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Numerical assessment on the performance of two-stage ejector to boost the low-pressure natural gas

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ABSTRACT

Increasing production and recovery from low-pressure natural gas fields in China is highly desirable. A two-stage ejector (TSE) is proposed to deal with this situation. The effect of the second stage geometrical factors (area and length to diameter ratios) on the TSE performance is analyzed through the numerical technique, as well as the operational factors. Results show that the improvement effect becomes larger under relatively larger induced pressure and area ratio. However, choosing a lower area ratio is more suitable because its performance is superior at low induced pressure. An optimal length to diameter ratio exists for the maximum entrainment ratio, and it varies with operational factors. In the present study, it's a good choice when the length to diameter ratio equals to 5. TSE has better entrained capacity compared than single stage ejector, when the primary or induced pressure is higher than the design value. Meanwhile, TSE has better entrained capacity when the pressure of the first stage induced inlet is higher than that of second stage induced inlet.

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1. Introduction

Energy conservation and emission reduction are primary concerns of researchers around the world (Chunnanond and Aphornratana, 2004). Natural gas is considered as clean energy and recommended or mandated by governments for use in certain industries fields. In China, many low-pressure gas wells exist, and they may be abandoned due to the high mining costs. Ejectors, which are used as pressure boosters, could be adopted to enhance the production of low-pressure natural gas, and such devices are known for their reliability and low maintenance cost (Chen et al., 2011).

Ejectors have been widely used in various applications, such as ejector-based refrigeration systems. As the ejector is the core part of the system, its performance is the basis of the overall system performance. However, the relatively low performance (entrainment ratio) of ejectors is the main obstacle to enlarging their range of applications. Therefore, improving the entrainment ratio is important.

Generally, the entrainment ratio (ω), which is the mass ratio between the induced and motive flows, is the key indicator of the ejector performance (Chunnanond and Aphornratana, 2004). Therefore, improving the entrainment ratio requires increasing the induced mass flow rate or reducing the motive mass flow rate. Moreover, the ejector performance is mainly affected by operational and geometrical factors. Zhu et al (Zhu et al., 2009). analyzed the effect of nozzle exit position (NXP) and the inclination angle of the mixing chamber on the R141b ejector. Results indicated that an optimal value of NXP existed for the maximum entrainment ratio, as well as the inclination angle. Pianthong et al (Pianthong et al., 2007). demonstrated that an optimal NXP corresponding to the maximum entrainment ratio existed, and the same conclusion was presented by other studies (Varga et al., 2009). The results from references (Pianthong et al., 2007; Varga et al., 2009) both indicated that the mixing tube length had little effect on the entrained capacity in their range of experimental parameters. However, Chen et al (Chen et al., 2013). indicated that the mixing tube length was closely related to the entrainment ratio, and the maximum entrainment ratio appeared when the length to diameter ratio was from 3 to 7. Meanwhile, Li et al (Li and Li, 2011). suggested that the optimal ratio ranged from 5 to 7 instead. To the knowledge of the authors', the mixing tube length has an effect on the entrainment ratio.

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Nomenclature

A	area ratio, m^2
D	diameter, mm
L	length, mm
m	mass flow rate, 10^4 m^3 d^{-1}
P	pressure, MPa
R	length to diameter ratio of mixing tube

Greek symbols

ω	entrainment ratio

Subscripts

c	back pressure
d	diffuser
H	high/motive
S	low/induced
m	mixing tube
1	first stage
2	second stage

The aforementioned studies mainly propose to improve the entrainment ratio by increasing the induced mass flow rate, because the primary mass flow rate is only sensitive to the diameter of the throat nozzle under identical operation conditions. Some researchers proposed to reduce the primary mass flow rate using a moveable spindle, which could adjust the primary mass flow rate by moving spindle location along the axis direction (Sun, 1996).

Table 1
Properties of methane.

Parameters	Unit	Values
Density	kg/m^3	Ideal gas model
Specific heat	J/(kg K)	2222
Thermal conductivity	W/(m K)	0.0332
Viscosity	kg/(m s)	1.087×10^{-5}
Molecular weight	kg/kmol	16.04303

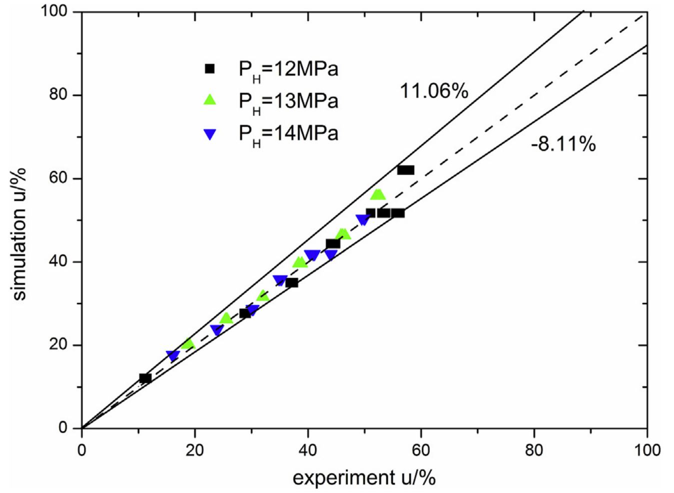

Fig. 2. Deviation comparison of entrainment ratios between experimental and simulated results.

Pereira et al (Pereira et al., 2014). studied the adjustable-geometry ejector and concluded that the maximum increment of COP was up to 70% compared to that of the fixed-geometry R600a ejector. Zhu et al (Zhu and Jiang, 2014). proposed to reduce the motive mass flow rate by punching cavities on the nozzle throat. Although these treatments could improve the entrainment ratio, the induced mass flow rate would decrease under most working conditions.

The mechanical energy loss during the mixing process and the momentum waste in the diffuser are the main reasons for the relatively low entrainment ratio. Chen et al (Chen et al., 2016). proposed a bypass which installed in a diffuser to improve the entrainment ratio by utilizing the redundant momentum. Besides, two-stage ejector (TSE) was introduced to enlarge the entrainment ratio, which was proposed to use the momentum of outflow from the first-stage exit of the single stage ejector (SSE). Grazzini and Rocchetti (Grazzini and Rocchetti, 2002) studied the TSE performance theoretically and created a function to obtain the maximum COP based on the mass flow, dimensions and temperature differences in the heat exchangers. Gamisans et al (Gamisans et al., 2002). investigated the Venturi tube performance under four

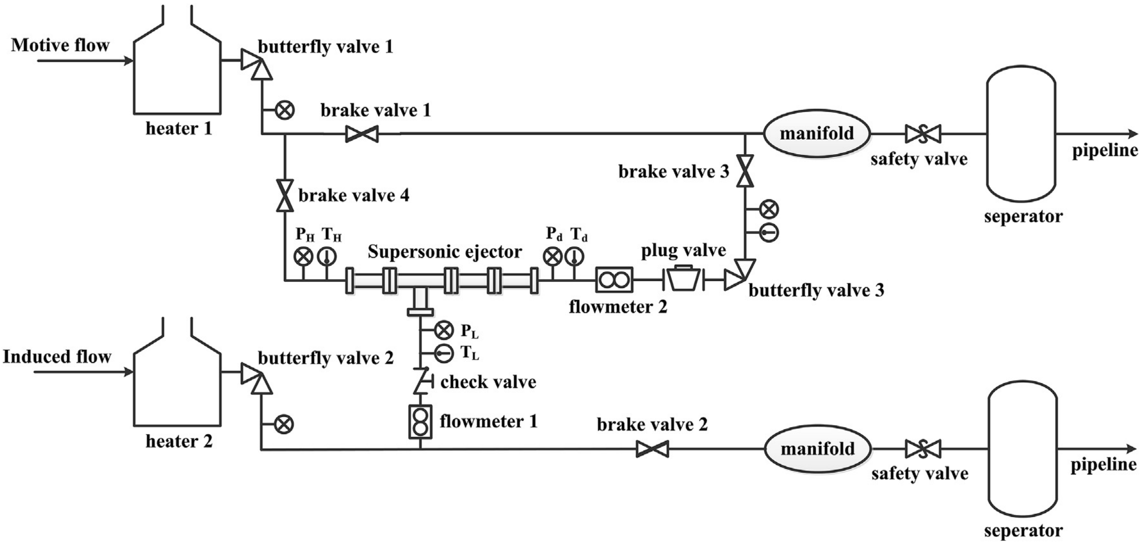

Fig. 1. Schematic of test system of supersonic natural gas ejector.

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