Journal of Natural Gas Science and Engineering xxx (2015) 1–9

Contents lists available at ScienceDirect

Journal of Natural Gas Science and Engineering

journal homepage: www.elsevier.com/locate/jngse

Modulating downhole cuttings via a pulsed jet for efficient drilling-tool development and field testing

Peng Wang [a], Hongjian Ni [a,*], Ruihe Wang [a], Zhina Li [b]

[a] School of Petroleum Engineering, China University of Petroleum (East China), Qingdao 266580, China
[b] School of Geosciences, China University of Petroleum (East China), Qingdao 266580, China

ARTICLE INFO

Article history:
Received 25 September 2014
Received in revised form
17 March 2015
Accepted 18 March 2015
Available online xxx

Keywords:
Enhancement in ROP
Self-oscillating
Cuttings pulsed jet
Tool development
Field tests

ABSTRACT

The method of pulsed-jet assisted rock-breaking using cuttings, which combines the advantages of a pulsed jet and an abrasive jet simultaneously, is an emerging drilling technology and can further improve the rate of penetration. Several key techniques of this method are discussed in this paper, including the structure and principle of the modulating tool, the modulation mechanism and the optimization method of the cuttings pulsed jet. An engineering prototype is developed based on the above research works and site conditions. Laboratory tests and field tests of the prototype are successively performed. The application effect is compared with actual drilling data of adjacent wells in the same formation and interval. The results are a good reference for the subsequent drilling.

In recent years, the increase in global demand for oil and gas resources has been met by the exploration and development of unconventional gas resources. In the USA, unconventional gas production accounted for approximately 43% of the total gas production (Slutz, 2007). In China, tight sand gas is abundant in Sichuan Basin and Ordos Basin (Ren et al., 2014). A drilling process accounts for up to one-third of the well-construction period and over half of the cost in the exploitation of these resources. Therefore, it is important to seek available cost-effective rock breaking methods for the improvement of ROP and for the reduction of drilling costs and exploration time (Fu et al., 2012; Cheng, 2012).

Since the 1970s, water-jet assisted rock breaking has been proposed and considered as the most promising assisted rock-breaking technology. The first underground drilling using a high-pressure water jet was conducted in an operating lead mine in Missouri (Summers and Lehnhoff, 1977). As the water pressure was too high, the equipment became more sensitive to water chemistry, enabling high erosion problems to arise. The resulting equipment was initially more expensive and delicate than was acceptable. As a result, several solutions have been proposed to overcome the need for high pressure. One proposed approach is to combine a water jet with mechanical bits. A second alternative is to use a cavitating water jet (Johnson et al., 1982). A third alternative is to use a pulsed water jet (Erdmann et al., 1980). A fourth alternative is to add an abrasive to the water jet (Fairhurst et al., 1986).

Research works indicate that the impact pressure of the pulsed jet will be at least four times higher than the continuous jet at the same velocity (Josef et al., 2004). Because of this potential of the use of pulsed jets, many attempts have been made for generating various types of pulsed water jets in the last 30 years (Vijay, 1994). On the basis of the hydroacoustics principle and fluid-transients theory, attempts were made to modulate jets using internal mechanical flow modulators (Nebeker, 1981), Helmholtz oscillators (Conn, 1989), self-resonating jets (Chahine and Conn, 1983), electrohydraulic discharge (Hawrylewicz et al., 1986), ultrasonic vibration of the nozzle body (Mazurkiewicz, 1984) and ultrasonic vibration of a tip situated inside the nozzle (Puchala and Vijay, 1984; Vijay, 1994). According to the above-mentioned various modulating methods of the pulsed jet and their feasibility in the drilling process, researchers have developed several types of downhole drilling tools, such as a negative-pressure-pulse tool (Kolle and Marvin, 1999), a shaped charge pulsed nozzle (Wang et al., 1999), a screw-type pressure intensifier (Wang et al., 2012) and an adjustable frequency pulse jet generating tool (Cui et al., 2012). However, most of these tools are not applied widely because their structure is too complex and the reliability of these

* Corresponding author.
E-mail address: wpainn@hotmail.com (P. Wang).

http://dx.doi.org/10.1016/j.jngse.2015.03.023
1875-5100/

tools is not adequate. Only a few tools that have simpler structure and better reliability are applied on site. Li et al. (2009) developed a hydraulic-pulsed cavitating-jet drilling tool which combined the advantages of a pulsed jet and a cavitating jet. This tool achieved a remarkable enhancement in the rate of penetration (ROP) (Li et al., 2010; Fu et al., 2012). Cheng et al. (2012) developed a self-oscillation pulsed percussive tool that combined the advantages of a pulsed jet and a high frequency axial impact. Simultaneously, research works demonstrated that the pressure required for breaking rocks can be significantly reduced by adding an abrasive to the jet. Most past theoretical and experimental studies have focused on the rock breaking efficiency, the factors of the abrasive jet and the injection manner of the abrasive (Fair, 1981; Kirby and Kramer, 1985; George et al., 1989). It was not until 2002 that a steel ball was added as an abrasive to the drilling fluid proposed by Curlet et al. (2003); the results indicated that the rock breaking volume by a particle jet is three to four times that by a water jet under the identical conditions. In addition, a large number of laboratory and field tests were performed between 2003 and 2008 (Rach, 2007; Gordon, 2008).

However, the applicability of the pulsed jet is questionable for cases in which the well depth and hardness of rock increase. Additionally, the particle drilling technique, compared with conventional drilling, requires complicated supporting facilities, including a particle injection system, an impacting bit and a particle recycle system; such requirements have restricted its application. Based on the above-described research works, Wang et al. (2011a); (2011b) proposed a new cuttings-based pulsed-jet assisted rock breaking drilling technology that combines the advantages of a pulsed jet and an abrasive jet to further improve the penetration rate. To improve the conventional pulsed jet, this technology used cuttings, which are produced by a bit while drilling, as an abrasive. As shown in Fig. 1, the cuttings at the bottom are scoured away and then circulate with the drilling fluid in the annulus. A part of these cuttings are sucked into the cuttings pulsed jet modulation tool in the position of the suction-eyes, and the surplus cutting particles continue to circulate with the drilling fluid and are discarded from the main stream when they flow through the solid control equipment on the ground. Previous research (Du et al., 2012; Ni et al., 2012) indicated that cuttings had a weak rock-breaking effect that is similar to that of the use of steel balls. However, with the use of cuttings, ground particle processing equipment is not required, and the field drilling process is not changed. Cuttings are the main abrasive agents, and another other abrasive, such as steel balls, can be added into drill pipe intermittently and recycled at the well head, which will greatly reduce the consumption of steel particles and make it possible for large-scale industrial applications. On the basis of earlier works, this paper focuses on the modulation mechanism of cuttings-based pulsed jet, structure optimization and laboratory tests of the cutting-containing pulsed jet modulating tool and exploratory field tests.

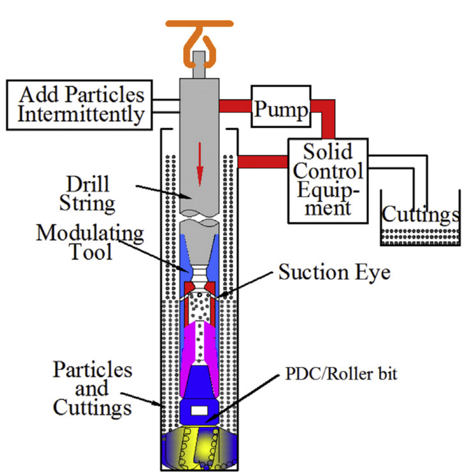

Fig. 1. Schematic of cuttings-based pulsed jet assisted rock breaking.

1. Structure and principle of the modulation tool

The structure of the modulation tool is shown in Fig. 2. A suction-type self-excited oscillation cavity and adapter are mounted inside the shell from top to bottom. There are two suction-eyes distributed symmetrically on the wall of the self-excited oscillation cavity, which is connected to the suction-eyes of the shell on the corresponding position.

The modulation tool is installed between the bit and drill collar or other drilling tools. The drilling fluid flows into the suction-type self-excited oscillation cavity along the inside flow channel of the shell, and then the steady flowing drilling fluid is modulated into a pulsed jet through the processes of resonance, feedback, frequency selection and amplification. At the same time, a low pressure zone is formed around the suction-eyes of oscillation cavity. Because of the existence of the low pressure zone, the cuttings are sucked into the self-excited oscillation cavity from the annulus and then are mixed with the high-speed pulsed jet. As a result, the cuttings are accelerated through the inside flow channel of the adapter and drill bit nozzle spurt, thereby forming the cuttings-based pulsed jet that is used to drill the rock (Wang et al., 2011a); (2011b).

2. Modulation mechanism of the cuttings-based pulsed jet

The suction-type self-excited oscillation cavity is the key component of the modulation tool. The Mixture multiphase flow model (Fluent 14.5 User's manual) based on the Euler method is used to analyse the flow field characteristics of the cavity and the suction/acceleration/mixture process of the cuttings.

2.1. Mixture model

The continuity equation for the mixture is

$$\frac{\partial}{\partial t}(\rho_m) + \nabla\cdot\left(\rho_m \vec{v}_m\right) = 0 \tag{1}$$

where $\rho_m = \sum_{k=1}^{n} \alpha_k \rho_k$ is the mixture density ; n is the number of phases; α_k is the volume fraction of phase k; ρ_k is the density of phase k; $\vec{v}_m = \sum_{k=1}^{n} \alpha_k \rho_k \vec{v}_k / \rho_m$ is the mass-averaged velocity; $\vec{v}_k$ is the velocity of phase k; t is the time.

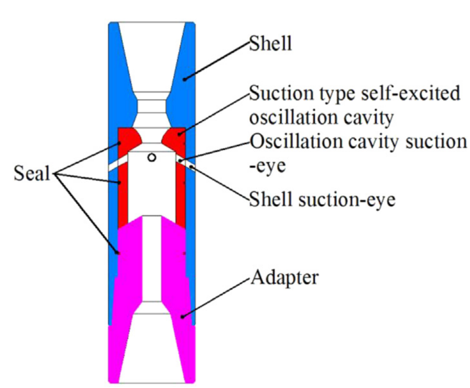

Fig. 2. Structure of the modulating tool.