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A discussion about the method to study the effect of ambient pressure on hydraulic jetting

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ABSTRACT

Hydraulic jetting techniques are widely used to improve the rate of penetration (ROP) and enhance oil recovery (EOR) in the oil and gas field. However, a high ambient pressure could significantly weaken the performance of hydraulic jetting at the bottom of wells, especially in the case of deep (> 4500 m) and ultra-deep (> 6000 m) wells. Hence, many excellent studies have been conducted to study the effect of the ambient pressure on a hydraulic jetting. A method to generate ambient pressure by changing the diameter of the outlet valve is widely used. However, in our study, it is proved that the method cannot simulate the real ambient pressure environment for a hydraulic jetting. In our study, an outlet valve is used to maintain the pressure in the pressure vessel. Jet pressure and impact pressure with different ambient pressures at different standoff distances are measured. The jet pressure remains unchangeable until the ambient pressure exceeds a threshold and then increases linearly with the ambient pressure. The threshold is approximately equal to the product of the pressure drop of the nozzle and the square of the nozzle discharge coefficient. The hydrostatic pressure is not evenly distributed in the pressure vessel under the generated ambient pressure. According to Bernoulli's equation, the process to generate ambient pressure by this method is the conversion process between the hydrostatic pressure and the dynamic pressure. Given that the ambient pressure is evenly distributed at the bottom of oil wells, it may not have an influence on the hydraulic jetting. Performing an experiment to measure the effect of the ambient pressure on hydraulic jetting at the bottom of oil wells is strongly recommended. The results in our study are helpful for the application of hydraulic jetting in oil and gas industry.

1. Introduction

The use of hydraulic jetting techniques has been growing in applications aimed to improve the rate of penetration (ROP) and enhance oil recovery (EOR) (Maurer et al., 1969; Shen et al., 1988; Domann et al., 1990; Nakhwa et al., 2007; Wells et al., 2008; Sun et al., 2012). To improve drilling rates, numerous researchers have studied methods of rock-breaking assisted by high pressure water jet, including optimization of the nozzle assembly, optimization of the fluid, and structural design of the nozzle (Cunningham and Eenink, 1959; Feenstra et al., 1964; Kolle et al., 1991; Khorshidian et al., 2014). To induce multiple fractures in open-hole horizontal wells, hydrajet fracturing technology is used; this technology combines abrasive jet perforating and hydraulic fracturing and has been studied for decades (Surjaatmadja et al., 1998; Rodrigues et al., 2005; McDaniel et al., 2008; Li et al., 2010). Rotary jetting technology has been reported in numerous papers (Stanley et al., 2000, 2004) and has the ability to remove near wellbore damage and optimize well stimulation treatments. Rotating jet technology has also been investigated and optimized to improve the sand cleanout efficiency in a horizontal wellbore (Song et al., 2010, 2014).

However, extensive laboratory and field studies have shown that hydraulic jetting are less dependable when wells are drilled to certain depths, especially when used for deep (4500 m) and ultra-deep (6000 m) wells. Maurer (1965) studied the bit-tooth penetration under simulated borehole conditions. When there is constant force on the teeth, an increase in hydrostatic fluid pressure (simulated water drilling) from 0 to 34.5 MPa decreases the crater volume in both sandstone and limestone by 50%. Sheshtawy and Kennedy (1973) worked with rotary high pressure jet parameters and the effect of nozzle geometry on the shape and performance of the jet. The effect of down-hole pressure on jet performance was believed to be as follows: the threshold pressure of the rock increased with the increase in simulated depth, reaching up to 5000 ft. An adjustable relief valve on the hydrostatic head reservoir maintains the constant pressure in the drilling cell while the jet flows. Feenstra and Van Steveninck (1974)

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Nomenclature

P_O	Pressure drop of the nozzle, MPa
P_1	Jet pressure of the hydraulic jetting, MPa
P_3	Total pressure, which is equal to the sum of hydrostatic pressure and impact pressure, MPa
P_{static}	Hydrostatic pressure at the measuring point, MPa
P_{impact}	Impact pressure at the measuring point, MPa
P_a	Ambient pressure in the pressure vessel, MPa
P_{in}	Pressure of the incoming water, which is equal to the jet pressure, MPa
P_n	Hydrostatic pressure in the nozzle, MPa
P_{out}	Pressure of the outflowing water, MPa
v_m	Maximum axial velocity, m/s
v_{in}	Velocity of the incoming water, m/s
v_n	Velocity in the nozzle, m/s
v_a	Velocity in the pressure vessel, m/s
v_{out}	Velocity of the outflowing water, m/s

found that this method of jet drilling rock in oil wells was feasible and promising. However, hydraulic kerfing does not work under down-hole conditions with plastering muds. An ambient-pressure control valve was used to control the ambient pressure. Alberts and Hashish (1996) investigated the effect of the ambient pressure on abrasive cutting jets. For ambient pressures between 17 and 69 MPa, the suspension jet cutting performance is not highly dependent on ambient pressure, however, a significant performance loss occurs when the pressure ranges from 0 to 17 MPa. High-pressure relief valves are used to hold the desired operating pressure in the test chambers. Surjaatmadja et al. (2010) concluded that it was much more difficult to use jetting techniques in deep formation at higher ambient pressures. The ambient pressure was controlled by the outlet choke. Liao et al. (2012) researched the effect of hydraulic ambient pressure on impacting characteristics of jets. The ambient pressure is considered to be the main cause of decrease in axial impact pressure and volume of rock removal. Khorshidian et al. (2014) studied the two mechanisms in which ambient pressure reduces ROP by experimentation. The borehole pressure increases the strength of the rock and intensifies the accumulation of cutting material beneath the cutter. A pressure relief valve that is installed after the drilling cell is used to adjust the ambient pressure inside the drilling cell.

For all the above studies, the pressure relief valve or outlet choke was used to generate the ambient pressure in the pressure vessel by changing the ratio between the diameters of the jet nozzle and the valve. The ambient pressure is believed to simulate the real downhole pressure environment. However, in recent research, we found that this method may not be suitable to study the effect of the ambient pressure on a hydraulic jetting. In our study, a jet impact pressure measuring device, which can generate ambient pressure (< 10 MPa) by controlling the diameter of outlet valve, is adopted. Jet pressures and impact pressures at different ambient pressures and standoff distances are measured. It is proven that the standard method of generating ambient pressure is not suitable for the study. The results in our study are helpful for hydraulic jetting applications in the oil and gas industries.

2. Facilities and methods

2.1. Jet impact pressure measuring device

The same jet impact pressure measuring device used by Liao (2012) is adopted for this study. As is shown in Fig. 1 and Fig. 2, the device mainly consists of a pressure vessel, a nozzle assembly, a pressure measuring hole, a standoff distance adjustment lever, a high pressure outlet valve, etc. The pressure gauge and pressure sensor are simultaneously installed at the inlet and outlet for observation and accurate measurement, respectively. A transparent pipe is used to recycle the water. By changing the diameter of the outlet valve, different ambient pressures can be created. This method used to generate ambient pressure has been adopted in studies on ambient pressure.

2.2. Measurement principle

As is shown in Fig. 1, high pressure water flows through the inlet into the device and sprays from the nozzle. The pressure gauge 1 and pressure sensor 1, which are installed close to the nozzle, simultaneously show and record the jet pressure labeled as P_1. After that, high velocity water impacts the pressure measuring hole, and the total pressure, which is the sum of impact pressure and hydrostatic pressure, is obtained by pressure sensor 3 and is labeled as P_3. At the end, water flows through the high pressure outlet valve, which generates ambient pressure. The ambient pressure, labeled P_a, is displayed and recorded by pressure gauge 2 and pressure sensor 2. According to the theorem of momentum, the impact pressure on a plane can be calculated by:

$$P_{impact} = \rho v^2 \quad (1)$$

Then, the total pressure obtained by pressure sensor 3 can be expressed as:

$$P_3 = P_{static} + P_{impact} = P_{static} + \rho v^2 \quad (2)$$

2.3. Apparatus

A high-pressure plunger pump is used as the power source with a rated pressure of 60 MPa and a certified capacity of 100 L/min. A hydro-pressure sensor with a measuring range of 30 MPa, an output current of 4–20 mA, and an accuracy of 0.1% F*S is used to record the pressure. Two pressure gauges with rated values of 10 and 30 MPa are used to display the pressure. A high-pressure output valve is used to control the ambient pressure. A data acquisition system with a National Instruments multi-channel data acquisition card installed is used to collect and store the pressure data (Fig. 3). To investigate the effect of the ambient pressure on the impact pressure, a general cylinder nozzle is used. The nozzle has an equivalent diameter of 3 mm with an outlet cylindrical section that has a diameter of 6 mm. To ensure concentricity of the nozzle and the pressure taps, the inlet nozzle is designed in a conical surface cone configuration, as shown in Fig. 4.

2.4. Projects

To study the effect of the ambient pressure on a high pressure water jet, flow rates are set to 0.62, 0.67, and 0.77 L/s. Standoff distances are

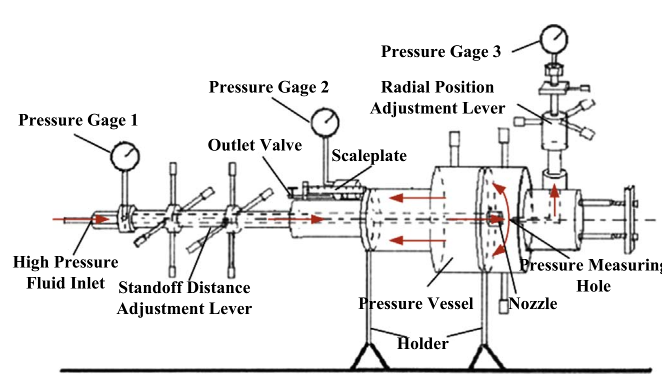

Fig. 1. Schematic diagram of the high pressure water jet simulator (Liao, 2012).