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Research Article

Estimation of gas blowout volume in wells with uncontrolled blowout and laboratory studies

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Abstract

Gas blowout occurred during drilling may cause catastrophic environmental hazards and economic losses. It is thus one of the important tasks to accurately determine the gas blowout volume so that an effective rescue plan can be worked out in case of gas blowout. In this paper, a numerical method for estimating the gas blowout volume was presented based on the Bernoulli Equation and the corresponding software was programmed. In the process of numerical estimation, the velocity distribution of the blowout flame characterized by the axisymmetric laminar flow was investigated through an analysis of the dynamic flowing features of the gas gusher, and the relationship between the gas production of a well and the height of the blowout flame was then analyzed with the Bernoulli Equation to obtain the numerical results of the gas blowout volume. The results were then compared with those laboratory measurements, and the software was revised based on the comparisons. Some conclusions were drawn. First, when the spout shape of a gusher is constant, the gas production is proportional to the height of the blowout flame, and inversely proportional to the gas kinematic viscosity, the stoichiometric ratio factor and the oxygen concentration. Second, the errors between the results estimated using the revised software and the laboratory measurements are within the allowable range, and the software can automatically generate a report. In a word, the method and software presented in this paper can be an effective technique for preparing a sound and safe rescue plan in case of gas blowout, and is of great significance in relieving the hazards of a well with uncontrolled blowout.

Keywords: Gas well; Well with uncontrolled blowout; Estimation of gas blowout volume; Gas production; Axisymmetric; Laminar flow; Gas gusher; Flame height; Software

1. Introduction

Blowout usually occurs in wells under operation rather than production. Known blowout accidents are almost all caused by mechanical failure, inaccurate knowledge of formation pressure and low drilling fluid density. Study on blowout mechanism can help to ensure safe production and reduce or avoid accidents [1]. The possibility of blowout could be predicted by investigating the blowout prediction mechanism and monitoring the drilling engineering parameters during well drilling. Study on gas–liquid flow during well kick shows that the destructive power of blowout increases with the flow velocity of the wellhead fluid after blowout [2]. After the occurrence of blowout, rapid and effective implementation of rescue actions on uncontrolled wells can mitigate the harms of accidents. Many scholars have worked on it. Studies on the prediction method of outflow velocity and kinematic characteristics of blowout of uncontrolled wells are of practical significance in helping quick firefighting and barrier clearance. Studies on the

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mechanical behavior of gas jet flow and burning body from uncontrolled and on-fire wells could help to make accident management plan and conduct emergency operation [3,4].

At present, the studies mostly focus on the blowout mechanism or blowout behavior of uncontrolled wells. Once a blowout accident occurs, the output of an uncontrolled well can hardly be estimated, which will present a negative impact on rescue actions. In this regard, this paper presents a method for estimating the gas blowout volume of an uncontrolled well. For verifying the accuracy of the theoretical study and calibrate the calculation software, the basic input parameters were determined according to field data and software results were compared with the experimental results. The study results could provide theoretical bases for the estimation of natural gas production and the subsequent development of uncontrolled wells. They are also practically significant to the rescue action of uncontrolled wells, helping to make reasonable emergency rescue plan, reduce personnel injury and economic loss, and minimize environmental pollution.

2. Method and model of gas blowout volume estimation

Generally, gas gusher of an uncontrolled well is basically a turbulent jet flow, and its behavior characteristics could be influenced by many factors. For facilitating gas blowout volume estimation of an uncontrolled well, a model was designed based on the following assumptions [5] that: ① the ground is horizontal and the effect of the ground effect on the jet is ignored; ② the ambient fluid density is equal to the local air density; ③ the impact of thermal conductivity on the heat transfer is ignored; ④ there is no barrier around the spout and the gas gusher which flows directly into the atmospheric environment; and ⑤ the spout has a regular shape with a definable cross-sectional area, which is defined according to the actual production and natural gas well drilling parameters.

Natural gas in the formation is blowout from the wellhead of the uncontrolled well and forms gas gusher in the air, which is a gas jetting process subject to the gas jet equation, continuity equation, momentum conservation equation and energy conservation equation [6]:

$$\frac{\partial \rho}{\partial t} + \nabla(\rho V) = 0 \tag{1}$$

$$\frac{\partial(\rho V)}{\partial t} + \nabla(\rho VV) = -\nabla p + \nabla\tau + \rho g \tag{2}$$

$$\frac{\partial(\rho h)}{\partial t} + \nabla(\rho Vh) = \nabla\left[p\left(\frac{\mu}{\sigma} + \frac{\mu_t}{\sigma_t}\right)\nabla h\right] \tag{3}$$

where, ρ is the density of the mixed gas, kg/m^3; t is the time, s; ∇ is the divergence operator; g is the acceleration of gravity, m/s^2; V is the speed of Renault average, m/s; p is the static pressure, Pa; τ is the viscous stress tensor, Pa; h is the enthalpy of the mixed gas, J/kg; μ is the turbulence molecular viscosity, Pa·s; μ_t is the turbulence viscosity, Pa·s; σ is the turbulent Prandtl number; σ_t is the turbulent Schmidt number.

The gas gusher of the uncontrolled well is a multi-component mixture of gas, which should be subject to the component mass conservation equation as follows:

$$\frac{\partial(\rho Y_i)}{\partial t} + \nabla(\rho V Y_i) = \nabla\left[p\left(\frac{\mu}{\sigma} + \frac{\mu_t}{\sigma_t}\right)\nabla Y_i\right] \tag{4}$$

where, Y_i represents the mass fraction of component i.

According to the combustion theory [7], when the jet is in a laminar flow state, the velocity distribution of the axisymmetric laminar flow combustion flame can be expressed as:

$$F(x, r') = \left(1 + \frac{48}{Re}\frac{x}{D}\right)^{-1}\left[1 - 2\left(\frac{r'}{D}\right)\left(1 + \frac{48}{Re}\frac{x}{D}\right)^{-1}\right] \tag{5}$$

where, x and r' are the axial and radial positions of the cylindrical coordinates, respectively; D is the spout diameter, m; Re is the Reynolds number.

In the laminar flow, when the momentum, heat and mass diffusion coefficients of the laminar flow are equal, the velocity field distribution is basically consistent with the temperature field and concentration fields. The equation of jet flow rate field, temperature field and concentration field is [4]:

$$F(x, r') = \frac{V}{V_i} = \frac{T - T_\infty}{T_i - T_\infty} = \frac{Y_F}{Y_{Fi}} \tag{6}$$

where, V_i is the gas flow rate at the center of the jet, m/s; T_i is the jet temperature, K; T_∞ is the ambient medium temperature, K; Y_F is the mass concentration of a position; Y_{Fi} is the mass concentration of the jet component.

Assuming the burning velocity is high, which is instantly completed at a stoichiometric ratio of the fuel and oxide, so, at the flame surface:

$$Y_O = Y_F = 0 \tag{7}$$

According to this feature, the variable b_{FO} is referenced,

$$b_{FO} = -Y_{O\infty} \tag{8}$$

where, $Y_{O\infty}$ is the oxygen concentration. At the spout position:

$$\begin{cases} Y_O = 0 \\ Y_F = 1 \end{cases} \tag{9}$$

then,

$$b_{FO} = -\left(\frac{1}{f_{st}} + Y_{O\infty}\right) \tag{10}$$

where, f_{st} is the stoichiometric ratio factor.

Taking Eqs. (8) and (10) into Eq. (6), we can get:

$$F(x, r') = \frac{Y_{O\infty}}{Y_{O\infty} + \frac{1}{f_{st}}} \tag{11}$$

When the spout shape is unchanged and the gas flow rate is constant, the maximum distance that the flame can extend x_c is the flame height l. When $r' = 0$ in Eq. (5), the axisymmetric laminar flow jet flame distribution could be obtained: