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Transient simulation of the blowing-out process of the air pockets in vertical wellbore

Jianyu Xie [a], Xinyu Zhang [a], Yawen Tang [a], Yan Wang [b], Qianqian Shao [a], Bo Yu [a,*]

[a] National Engineering Laboratory for Pipeline Safety/Beijing Key Laboratory of Urban Oil and Gas Distribution Technology, China University of Petroleum, Beijing 102249, China
[b] Navy Institute of Engineering Design & Research, Beijing 100070, China

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ABSTRACT

For a better control of drilling flow, it is important to grasp the changing rule of well-head parameters during blowout. In this study, we develop a one-dimensional ideal transient model composed of a set of governing equations, and a numerical code is developed by Fortran based on the model. The method of characteristics is employed to transform the nonlinear coupled differential equations to ordinary ones. The simulation results indicate that the effect of well depth on the outlet velocity of wellhead is more significant than that of hydraulic diameter, fluid density and slug unit length.

1. Introduction

During the drilling process, minor incidents such as gas cut and gas kick are likely to emerge when the pressure in the wellbore is smaller than the formation pressure. As a result, air pockets formed by the accumulation of gas will move upward. If proper measures are not taken against this situation, uncontrolled pressurized fluids flowing from the well, which is termed blowout, may strike and further cause heavy casualties and widespread damages to both the environment and the property in a form of formidable blowout-generated shock-waves [1–3]. Moreover, there is a possibility of gas/oil combustion, and if the gas plume erupted ignites, various additional problems emerge. Hence, in order to provide data for the well control in the future, it bears significant importance to accurately simulate and predict variation of the wellhead parameters during blowout, especially the velocity at wellhead.

Most relevant studies address kick detection and blowout control, but only a few references deal with actual blowout process. As the blowout process involves the transient multiphase flow and heat transfer, steady models were developed by the earlier researchers [4–6]. J. LeBlanc and R. Lewis [4] assumed that there was only slug flow in the wellbore, and presented a mathematical model to analyze annular backpressure variations associated with controlled gas kicks and their significant influences on casing strings and exposed underlying formations. However, there is only one single continuous slug in the whole process. E. Blount and E. Soeiinah [5] developed a steady mathematical model to study the influence of the various parameters on the severity of the gas kick under both water-base drilling fluid and the oil-base drilling fluid condition. A. Clark and T. Perkins [6] established a method, for calculating the critical flow rates, pressure, and temperature at the exit of a blown-out oil well, which depends on the wellbore geometry, the thermal properties of the wellbore and its surrounding. Until now, this method remains the best one to comprehend. Later, transient models were also employed to study blowout issues [7–11]. Some representative works will be introduced as follows: H. Nickens [9] represented a model which could predict the detailed flow and pressure variations of the well during the blowout process. The limitation of the model is that it could only be utilized for one time of kick. F. Jun et al. [10] proposed a transient model, which is composed of a set of equations with respect to gas/mud transient flow natures, gas influx and pressure balance relationships, and obtained necessary parameters for control of the empty hole blowout. A. Hasan et al. [11], on the basis of G.B. Wallis's work [12], developed a one-dimensional homogeneous model of the fluid flow in the blowout process, and the influence of the various parameters on the time and velocity of the blowout were also analyzed.

* Corresponding author.
E-mail address: yubobox@vip.163.com (B. Yu).

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Nomenclatures

a	pressure wave velocity (m/s)
D	diameter (m)
m	molecular weight (g/mol)
P	pressure (Pa)
R	ideal gas constant (J/(mol K))
T	temperature (K)
V	velocity (m/s)
t	time (s)
Greek symbols	
ρ	density (kg/m^3)
γ	polytropic exponent
Subscripts	
g	gas phase
I	initial time instant
i	the ith node
l	liquid phase
M	moving mesh
n	the nth time instant
O	outlet
BTM	bottom
sl	slug

Previous researchers have carried out a lot of studies about the well control, but few of them actually have involved the blowout process. Due to the different types of drilling wells, these studies are lack of universality. In this study we aim to develop a one-dimensional ideal model to describe the fluid flow in one sort of blowout problems described in the physical model, and find the relationship between time and velocity of blowout under the influences of different factors.

The layout of this paper is as follows: the physical problem and mathematical models are firstly described, and then they are employed to calculate the coupled variations especially the velocities of the different sections of the fluid flow. At last, different factors which may have influences on the blowout process are analyzed.

2. Mathematical model

When blowout occurs, the flow pattern in wellbore is most likely to be slug flow and churn flow [13], which are similar in that gas phase and liquid phase are separate and alternate in the dominant section. Moreover, what is cared about most in engineering practice is the wellhead flow rate during the blowout control process. Based on the above situation, this paper puts its emphasis on the hydraulic characteristics after the slug flow or churn flow in wellbore, which have been fully developed. For the convenience of solving the mathematical model, some assumptions are made as follows to simplify the practical situation.

(1) According to the work in Refs. [14], when the wellbore depth is less than 1500 m, the temperature difference of the fluid in the wellbore is less than 25 K. In our study, the maximum wellbore depth is 1200, it can be estimated that the drilling fluid temperature difference is small and the thermal influence on the physical properties of the drilling fluid can be neglected. For simplicity the physical properties of the drilling fluid are evaluated by its mean temperature.

(2) The slug flow and churn flow have been fully developed before the simulation, thus, some general parameters are employed in this paper.

(3) The interface between gas and liquid phase is clear and vertical to the wellbore axis. For calculation convenience, the drill pipe outer diameter and hole size is treated as unchanged in different depths without considering the irregular open-hole size, casing internal diameter and other anomalies in the wellbore.

(4) Phase transition such as vaporization is not considered. Gas in the air pocket is treated as ideal gas.

Based on the above assumptions, we abstract the physical model from the actual physical problem, as shown in Fig. 1.

According to the above assumptions and simplifications, a mathematical model describing the transient blowout process is established as follows:

(1) Governing equations of the liquid and gas phase

The momentum and continuity equations for liquid phase are

$$\frac{\partial V_l}{\partial t}+v_l\frac{\partial V_l}{\partial x}+\frac{1}{\rho}\frac{\partial P_l}{\partial x}+\frac{2f}{D}V_l|V_l|+g=0 \quad (1)$$

$$\frac{\partial P_l}{\partial t}+v_l\frac{\partial P_l}{\partial x}+\rho_l a_l^2\frac{\partial V_l}{\partial x}=0 \quad (2)$$

Those for gas phase are

$$\frac{\partial V_g}{\partial t}+v_g\frac{\partial V_g}{\partial x}+\frac{2}{\gamma-1}a_g\frac{\partial a_g}{\partial x}=0 \quad (3)$$

$$\frac{\partial a_g}{\partial t}+v_g\frac{\partial a_g}{\partial x}+\frac{\gamma-1}{2}a_g\frac{\partial V_g}{\partial x}=0 \quad (4)$$

where γ is a polytropic exponent, whose value assigned to be 1.2 in this paper.

(2) Additional equations in the blowout process

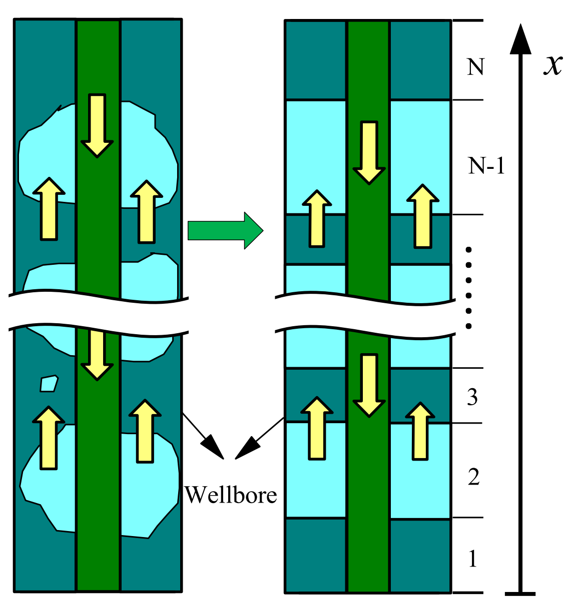

Fig. 1. Ideal physical model.

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