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Study on the migration of gas kicks in undulating sections of horizontal wells

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ABSTRACT

Undulations are typically encountered in horizontal wells. Gas gathers at the top of undulating sections at low liquid velocity or well shut-in conditions. Thus, a gas slug is formed if gas kicks occur because of buoyancy, which makes well control more complex and difficult. In this paper, the storage and removal processes of the gas slug are simulated by experiments and the migration of the gas slug are analyzed. The results indicate that a minimum circulation velocity is required to remove the gas slug for a certain size and shape of undulating section of horizontal well. In addition, a migration model of gas kicks in undulating sections of horizontal wells is proposed based on the theoretical analysis. The model considers the effects of density difference, degree of curvature, surface tension, viscosity, and pipe diameter on gas slug removal rate and shows a good consistence with experimental results.

1. Introduction

The horizontal well widely exists in the oil and gas development with several advantages compared with the traditional vertical well, such as long oil reservoir penetration distance, enlarged drainage area and high well yield. The horizontal well also has obvious advantages in input–output ratio compared to various other well types [1–4]. If a gas kick occurs in the drilling process, the intruding gas has to be circulated out of the well section with low displacement to ensure drilling safety [5,6]. In the horizontal section of the well, gas cannot move along the flow direction easily because of buoyancy and circulation removal is more difficult than in vertical well sections [7]. The gas migrations in wellbores have attracted extensive attentions from many scholars and a great number of effective achievements have been received [8].

Commonly, the relationship of phase velocities in gas-liquid flow can be described using a drift flux model. Actually, the key model parameters including the distribution parameter and drift velocity can significantly different for various flow characteristics. The model of Zuber and Findlay [3] and the models of Hasan [4] and Cai et al. [5] are considered to be suitable for a typical bubble flow or slug flow, in which the distribution parameter is estimated as 1.2. The variations of flow rate and density are included in the correlations of distribution parameter given by Rouhani and Axelsson [6] and Woldesemayat and Ghajar [7] and those correlation further improve the accuracy of drift flux model. The distribution parameters expressed by the comprehensive drift flux model proposed by Chexal et al. [8] are variables, where the model is quiet complex for the field application, because fluid combinations are formed by several empirical curve fitting parameters through the correlation of the distribution parameters. The drift speed equations proposed by Hibiki and Ishii [9] and Beattie and Sugawara [10] are suitable for slug flow [2]. The entrained gas bubbles in liquid slugs are considered in the model established by Bonizzi and Issa [11]. The drift speed equation proposed by Woldesemayat and Ghajar [7] considers the influences of surface tension and pipeline diameter on drift speed apart from the influences of pipeline direction and system pressure.

The studies mentioned above mostly focus on vertical well sections and the characteristic of undulations of actual wellbore is not considered, especially for the undulations of the horizontal well sections. In the practical application of the drilling process, because the well track is difficult to control, the horizontal section is not absolutely horizontal and undulations sometimes occur where gas may be liable to be entrapped in a gas trap [12], as shown in Fig. 1.

In the downwards section of an undulation, buoyancy provides resistance to gas migration out of the wellbore. When the kill rate

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Nomenclature

E_g	gas volume fraction (dimensionless)	V_m	liquid phase velocity (m/s)
G	acceleration of gravity (m/s^2)	p	pressure (Pa)
F_{WG}	friction resistance of unit length of the wall acting on the gas phase (Pa/m)	θ	local inclination (°)
F_i	unit length of the gas–liquid interface force (Pa/m)	$\Delta\rho$	density difference of the gas phase and liquid phase (kg/m^3)
H/L	ratio of the downdip height to the inclination section and reflects the overall inclination of the bent downdip section (dimensionless)	ρ_g	gas phase density (kg/m^3)
		ρ_l	liquid phase density (kg/m^3)
		μ	liquid phase viscosity (kg/m·s)
U_g	gas phase speed (m/s)	σ	surface tension (N/m)
V_{gs}	migration velocity of the trapped gas (m/s)		

is low, gas entrapped in a gas trap cannot be released. When the drilling operation is restarted, the entrapped gas is displaced by dissolving into drilling fluid or through displacement increase. Consequently, overflowing will occur. The safety operation should be followed because the overflowing happened, which pumping is stopped and shut in and circulation kill need to be conducted again and further lead to the large waste of time. The results of previous researches have been summarized by E.H. Vefring, Zhihua Wang, and Sigurd Gaard et al., and a gas migration model of the horizontal well section has been established considering that the relative speed is a function of parameters such as viscosity and borehole size [13–18], but the key parameter of gas relative migration speed expressions is not taken into account.

In this study, in view of the special condition of the gas trap caused by undulations of the horizontal section, an experimental facility was established and the factors influencing gas trap discharges were obtained.

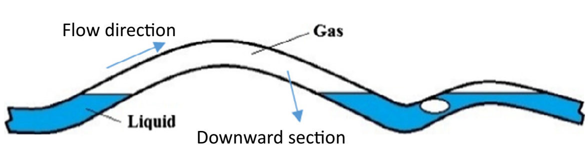

Fig. 1. Gas trap formed by undulations of the horizontal section.

2. Horizontal well gas trap migration experiment

2.1. Experimental facilities

Vefring et al. believed that the gas trap is discharged mainly as forms of replacements of large bubbles under the high liquid-phase speed condition. For the discharge of the gas trap under the medium liquid-phase speed condition, the gas core prefers to be entrained by liquid phase due to shearing force. For the discharge of the gas trap under the low liquid-phase speed condition, the gas will dissolve into the liquid phase firstly and then move out of the well with liquid phase.

We set up a visual experimental facility to simulate the undulations of horizontal wells, analyzed the discharge process, and studied the discharge process and factors influencing the entrapped gas. A flow chart of the experimental facility is shown in Fig. 2 and a photograph of the facility is shown in Fig. 3. The experimental system consists of a gas intake system, a liquid inlet system, an experimental pipe section system, and a measurement system, within which the experimental horizontal measurement section is an organic glass pipe simulation wellbore pipe with a length of 12 m and an inner diameter of 0.05 m. The intake system consists of an air compressor, a gas tank, and a hydraulic line. Compressed air is supplied to the gas tank by means of an air compressor, a gas storage tank, and a hydraulic pipeline, and its flow rate is controlled by another mass flow meter ranges from 0 to 150 Nm^3/h. The compressed air is conveyed into the gas storage tank through

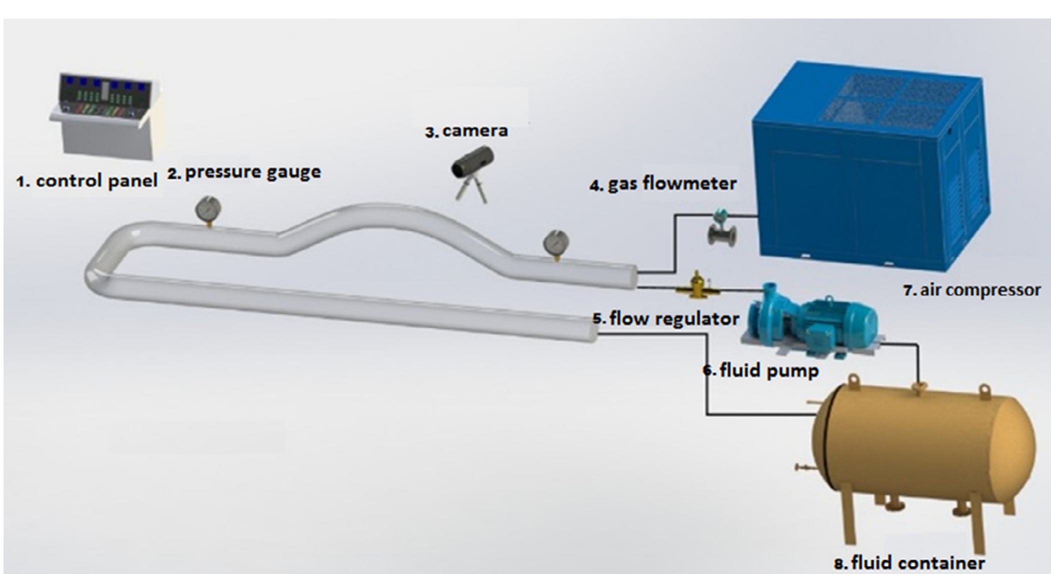

Fig. 2. Flow chart of the horizontal gas–liquid flow experiment.