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Technical Note

Wellbore instability in shale gas wells drilled by oil-based fluids

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1. Introduction

Seventy-five percent of all drilled formations are shale and 90% of wellbore stability problems occurred in these shale formations [1]. Most conventional oil-based fluids (OBFs) systems are formulated with calcium chloride brine, which appears to offer the best inhibition properties for most shale. The attempt by many engineers to look for answers to their wellbore instability problems from oil-based drilling fluids had been extremely successful most of the time in past decades, so we naturally hope that the similar problems could be settled when drilling shale gas wells. In the past decades, the exploration and exploitation of shale gas reservoirs has driven horizontal wells into a rapid increase, since a horizontal well with a multi-fracturing technology is accepted as the major methods in developing shale gas reservoir.

Organic-rich shale gas formations are quite different from conventional shale formations due to the characteristic of hydrocarbon source rocks, such as rich organic matter and developed fracture networks. Well instability is one of the key challenges while drilling horizontal shale gas wells [2,3]. Wellbore quality plays a fundamental role in drilling operations and subsequent successful well completion.

Shale gas wells drilled with OBFs perform better than those with water based fluids [4], but some experts have come to recognize that OBFs are not the best way, reckoning with the problems during drilling shale gas wells [5,4,6], and have been exploring alternatives [7]. Some papers reported that wellbore instability problems [8,4] as well as other problems, such as high costs and formation damage, are due to the use of oil based drilling fluids.

This paper takes an organic-rich shale gas reservoir in Southern Sichuan Basin as an example, and presents a new insight on why wellbore instability can still occur in shale gas wells drilled by OBFs, in terms of a friction theory and some experiments of interaction of OBFs and shale. Oil based drilling fluids used in the related experiments were from shale gas well Y1 in the studied reservoir.

2. Borehole instability problems

The Longmaxi and Niutitang gas shale formation in Southern Sichuan Basin are major objective. Their total organic carbon (TOC) content ranges 4 wt%–8 wt% and vitrinite reflectance (*Ro*) measured is 1.62%–3.5%, and illite is the main clay mineral. Swelling test conducted by linear swelling tester showed that the swelling rate is 6.6% after exposed to the distilled water for 16 hours, which indicates a lower swelling.

Shale wellbore wall collapses were often encountered during drilling W-H1 well (Fig. 1) the first shale gas well in China, although it was drilled using an oil based drilling fluid system and the density of the drilling fluid was gradually increased [6]. Wellbore instability problems also occurred in the first several shale wells drilled by oil based drilling fluids in Southern Sichuan Basin, China (Table 1). The oil based drilling fluid was selected from shale horizontal well Y1, whose borehole clasped severely

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according to the well logging curves (Fig. 2). The swelling test showed that the swelling rate of the shale in the oil based drilling fluid is very low, near zero.

3. Mechanisms of friction reduction

3.1. Overpressure and pore pressure increase

Most shale gas reservoirs exhibit overpressure due to in-situ continuous gas generation [9,10]. According to the existing data, the pressure coefficient of shale gas reservoirs in Southern Sichuan Basin can reach 2.25. Gas cut, kick or wellbore instability can often occur during drilling a high-pressure gas well. In order to prevent these unfavorable phenomena, the density of drilling fluids is usually rapidly elevated to achieve overbalanced drilling. Hence the drilling fluids can invade along with a fracture network into the formation around the well and increase pore pressure of the fracture network [11] to form a local high pressure zone because of very poor pressure transfer ability of nano-Darcy permeability of shale. Swelling stress is negligible since oil based drilling can inhibit swelling of active clays. When the pore pressure near wellbore increases to a certain value, fragmentized shale blocks may float in the drilling fluids. Some of them will be driven out of the heavily fractured wall of the wellbore when an underbalanced pressure difference can conquer the friction force between fragmentized shale blocks.

3.2. Fracture width increase and contact surface decrease

Shale gas reservoirs in Southern Sichuan Basin are all heavily fractured (Fig. 3) like Barnett shale [12]. The shale gas matrix provides nano-Darcy permeability, and natural fractures play a significant role in transferring gas from pores to hydraulic fractures or wellbore. Thus the intensity of natural fractures development is one of the most important indexes assessing a "sweet spot" of shale gas formation. Fracture width may increase due to the invasion of a large amount of drilling fluids into natural farceurs or shale bedding under the condition of poor mudcake during overbalanced drilling. So the fractures are full of drilling fluids, which decreases the contact surface of fracture faces and even makes one fracture face disconnected from another, reducing the friction force to zero. Then a very little force can move and collapse them from the wellbore wall.

Fig. 1. Collapsed debris retuned out from wellhead [6].

3.3. Oil invasion and lubrication

Water, white oil and kerosene can invade into shale to a certain degree [13] along with bedding planes when exposed to the shale. White oil and kerosene are the main components of oil based drilling fluids used in shale gas reservoirs. Contact angle test

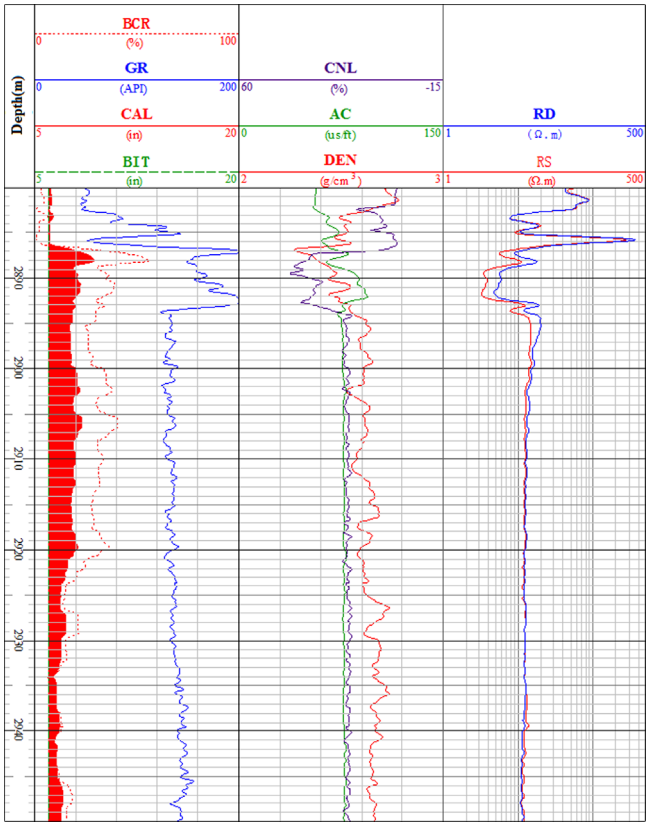

Fig. 2. The well logging curves of a shale gas well drilled by oil based fluids. The wellbore instability problem is severe.

Table 1
Downhole problems during drilling shale wells in Sichuan Basin.

wells	Formation	Drilling fluids	Borehole instability problem
W-H1	Longmaxi group	Oil based fluids	Borehole collapse occurred and a large amount of black collapsed debris with the size of 5–8 cm retuned out from well head during drilling shale formations of Longtan Group and Longmaxi Group.
W-H3	Qiongzhusi group	Oil based fluids	Serious shale collapse caused pipe sticking so drilling finished in advance.
N-H1	Longmaxi group	Oil based fluids	Shale sloughing often occurred, and a large amount of black collapsed shale debris retuned out from wellhead during drilling; pipe stuck happened during picking out drilling tools.
Y1	Longmaxi group	Oil based fluids	Serious shale collapse and lost circulation occurred during drilling a horizontal zone in Long maxi Group.
Z101	Niutitang group	Sulfonated polymer fluids	Serious wellbore diameter enlargement.