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State-of-the-art cuttings transport with aerated liquid and foam in complex structure wells

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A B S T R A C T

Both aerated liquid and foam drilling as underbanlanced drilling candidates have obtained the rapid development to better protect the reservoir. Due to the presence of highly-deviated and horizontal section of complex structure wells, if the fluid velocity is lower than a critical value in annulus, cuttings will accumulate and eventually develop cuttings bed, and may result in severe problems such as stuck pipe, higher torque and drag, and poor cementing quality. Here, the sensitive analyses, empirical correlations and mechanical models for cuttings transport with aerated liquid and foam were reviewed. Studies indicate that cutting parameters, fluid parameters, operational parameters and formation parameters have effects on cuttings transport, and fluid flow rate and rheology are mainly controlled parameters. Models for aerated liquid include particle movement model, maximum cuttings volume model, optimal gas and liquid flow rate model. Models for foam include vertical-section model, two-layer model, three-layer model, three-segments model and critical velocity model. We suggest that the future researches will mainly focus on comprehensive experiments with advanced flow loops, flow simulations, mechanical models, hole-cleaning techniques and hole-cleaning optimizing system.

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1. Introduction

Due to the rapid development of China's economy, the growing number of crude oil demands is presented. As shown in Fig. 1, the ratio of import and consumption has broken through 50% from the year 2008, and the contradiction between crude oil supply and demand becomes more and more obvious. Meanwhile, the mature oilfields in the east still serve as the main contributor to the oil production, and account for about two-thirds of China's crude oil production. As a result, enhancing oil recovery of these mature oilfields is still the key to increasing or stabilizing oil production.

Complex structure well has been an effective way to enhance oil recovery of mature oilfields by using the horizontal well and multilateral horizontal well [2]. During the process of drilling, if conventional drilling fluids are used, the hydrostatic pressure will be more than the formation pressure, which leads to lost circulation and serious pollution in the reservoir, especially in low-pressure reservoir or depleted reservoir. The aerated liquid and foam drilling can overcome these problems, but the performances of cuttings transport with aerated liquid and foam are critical in the highly-deviated and horizontal section. In this case, poor hole cleaning may result in stuck pipe, reduced rate of penetration (ROP), transient hole blockage leading to lost circulation, excessive drill pipe wear, extra cost for special drilling fluid additives and wastage of time by wiper trip maneuvers [3]. As a result, cuttings transport has continued to be a subject of interest to researchers and engineers.

Initially, experimental investigations were the major methods to observe cuttings-transport phenomenon and analyze the effects of various parameters on cuttings transport with a gas–solid–liquid three-phase flow. Therefore, many institutions and universities established simulated flow loops, such as BJ Services [3], Institut Français du Pétrole [4], Japan National Oil Corporation (JNOC) [5], Petrobras [6], Tulsa University Drilling Research Projects (TUDRP) [7], Middle East Technical University (METU) [8]. Meanwhile, in recent years, computational fluid dynamics (CFD) software [9] is also applied to simulate the cuttings-transport behavior in different conditions, and provides some additional information that experimental observations and filed tests are either difficult or impossible to obtain. These studied parameters which affect cuttings-transport behavior can be divided into four different groups based on the study by Ali [10]. The first group consists of cutting parameters such as cutting density, cutting shape and size, and cutting concentration. The second group consists of fluid parameters, i.e. fluid viscosity, fluid density, and fluid flow rate. The third group consists of operational parameters including inclination, pipe rotation speed, annuli size, and eccentricity. The fourth group consists of formation parameters such as temperature, pressure, and porosity.

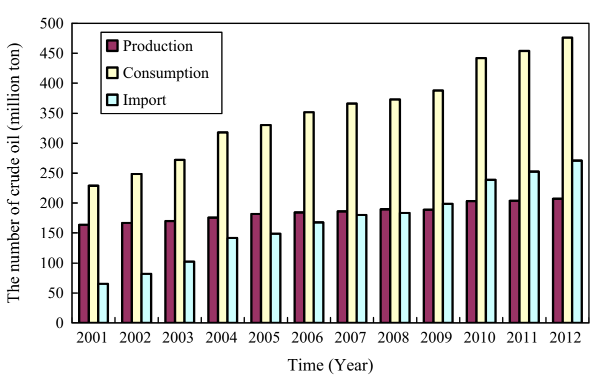

Fig. 1. Statistics of China's crude oil production, consumption and import [1].

To describe cuttings-transport efficiency quantitatively, a large number of empirical correlations and mechanical models were developed, and two types of parameters were used as target variables [11]. The first type indicates the amount of annular cuttings under a given drilling condition. Bed height (BH) [3], equivalent cuttings-bed height [12], dimensionless cuttings-bed height (DCH) [13], cuttings concentration (CC) [14], the ratio of cuttings bed area to wellbore area (RCW) [15], dimensionless cuttings-bed sectional area [16] are typical examples. The second type shows the required annular velocity to keep a minimum number of cuttings in a well. There are different names, such as required flow rates (RFV) [17], minimum foam volumetric requirement [18], maximum volume of cuttings [19], critical superficial gas velocity [20], critical foam velocity [21], optimum foam velocity (OFV) [22], and critical gas-flow rate [23].

2. Cuttings transport using aerated liquid

2.1. Effects of key parameters on cuttings transport with aerated liquid

Based on the previous experimental observations, there are many factors that affect the ability of the drilling fluid to efficiently carry cuttings and provide optimal hole cleaning, and some of such factors include liquid and gas velocities, inclination, pipe rotation, gas–liquid

Table 1
Effects of liquid/gas velocity on cuttings transport with aerated liquids.

Source	Gas velocity	Liquid velocity	Methods	Conclusions
Li and Walker [3]	6–36 m^3/h	6–36 m^3/h	BJ services, 12.7 × 6.0 cm	Carrying capacity increases dramatically for the in-situ liquid velocity larger than the critical value, and increasing liquid flow rate results in a lower cuttings-bed height
Naganawa et al. [5]	20–70 m^3/h	0.2–0.5 m/s	JNOC, 12.7 × 5.1 cm	Air injection can reduce significantly critical flow rate, and a small effect is presented in wavy stratified flow
Ozbayoglu et al. [8]	0.3–36 m/s	0.3–3 m/s	METU, 7.4 × 4.7 cm	Increasing gas flow rate or liquid rate can improve cuttings transport
Zhou et al. [12,24]	0–34 m^3/h	18–34 m^3/h	TUDRP, 15.2 × 8.9 cm	Gas injection has both positive and negative effects on hole cleaning depending on other flow parameters. The accumulation of cuttings is very sensitive to the liquid flow rate
Avila et al. [23]	11–91 m^3/h	45–114 m^3/h	TUDRP, 20.3 × 11.4 cm	Cuttings concentration is decreased by air injection
Osaouei [25]	0.3–36 m/s	0.3–3 m/s	METU, 7.4 × 4.7 cm	Carrying capacity of water-gas mixture is raised dramatically with the increase at liquid flow rate

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