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Hydraulic pulse jet: Test of characteristics and field applications in ultra-deep wells

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A R T I C L E I N F O

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A B S T R A C T

Low rate of penetration has been recognized as a major problem affecting the cost of operation in drilling ultra-deep wells (UDW) in the oil and gas industry. This study investigated hydraulic pulse jet (HPJ) technique for increasing rate of penetration in UDW drilling. Results of full-scale testing, numerical simulation, and field applications in the UDW conditions are presented in this paper. The full-scale testing indicates that the HPJ has characteristics of fluid-flow rate dependent amplitude and frequency of pressure fluctuation. This performance was confirmed by numerical simulation of fluid mechanics inside the tool. Field applications in the Tarim and Tahe oilfields, China, show that the rate of penetration (ROP) was increased by 22.2%–54.9% in drilling well sections ended at up to 6162 m. It has been concluded that the HPJ technique is suitable to drilling ultra-deep wells in China.

1. Introduction

Oil and gas wells deeper than 6000 m are called ultra-deep wells (UDW) in the oil and gas industry. With the increasing demand for energy and the recent advances in drilling equipment and technologies, the number of UDW increased rapidly in the last decade. However, the rate of penetration (ROP) in drilling UDW remains low, resulting in high cost of operation and low performance of engineering projects. It has become a major challenge to the development of deep oil and gas resources in China.

Factors affecting rate of penetration (ROP) in well drilling have been investigated by several scientists including Murray and Cunningham (1955), Johnson et al. (1975), Black and Green (1978). Drill bit hydraulic parameters are found important affecting the ROP in hard rock drilling. Johnson et al. (1982) designed a new type of bit nozzles that generate acoustic self-resonant cavitating jet to create dynamic force for hole-cleaning. Ghalambor et al. (1988) developed bits with a rotating disc structure to enhance the velocity of intermittent jet of drilling fluids. Kollé and Marvin (1999) designed a tool by installing a self-circulating lift valve to the bit to create negative pressure pulse.

Shen (1987) carried out preliminary theoretical and experimental research on the hydraulic pulse jet (HPJ) technology. On the basis of hydro-acoustics theory, Li and Shen (1991) developed an efficient self-resonant cavitating nozzle. Through theoretical research and lab experiments, Li found that hydraulic pulse jet can effectively improve the energy conversion efficiency by making use of continuous periodical impact to cause fatigue failure of rocks (Li et al., 2003, 2005, 2008). Then a hydraulic pulse generator was developed and has been widely tested in conventional on-land and offshore well drilling to increase the ROP (Li et al., 2009a, 2009b, 2010; Fu et al., 2012). The results have practically proved the hydraulic pulse jet drilling to be very useful in increasing ROP (Wang et al., 2009; Shi et al., 2010, 2014).

Very hard rocks under high pressure and stresses are found in drilling UDW. It is not known whether the HPJ technology can be adapted to help increase ROP. High-density drilling fluids used for controlling formation pressure in deep and ultra-deep well drilling can reduce ROP significantly due to the low hole-cleaning efficiency at the bottom hole. The side effect of heavy fluid can cause repeated crushing and hold-down effect, resulting in low ROP (Mohamed et al., 2009; Cheng et al., 2011). On the other hand, Underbalanced drilling (UBD) has been found to increase ROP significantly due to the low bottom hole pressure that promotes rock-breaking efficiency (Kollé, 2000; Zhang et al., 2012). These facts encouraged us to investigate the characteristics of the HPJ in ultra-

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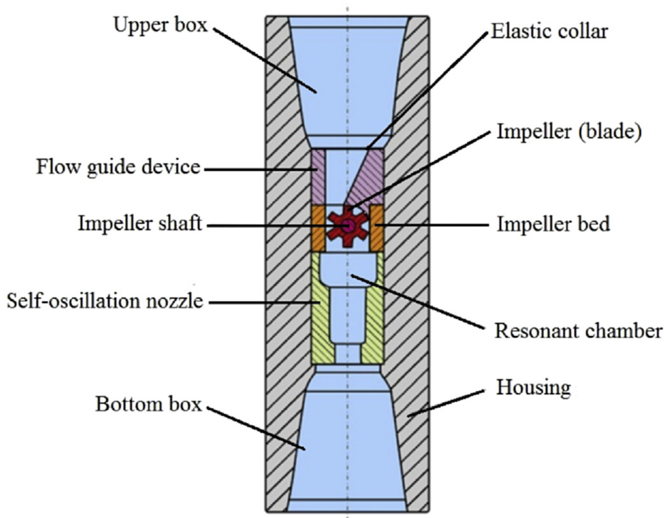

Fig. 1. Structure of hydraulic pulse jet generator.

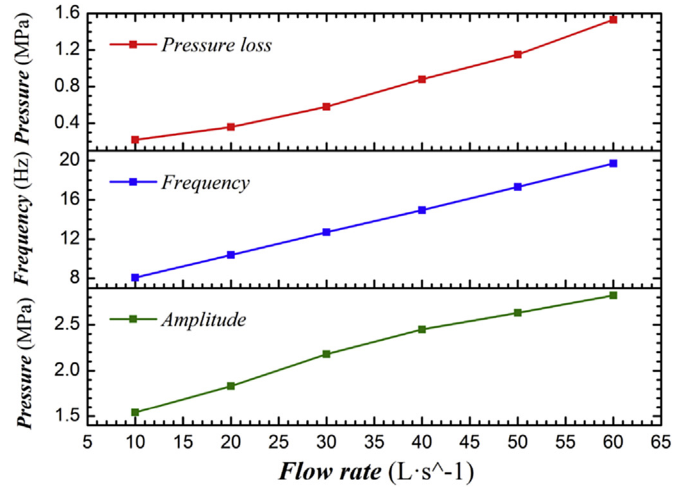

Fig. 3. Test result of a Φ198 mm generator.

deep well drilling conditions. Results of full-scale testing, numerical simulation, and field applications in the UDW conditions are presented in this paper. The full-scale testing indicates that the HPJ has characteristics of fluid-flow rate dependent amplitude and frequency of pressure fluctuation. This performance was confirmed by numerical simulation of fluid mechanics inside the tool. Field applications in the Tarim and Tahe oilfields, China, show that the rate of penetration (ROP) was increased by 22.2%–54.9% in drilling well sections ended at up to 6162 m. It is concluded that the HPJ technique is suitable to drilling ultra-deep wells in China.

2. Description of HPJ generator

Shown in Figs. 1 and 2 are the sketch and major components of the hydraulic pulse jet generator. The generator consists of housing, a flow guide device, an impeller assembly and a resonant chamber.

The generators are designed to have different sizes of the housing and impeller assembly. The flow channel with a slope in the flow guide device changes the direction and magnitude of the flow velocity and produces a tangential force. The impeller assembly consists of body, an impeller, an impeller shaft and an impeller bed. The impeller, sitting on the shaft, is installed on the impeller bed via the link joint of the two ends of the shaft to the bed. The created tangential force acts on the blades of the impeller, driving it to rotate continuously at high speeds. The effective area of the flow channel changes periodically due to the rotation of the impeller blades so that hydraulic pulses are generated. In the chamber, the pulse frequency of the drilling fluid is amplified. When the drilling fluid flows through the inclined section of the resonant chamber, pressure fluctuation occurs. The signal is fed back to the chamber. Once the frequency of the pulse pressure matches the natural frequency of the resonant chamber, acoustic resonance of drilling fluid and the chamber occurs and pressure pulse is amplified. Intense pulsing turbulent vortex rings are expected to form at the outlet and it in turn creates dynamic impact on the bottom hole. Under the periodical impact force of jet fluid, the bottom hole rock is expected to undertaken fatigue failure. The ROP is thus increased.

3. Full–scale testing

In order to verify the generation of periodical pressure fluctuation at the exit of the generator, a full-scale testing with drilling

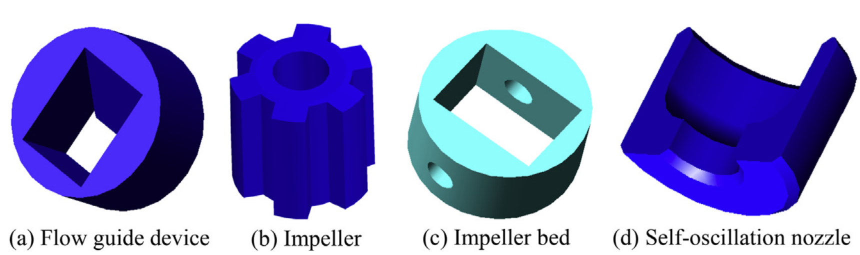

Fig. 2. Major components of the HPJ generator.

Table 1
Test parameters of a Φ198 mm generator.

Flow rate (L/s)	Amplitude of pressure fluctuation (MPa)	Pressure loss (MPa)	Frequency of pressure fluctuation (Hz)
10	1.54	0.22	8.07
20	1.83	0.36	10.37
30	2.18	0.58	12.70
40	2.45	0.88	14.96
50	2.63	1.15	17.31
60	2.82	1.53	19.74