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Investigation of casing deformation during hydraulic fracturing in high geo-stress shale gas play

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ABSTRACT

A total of 101 wells in the Changning-Weiyuan shale gas play (Sichuan Basin of China) had been drilled and stimulated by the end of March 2016, including 11 vertical wells and 90 horizontal wells. Casing deformation is one of the more difficult problems that occur during the reservoir hydraulic stimulating process. Especially for horizontal wells, the casing deformation rate was up to 30% (30 wells of 90). Based on the characteristics of the cementing process in shale reservoir horizontal wells and combined with the APB (Annular Pressure Buildup) effect in conventional wells, both physical models and finite element models were established. Many factors, such as the void angles, temperature change, magnitude of the inner pressure and in-situ stress were investigated. The results show that (1) in the process of high-flow-rate hydraulic fracturing, the retention fluid in the cement voids contracted due to sudden temperature decrease inside the casing. Consequently, the pressure dropped inside the cement sheath voids. In particular, tight shale reservoirs have an extremely low permeability and cannot supplement the pore pressure within a short time. Finally, the casing was placed in a non-uniform external supporting situation. On the other hand, the results show that (2) a high pumping pressure was needed in a high geo-stress shale block to fracture the formation, inducing a higher internal pressure inside the casing. Lastly, (3) under the combined effect of high internal pressure and non-uniform external support, the downhole casing has a high risk of deformation. The cement voids pressure decline (CVPD) effect might be the main reason behind the casing deformation in this high geo-stress shale gas play. Rotating the casing string during the cementing process to avoid the cement voids forming or using warm fracturing fluids to minimize the pressure drop inside the voids are possible innovative strategies to solve these difficult problems.

1. Introduction

Shale gas, a typical component of marginal oil and gas resources, is characterized by low porosity and low permeability and can only be commercially exploited through fracture stimulation (Olson and Taleghani, 2009; Abass et al., 1996; Ge et al., 2013; Meyer and Bazan, 2011; Xu et al., 2009; Wu et al., 2014; Chen et al., 2015). However, during the volume fracturing process, the casing must endure the internal fluid pressure and abrupt temperature change, especially in the areas where geo-stress is high and the operation internal pressure is up to 80–90 MPa (downhole pressure), where casing deformation and damage problems become very prominent. As a result of casing damage, the bridge plugs have a difficult time passing the deformation section for further fracturing operations.

For conventional oil and gas development, casing deformation problems are common, and generally, casing deformation is considered to be caused by the following reasons: (Peng et al., 2007; Huang and Gao, 2015; Wang et al., 2011) (1) an unreasonable casing string design, especially in salt-gypsum rock and mudstone (shale) formations, where the downhole casing is not strong enough; (2) low casing strength induced by perforation, which accelerates casing deformation; (3) corrosion and erosion degenerating the casing strength; (4) sand production and cement sheath defects caused by casing deformation; and (5) inappropriate development plan. Casing damage wells in the United States predominantly occur in California Belridge and Williston oilfields. More than 1,000 casing damage wells have been found in Belridge oilfields in the past 20 years since the overexploitation of the 1970s, which resulted in significant formation compaction. Casing deformation occurs in the form of axial extrusion and shear. Axial extrusion damage takes place during the production stage, while axial shear damage takes place in the margin of the subsidence area (Fredrick et al., 1998).

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However, the casing deformation occurring during Changning-Weiyuan shale gas reservoir stimulation is hard to explain by the conventional reasons listed above. Shale gas reservoirs are different from salt-gypsum and mudstone formations, where, the formation creep load is generally not considered. Second, the casing has no service time and its internal strength will not be reduced due to external corrosion and internal erosion. Third, casing deformation does not occur in the perforation intervals, and has little relation with the casing strength decline induced by perforation. Fourth, the oil and gas of this area has not been developed yet; thus, there are no formation compaction and subsidence problems.

The pressure variation of the fluids in a confined space outside the casing produced by significant temperature variation, also known as the APB effect (Pattillo et al., 2004), can result in casing damage. Jandhyala and Chiney (2014) studied the enclosed casing annular pressure buildup (APB), they considered that APB might cause severe damage in the cement sheath under extreme conditions; moreover, its collapse on the casing or rupture was also a potential threat. They proposed that elastic cement could be used to prevent "casing-cement sheath-formation" system damage generated by "APB". It was proposed that a casing strength check should consider the influence of the temperature effect during exploitation and fracturing, and a casing security factor was analyzed by adopting WELLCAT software. However, it was still difficult to explain the reason for the shale gas well casing deformation of Sichuan through these study results and WELLCAT software calculation and analysis. The model in WELLCAT assumes that the enclosed liquid in an annular segment is an entire circle (360°); however, cement sheath voids formed in the long horizontal segment annular are not possible at more than 180°.

According to the APB theory and the characteristics of the shale gas horizontal well, a physical model including the shale reservoir, cement sheath and casing was proposed and analyzed. The casing strength influenced by the geo-stress, internal fracturing liquid pressure and temperature variation was analyzed. The mechanism for casing deformation during shale gas fracturing was presented, and a casing security technical strategy was proposed as well.

2. Overview of the casing deformation in Changning-Weiyuan shale gas play

The Changning-Weiyuan shale gas plays are the two model areas of CNPC (China National Petroleum Company), located in the Sichuan Basin. The shale reservoir of Longmaxi Formation is at a vertical depth of 2500 approximately. The regional geo-stress is very high, with the minimum horizontal principal stress gradient between 2.3 and 2.4 MPa/100 m and the maximum horizontal principal stress gradient over 3.0 MPa/100 m. The reservoir temperature is approximately 90 °C. Oil-based drilling fluids were adopted during the horizontal drilling, with a drilling fluid density of 2.0–2.2 g/cm^3. Casing perforation completion and bridge plug staged fracturing were adopted, with a single-stage fracturing liquid of 1800–1900 m^3 , displacement of 10–12 m^3/min and pumping pressure of over 80 MPa.

As shown in Table 1, there are generally four development stages from 2009 to 2016 in Changning-Weiyuan shale play, and a total of 101 wells were successfully fractured and stimulated. In stage 1 (2009–2010), 4 vertical wells were drilled and fractured, among which 2 wells occurred casing deformation, the 5-1/2″ casing grade was P110; in stage 2 (2011–2012), 7 vertical wells and 3 horizontal wells were drilled and fractured, all of the 3 horizontal wells occurred casing deformation, the 5-1/2″ casing grade was Q125; in stage 3 (2013–2014.3), 9 horizontal wells were fractured, among which 4 wells occurred casing deformation, both of the 5-1/2″ and 5″ casing grade were TP140 or VM140; in stage 4 (2014.4–2016.3), 77 horizontal wells were fractured and among which 25 wells occurred casing deformation, both of the 5-1/2″ and 5″casing grade were Q125. The overall casing deformation ratio of the 101 wells is 31.7% (32/101), the horizontal

Table 1
Summary of the casing deformation in Changning-Weiyuan shale gas play.

Stages	Shale play	Fractured wells	Casing deformation wells	Casing deformation ratio (%)	Totally designed intervals	Successfully fractured intervals	Give up intervals	Give up ratios (%)
Stage 1 (2009–2010)	Changning and Weiyuan	4	2	50	/	/	/	/
Stage 2 (2011–2012)	Changning and Weiyuan	10	3	33.33	33	27	6	18.2
Stage 3 (2013–2014.3)	Changing	7	4	57.14	88	80	8	9.09
	Weiyuan	2	0	0	24	23	1	4.16
Stage 4 (2014.4–2016.3)	Weiyuan	1	0	0	19	19	0	0
	Changing	25	8	32	535	507	26	4.86
	Weiyuan	52	17	32.7	967	849	69	7.1
	Total	101	34	33.7	1666	1505	110	6.6