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Experimental investigation aiming at improving the suction flow capability of a gas expeller

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ABSTRACT

An expeller performance has been evaluated in terms of its capability to induce higher suction flow for application to evacuate combustible gases from a blown down natural gas pipelines. The investigation involved a test rig and testing of a typical 150 mm (nominal size) expeller. This particular expeller has 12, 2.35 mm diameter holes, equally spaced around the throat circumference of the expeller. This was referenced to as the base (or original design). The aim of the present investigation is to improve the suction flow capability of this expeller by four modifications to both the number and/or sizes of these holes. The experimental results showed that the performance of the expeller in terms of its capability of driving higher suction flows for a given flow resistance system can be improved by increasing the number and sizes of the drive air holes which in turn permit higher drive air flow. However, with increased drive air flow, the performance of the expeller in terms of the induction ratio (*IR*) deteriorates, but luckily not at the same rate as the suction flow increases. Hence a cost effective means to improve the suction flow capability of an expeller is to drill more and larger size holes around its throat. The loss in the *IR* (which is efficiency related), however, is generally not a concern in practice when the economic benefit of evacuating the pipeline section in a timely and safe manner greatly overweigh any potential loss in the expeller *IR* efficiency. It was also shown that expeller performance in terms of its *IR* improves with smaller hole size. Therefore, to improve an expeller suction flow capability, while maintaining its performance efficiency (i.e. *IR*), larger number of the same or smaller holes should be considered.

1. Introduction

Expellers are commonly used in the gas pipeline industry to remove (expel) remaining gas in an isolated section of a pipeline after the section has been blown down to ambient pressure through the blowdown stacks at either end. Once this first step is completed (i.e. blowdown from line pressure to ambient pressure), expellers are mounted either on one side or two sides of the pipeline section, again on the respective blowdown stacks. (Fig. 1). When the expeller(s) are turned on either or both ends, air is drawn into the pipeline section at the work site (Bacon, 2000; Huang et al., 1999; Chen et al., June 1998; Villa et al., November 1999; McElligott et al., 1998; Parker, 1989; Pankratov et al., December 1987), and hence drive the combustible gas through the pipe toward the expeller (Fig. 1). Compressed air (up to 1034 kPa-g or 150 psig) is used to drive expellers, which allows the operator to control the amount of airflow ingress through the opening at the work-site as well to balance the amount of airflow going in either direction depending on the location of opening along the pipeline section in relation to the two ends where the expellers are mounted.

The drive air is fed to the expeller by a portable air compressor in the field. One or two compressors (depending on the air flow requirement) are typically used. No additional moving parts are employed by expellers, but they operate on the venturi principle where low pressure is created (induced) at the throat of the expeller by the compressed drive air flowing through a set of holes at the bottom of the device, as shown in the schematic of Fig. 2. The venturi concept is similar to that employed in subsonic ejectors (Sun and Eames, Jun 1995; Huang et al., 1999; Chen et al., June 1998; Villa et al., November 1999). The industry provided a guideline (American Gas Association, June 2001) for the appropriate selection of expellers and the appropriate practices of evacuating gas pipeline sections of different lengths and diameters.

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Nomenclatures

A_o	hole area of drive air
A_{exp}	expeller throat area
C_1	constant
C_2	constant
C_d	orifice discharge coefficient
D	pipe internal diameter
g	acceleration of gravity
$I.R.$	induction mass ratio
K_e	equivalent resistance coefficient
$\dot{m}_d$	drive air mass flow rate
$\dot{m}_s$	induced (or suction) mass flow rate
P_o	drive air pressure
$(V_{purge})_{\min}$	minimum purge velocity
ρ_a	density of air
ρ_g	density of gas

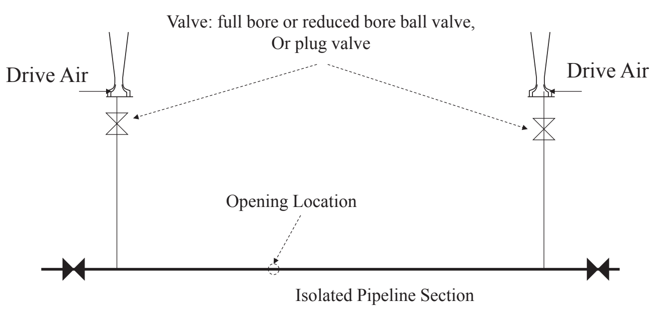

Fig. 1. Evacuation of an isolated pipeline section with two expellers at both ends.

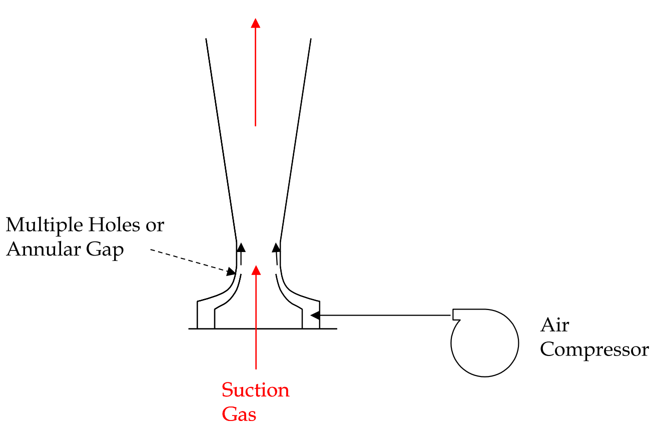

Fig. 2. The venturi concept at the throat of an expeller.

The flow rate of air drawn into the pipeline section through the opening, which is driven by the blow off gas drawn by the expeller(s) (suction flow) is dependent on the drive air flow and the drive air pressure, as well as the flow resistance to the suction flow introduced by the pipeline wall friction, entrance losses at the bottom of the stack, and all other fittings along the suction flow path. A methodology has been developed in (Botros et al., 2007a, 2007b), which allows proper quantification of the effects of these resistive elements on the effectiveness of the expelling procedure and the time it takes to completely evacuate the pipeline section. The performance of expellers is given by the induction ratio, *IR*, which is defined as the ratio of the mass flow of the suction flow ($\dot{m}_s$) induced by the expeller and the drive flow of the compressed air or gas ($\dot{m}_d$) (Botros et al., 2007a). The induction ratio of an expeller installed on a pipeline system is related to the overall equivalent flow resistance coefficient (K_e) of the pipeline, referenced to the dynamic head at the throat of the expeller, and is expressed by the following relationship (Botros et al., 2007a, 2007b):

$$IR = \frac{\dot{m}_s}{\dot{m}_d} = C_1 (K_e)^{-C_2} \tag{1}$$

where the two constants C_1 and C_2 define the performance characteristics of the specific expeller type and size. The values of these constants can be determined from actual testing of the specific expellers subjected to a varying flow resistance at inlet. The value of the constant C_2 was previously found to be approximately equal to 0.5 (Botros et al., 2007a, 2007b). Clearly, the higher the value of the constant C_1 the higher the induction ratio (stronger expeller), and hence the larger the suction flow for a given drive airflow.

In recent years, the spacing between pipeline block valves became longer, which was primarily brought about by accessibility constraints and rough trains, among other factors. Clearly, when the length of a pipeline section increases, the resistance to the suction flow increases, the suction flow induced by the expeller decreases and hence the purge velocity decreases. Therefore, it is important to install the appropriate expeller size and use sufficient drive air pressure such that the purge velocity is maintained above a minimum value to prevent stratification, i.e. two counter-flowing layers of gas on top and air at the bottom (American Gas Association, June 2001). This minimum purge velocity, $(V_{purge})_{\min}$, is determined by the difference in gas and air densities and pipe internal diameter via (American Gas Association, June 2001):

$$(V_{purge})_{\min} = \sqrt{\left(\frac{\rho_a - \rho_g}{\rho_a + \rho_g}\right) gD} \tag{2}$$

Commercially available expellers are currently limited in size and capability in permitting enough drive airflow, and hence the required suction flow according to Eq. (1) and the constraint of Eq. (2) may not be realized. Botros and Hawryluk (Hawryluk and Botros, 2008) showed that mounting two expellers in parallel at one location does not necessarily increase the induced flow. Therefore, there is a need to explore innovative and cost effective means to improve the capability of a given expeller to permit higher drive airflow within its geometrical and size limitation. This in turn should result in inducing higher suction flow (via Eq. (1)), even if the performance in term of the *IR* may drop somewhat.

The present paper presents results of measurements conducted on a typical (commercially available) expeller which was slightly modified, again within its geometrical and size limitation, to permit increase in the drive airflow. This was achieved by increasing the number and size of the drive air holes around the collar of the expeller. Flow resistance imposed by a pipeline section attached to the expeller/stack assembly is assimilated experimentally by a restriction orifice at the other end of a plenum attached to the bottom side of the stack. Performance characteristics were determined in terms of drive airflow, drive air pressure, induced (suction) flow and the *IR*. Several modifications were made to the tested expeller and the relative increase in the suction flow achieved in relation to the original design was quantified in relation to the potential loss in the *IR*. Section 2 provides description of the experimental setup,