids. As to cement slurry systems for shale gas wells, a toughening inflatable cement slurry system (ElastiCem Cement of Halliburton, Flexstone of Schlumberger and DuraSet of BJ), foam cement system (Automated Foam Cement of BJ Services), acid-soluble cement system, and anti-channeling cement slurry system have been developed. As to cementing techniques for horizontal shale gas wells, specific software for cementing operations have been developed to ensure casing centralization under different positioning conditions of centralizers, to maintain sufficient displacement efficiency under different slurry flow rates, and to simulate and optimize wellhead pressures and annular pressures in different working stages. Generally, shale gas exploration and development are still in their initial stages with relevant cementing technologies still under development. To ensure high-efficiency development of shale gas, systematic studies should be performed on cementing technologies for shale gas wells in view of the technical bottlenecks in horizontal shale gas well cementing.

1. Technical difficulties in cementing operations and factors affecting wellbore integrity of horizontal shale gas wells

Geologic characteristics of shale gas reservoirs and development objectives to enhance individual well productivity jointly determine the technical features in drilling and completion of horizontal shale gas wells. Reversely, geologic features and technical features in drilling and completion operations determine the difficulties in cementing operations for shale gas wells.

Geologic features of shale gas wells may make their cementing operations difficult in the following aspects. First, in the Weiyuan block, shale gas formations have high pressures and poor fracturability. In addition, high fracturing pressure may usher in significant challenges to wellbore sealing in later stages. Second, with thin sheet beddings, shale reservoirs have outstanding anisotropic features such as strengths and Poisson's ratios. Consequently, shale formations are characterized by extremely high water sensitivity and susceptible to collapsing. Under such circumstances, it is difficult to install casing and to maintain high displacement efficiency in cementing operations.

Specific features in drilling and completion of shale gas wells may bring the following technical challenges [2–13]. First, long horizontal sections (1500–2000 m) in shale formations make installation and centralization of casing extremely difficult. Second, since shale formations are characterized by difficulties in side-wall stability and reservoir protection, oil-based drilling fluids are extensively deployed in shale formation drilling. With high viscosity and strong adhesive capacity, oil-based drilling fluids can hardly be flushed and displaced by conventional water-based preflush. In addition, cement slurry and oil-based drilling fluid are incompatible. If the oil-based drilling fluid cannot be effectively displaced, a water-wet surface would not occur between the sidewall and the casing wall. In this case, cementation performances of the cement sheath on the primary and secondary interfaces may be compromised significantly and eventually generate unfavorable conditions for reservoir stimulation in later stages. Third, volume fracturing deployed in shale gas wells may present high demands of mechanical properties of the cement sheath. Under high fracturing pressure, temperature changes in wellbore during fracturing may negatively affect the collapsing strength of the casing. Consequently, possibility of casing failure may be increased. Since the sealing capacity of cement sheath is highly dependent on the burst strength of the casing, higher fracturing pressure may bring significant problems related to casing deformation and abnormal pressurization in annulus. And forth, cementing operations in shale gas wells may involve high pressures in freshwater displacement. Cementing facilities with higher pressure ratings should be deployed. Consequently, higher requirements for auxiliary cementing tools may be presented. For example, floating collars with high resistance to reverse pressures and abrasion-proof rubber plugs should be used.

2. Key techniques for horizontal shale gas well cementing

2.1. Theoretical model for the integrity of cement sheath sealing

During the fracturing and production of shale gas wells, failure in sealing capacity of cement sheath may include damages in the cement sheath due to tensile or shearing forces. Besides, high pressures during fracturing and pressure release after fracturing may also generate micro-annulus on the primary interface (cement sheath–casing interface) or the secondary interface (cement sheath–wall rock interface).

For an analysis of the cement sheath integrity during the fracturing and production of shale gas wells, a combined mechanical model considering the plastic properties of the cement sheath and the cementing strength of interfaces was developed [14] (Fig. 1). By simulating the ups (during loading) and downs (during unloading) of casing pressures during hydraulic fracturing and other operations, root causes for the generation of micro-annulus were analyzed. In addition, the theoretical formula used to determine the sizes of micro-annulus on interfaces under variable internal pressures were derived. Damages on cement sheath, together with the development of micro-annulus on the primary and secondary interfaces, were clarified. In this way, the integrity of the cement sheath was analyzed during the entire fracturing process. Moreover, integrity simulation test data for the combination specified in Ref. [15] was used to verify the results obtained by using the model.