Journal of Loss Prevention in the Process Industries 31 (2014) 105–112

Contents lists available at ScienceDirect

Journal of Loss Prevention in the Process Industries

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

Numerical analysis of the effects of fluctuations of discharge capacity on transient flow field in gas well relief line

Hongjun Zhu*, Jian Wang, Xiaoyu Chen, Juan She

State Key Laboratory of Oil and Gas Reservoir Geology and Exploitation, Southwest Petroleum University, Chengdu, Sichuan, 610500, China

A R T I C L E I N F O

Article history:
Received 7 September 2012
Received in revised form
3 June 2014
Accepted 20 July 2014
Available online 28 July 2014

Keywords:
Mass flow rate
Relief line
Discharge capacity
Transient gas flow
Numerical simulation

A B S T R A C T

Transient gas flow in relief line is computed to determine the effects of fluctuations of discharge capacity on flow field. Based on the theories of computational fluid dynamics and aerodynamics, the solution and the analysis were carried out using finite volume CFD solver FLUENT 13.0. Flow fields in seven working conditions were simulated in the numerical investigation and their results were compared. The results showed that the fluctuations of discharge capacity, including extent and period, exert obvious effects on transient gas flow field in relief line. The larger the fluctuation extent and the shorter the fluctuation period, the more significant is the effect. The application method of simulation results is provided to guide the laying and fixing of pipelines, which is verified by filed measurement.

1. Introduction

For high-pressure gas well, safe tests act on the premise that gas flow is discharged through relief lines and blazed adequately in the burner at the end of pipes. Fluctuations of discharge capacity put a direct impact on the transient gas flow field in relief line, giving rise to pipe vibration or swing, which is a potential safety hazard to the field operation. For example, the gas discharge capacity of a well in Sichuan–Chongqing region is about 0.2 million to 1 million m^3/d, and the fluctuation is about 0.1 million to 0.3 million m^3/d. Flow field thus changes significantly in relief line and gas flow usually reaches the speed of sound in the end. In addition, the installation of relief lines with bends is sometimes unavoidable, which exacerbates the pipe vibration. Especially, gas wells in Sichuan–-Chongqing region generally have high sulfur content. Once relief lines failure occur due to pipe vibration, the consequences may be disastrous.

In order to control the pipe vibration, recently, gas well relief lines are fixed with anchor bolts in cement blocks in some oil fields, as shown in Fig. 1. However, there still have been no accurate calculation method and basis to determine the size of cement block and the arrangement distance. Since the pipe vibration is caused by the change of flow field in relief line, the transient gas flow properties are urgently needed to guide the laying and fixing of pipelines and the design of relief lines.

Considerable research has been performed on steady-state gas flow in pipes. Stanley (1990) studied a practical approach to the design of relief systems for handling multi-component flashing flows. Friedel and Schmidt (1993) proposed a fluid dynamic design methodology for long safety valve vent line systems for gas relief. Perbal (1993) performed experimental research on gas flow in pipelines. Ouyang and Aziz (1996) developed new general flow equations of simple form to account for the pressure drops of steady-state gas flow in pipes. Herty, Mohring, and Sachers (2010) built a new model for gas dynamics in pipe networks by asymptotic analysis. However, few studies have been performed on transient gas flow in high-pressure gas well relief lines.

The goal of this paper is to analyze the effects of fluctuations of discharge capacity, including the fluctuation extent and fluctuation period, on transient gas flow field in relief line. Based on the theories of computational fluid dynamics and aerodynamics, velocity and pressure distributions in relief lines under seven working conditions were simulated using finite volume CFD solver FLUENT 13.0. The results not only give valuable information about the transient gas flow field due to fluctuations of discharge capacity, but also provide information for the design of relief lines.

* Corresponding author.
E-mail address: ticky863@126.com (H. Zhu).

http://dx.doi.org/10.1016/j.jlp.2014.07.008
0950-4230/

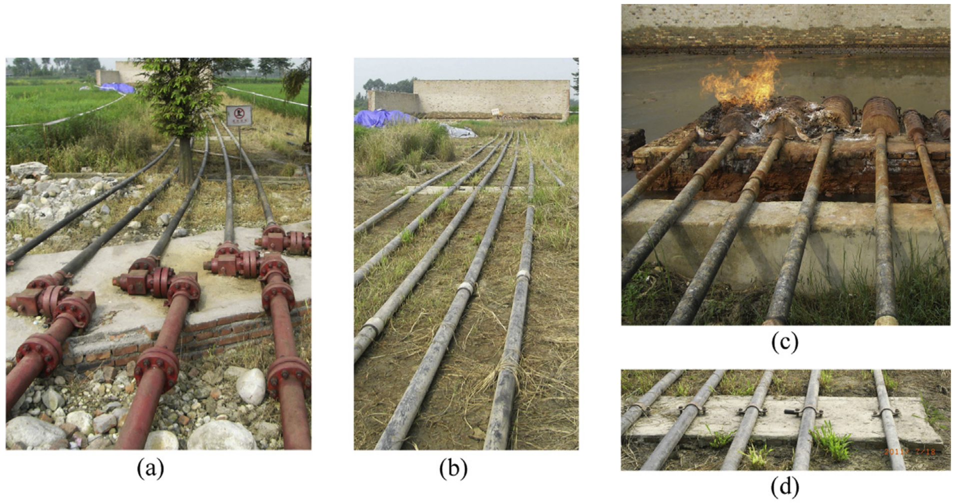

Fig. 1. Relief lines of a gas well in Sichuan–Chongqing region in China: (a) elbows in front of straight pipes, (b) straight pipes, (c) ignition in the outlet of relief lines, (d) pipes fixing with anchor bolts in cement block.

2. Numerical procedure

2.1. Governing equations

In this study, compressible and unsteady flow was assumed. Euler approach (Arif & Ramon, 2009; Khurram & Arif, 2006; Yinnian, Aiwen, & Liquan, 2005; Yinnian & Kaitai, 2005) was used to calculate the gas flow field in relief line. The governing equations, including continuity equations and momentum equations, are as follows:

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

$$\frac{\partial(\rho \vec{v})}{\partial t} + \nabla(\rho \vec{v}\vec{v}) = -\nabla p + \nabla \tau + \rho \vec{g} + \vec{F} \tag{2}$$

in which ρ is the density of natural gas (kg/m^3), v is the velocity (m/s), τ is the viscous stress (Pa), p is the pressure (Pa), F is the other volume force (N/m^3) and g is gravitational acceleration (m/s^2).

2.2. Turbulence model

Turbulent flow presents in relief line due to the high velocity of gas flow. So the realizable k-ε turbulence model (Kimura & Hosoda, 2003; Maele & Merci, 2006; Xie, Liu, & Leung, 2006) was used to close the flow governing equations and describe the turbulent properties.

$$\frac{\partial(\rho k)}{\partial t} + \frac{\partial(\rho k u_i)}{\partial x_i} = \frac{\partial}{\partial x_j}\left[\left(\mu + \frac{\mu_t}{\sigma_k}\right)\frac{\partial k}{\partial x_j}\right] + G_k + G_b - \rho\varepsilon - Y_M \tag{3}$$

$$\frac{\partial(\rho \varepsilon)}{\partial t} + \frac{\partial(\rho \varepsilon u_i)}{\partial x_i} = \frac{\partial}{\partial x_j}\left[\left(\mu + \frac{\mu_t}{\sigma_\varepsilon}\right)\frac{\partial \varepsilon}{\partial x_j}\right] + \rho C_1 E\varepsilon - \rho C_2 \frac{\varepsilon^2}{k + \sqrt{\upsilon\varepsilon}} + C_{1\varepsilon}\frac{\varepsilon}{k}C_{3\varepsilon}G_b \tag{4}$$

where,

$$C_1 = \max\left(0.43, \frac{\eta}{\eta + 5}\right) \tag{5}$$

$$\eta = \left(2E_{ij}\cdot E_{ij}\right)^{1/2}\frac{k}{\varepsilon} \tag{6}$$

$$E_{ij} = \frac{1}{2}\left(\frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i}\right) \tag{7}$$

in which k is turbulent kinetic energy per unit mass (m^2/s^2), ε is turbulent kinetic energy dissipation rate per unit mass (m^2/s^3), μ_t is dynamic viscosity (Pa·s), υ is molecule kinetic viscosity (m^2/s), G_k is production term of turbulent kinetic energy due to the average velocity gradient (N/(m^2·s)), G_b is production term of turbulent kinetic energy due to lift (N/(m^2·s)), Y_M is the impact of compressible turbulence inflation on the total dissipation rate (kg/(m·s^3)), E is time-averaged strain rate (S^{-1}), C_1 and η are constants calculated by Eq. (5) and Eq. (6), $C_{1\varepsilon}$, $C_{3\varepsilon}$ and C_2 are empirical constants taken as 1.44, 0.09 and 1.9 respectively, σ_k and σ_ε are Prandtl numbers corresponding to turbulent kinetic energy and turbulent kinetic energy dissipation rate, taken as 1.0 and 1.2, respectively.

2.3. Numerical solution methodology

All computations in this study are performed using the finite-volume commercial CFD code, FLUENT 13.0. The compressible flow computations have been performed using the coupled implicit iterative solution procedure. And the Second-order upwind scheme is adopted for the momentum equation. Convergence and steady-state are examined by noting the diminishing normalized residual levels ($<10^{-5}$). The details of the computational procedure are available in the FLUENT code documentations.

In order to compare the changes of flow field before and after the fluctuation of discharge capacity, steady-state flow field in a given discharge capacity was calculated firstly, and then transient flow field induced by the fluctuation of discharge capacity was calculated with a time step Δt 0.01 s, which was obtained by repeating computations until a satisfactory precision was found.

2.4. Computational domain and mesh

A relief line of a gas well in Sichuan–Chongqing region in China was selected to analyze. This relief line includes three straight pipes, the lengths of which are 5 m, 10 m and 100 m respectively