Process Safety and Environmental Protection xxx (2014) xxx–xxx

Contents lists available at ScienceDirect

Process Safety and Environmental Protection

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

Investigation of gas purging process in pipeline by numerical method

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ABSTRACT

Gas purging processes in pipeline safety maintenance were studied using the Computational Fluid Dynamics (CFD) methods. A new model (model 1) closer to actual working conditions and another two-side injection model were investigated. The simulation results showed that the relative purging efficiency of model 1 decreases compared to the ideal model (model 0), and two-sided injection model increases the efficiency relative to the single sided purging model. In addition, the models with different intake methods, outlet positions, outlet sizes and outlet pressures were simulated. If the outlet is opened after delaying some time, purging efficiency is improved. Furthermore if "relay purging" method is adopted, the efficiency is increased by 18% with two gas inlets and by 11% with a single inlet. The outlet position affects the average velocity in the last purging time. If the outlet diameter is equal or larger than that of the inlet, the purging efficiency is much higher.

Keywords: Hot work; Nitrogen replacement; Gas purging; Oil and gas transportation; Pipeline

1. Introduction

Welding and other hot work repairs are normally carried out when leaks occur during oil and gas pipeline network maintenances (Cruz et al., 2005; Mahgerefteh et al., 2005; Abhulimen and Susu, 2007; Lopes et al., 2012; Lowesmith and Hankinson, 2013). Potentially dangerous situations could arise if the inflammables mixed with air or oxygen gas meet the flames or sparks. Therefore, some safety strategies, including separating, sealing, pigging, venting and so on, should be adopted (Perkins and Euchner, 1988, Moore and Spring, 2005; Escoe, 2006; Roland et al., 2008). Gas purging is one of the most important processes for pipeline hot work. The American Gas Association (AGA, 2001) has released a criterion XK0101, which contains principles and practices for pipeline purging. Nitrogen is usually used to displace the combustible gases in the pipe with or without isolator. Pig is often adopted as the replacement isolator in purging process (Tolmasquima and Nieckele, 2008; Vik et al., 2010). Another gas to gas replacement method without isolator was also taken attention on, in which the nitrogen gas section in a pipe can be viewed as the isolator (Hu, 2006; Fu, 2009), which is also the method discussed in the present work.

There are two main devices used for gas purging, blower and expeller (AGA, 2001; Hawryluk and Botros, 2008), which are shown in Fig. 1. Here, Fig. 1a is the expeller method and Fig. 1b is the blower method. The expeller method uses an air mover to draw air into the pipe at the work site and moves the combustible gas through the pipe toward the expeller, while the blower method uses a gas compressor to inject an inert gas into the pipe at the inlet and moves the combustible gas toward the outlet near the work site. Numerous investigations have been carried out to improve gas purging efficiency. Botros et al., 2007a, Botros et al. (2007a, b) of the NOVA Chemicals Research and Technology Corporation proposed an equivalent resistance coefficient (K_e) and induction

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http://dx.doi.org/10.1016/j.psep.2014.04.013

0957-5820/

Please cite this article in press as: Ma, D., et al., Investigation of gas purging process in pipeline by numerical method. Process Safety and Environmental Protection (2014), http://dx.doi.org/10.1016/j.psep.2014.04.013

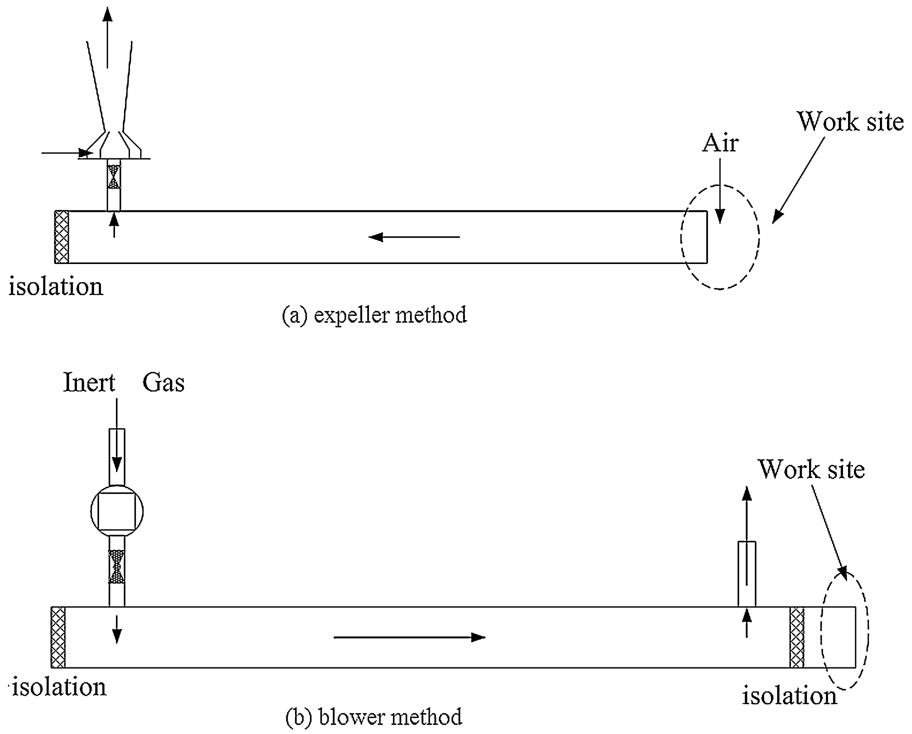

Fig. 1 – Types of gas purging for pipeline: (a) expeller method and (b) blower method.

ratio (R) to determine the performance of a given expeller on any given pipeline system. They also tested two different types of expellers in field and found that there is a limiting characteristic of the system, beyond which a larger size expeller does not induce higher suction flows. CFD methods were also used to study the gas transportation in pipeline. Ekambara and Joshi (2004) developed a computational model to simulate the axial dispersion phenomena in laminar pipe flows. Sami and Ezzeddine (2008) studied the transient flow in pipelines of high-pressure hydrogen–nature gas mixture using the finite difference method. Behbahani-Nejad and Shekari (2010) studied a reduced-order model for transient flow analysis in gas pipelines. The implicit Steger–Warming flux vector splitting method (FSM) was used to solve the governing equations. Kaushala et al. (2012) used a CFD model for pipeline flow of fine particles at high concentration, in which the software Fluent was used and the results with Mixture and Eulerian two-phase model were both in well agreement with the experiment. Shahirpour et al. (2013) used the Large Eddy Simulation (LES) method to study CO_2 turbulent pipe line transportation and the results were compared with those from direct numerical simulation (DNS). Hu (2006) and Fu (2009) studied the nitrogen replacement in natural gas pipeline using a model based on the blower method by CFD tool. Liu et al. (2011) used a numerical simulation method to acquire some replacement information and then some parameters for nitrogen displacement are predicted by the neural network.

However, only the full-size free-access inlet and outlet model was used in their work, as shown in Fig. 2a, which does not agree well with the real case in the field. Hence, the methodology adopted in this paper is a model which is close to the actual working condition, as shown in Fig. 2b. Moreover, some methods on how to improve purging efficiency based on this model and how to quantify the purging performance of these different methods will be discussed in this paper. Since CFD simulation is a useful tool to study the fluid flow in pipelines (John, 1995; Galeev et al., 2012), a commercially available CFD software, Fluent 13, is selected here as the numerical tool to study the pipeline gas purging.

2. Mathematic model

2.1. *Basic mathematic model*

Here, in order to simplify the computation process, the purging gas is nitrogen and the pipeline is 500 m long; the diameter of the pipe is 0.5 m, and the following three assumptions are adopted (Fu, 2009):

(1) The variations of pipe radius are neglected.
(2) There are no circumferential variations of flow and concentration in the pipe. For model 0 in Fig. 2, the gases passes from full-size inlet to outlet, therefore it can be viewed as a 2-dimension axial symmetry problem. For model 1 and model 2, the mathematical model is 2-dimension full size model because of their geometric structures.
(3) Air is viewed as a single material. The transporting process can be treated as a problem with two kinds of gases, air and inert gas.

Therefore, a 2-dimension mixed gas transporting model is built based on the following basic mathematic governing equations (Batchelor, 1967; Patanker and Spalding, 1972; John, 1995; Ekambara and Joshi, 2004; Launder and Spalding, 1974).

The equation for conservation of mass, or continuity equation, can be written as follows:

$$\frac{\partial \rho}{\partial t} + \nabla \cdot (\rho \vec{u}) = S_m \quad (1)$$

where ρ is the density of mixed gas; $\vec{u}$ *is the* velocity vector; t is gas purging time; the source S_m is the mass added to the continuous phase from the dispersed second phase and any user-defined sources.