Applied Thermal Engineering 59 (2013) 21–29

Contents lists available at SciVerse ScienceDirect

Applied Thermal Engineering

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

The numerical analysis of the effect of geometrical factors on natural gas ejector performance

WeiXiong Chen, DaoTong Chong*, JunJie Yan, JiPing Liu

State Key Laboratory of Multiphase Flow in Power Engineering, Xi'an Jiaotong University, No. 28, Xianning West Road, Xi'an 710049, China

HIGHLIGHTS

- Numerical investigation is carried out to analyze the natural gas ejector.
- The influence of two main geometry factors on ejector performance is investigated.
- The CFD visualization is applied to analyze the flow field and mixing process inside the ejector.

ARTICLE INFO

Article history:
Received 6 September 2012
Accepted 21 April 2013
Available online 6 May 2013

Keywords:
Natural gas ejector
Geometrical factors
Entrainment ratio
Pressure ratio

ABSTRACT

Supersonic ejectors are applied to increase production and recovery from mature oil and gas fields. Compared to compressors, natural gas ejectors are a cost-effective way to boost the production of low pressure natural gas wells. In this study, two main ejector geometrical factors, the primary nozzle exit position (NXP) and the mixing tube length to diameter ratio (*R*), are investigated based on the CFD technique. Additionally, these two geometrical factors are proved to be influential factors with respect to ejector performance, including not only the entrainment ratio but also the pressure ratio. The numerical results show that the optimum NXP for the entrainment ratio varies from 3.6 to 7.2 mm, but for the pressure ratio, it is in the range of 1.2–7.2 mm. The optimum value *R* decreases with increasing primary flow pressure, and the optimum *R* for the entrainment ratio varies from 2 to 8, but for the pressure ratio, it is in the range of 3–7. The CFD technique is found to be an effective performance predictor and also provides an insightful understanding of the flow and mixing process within the ejector. This study may provide a beneficial reference for the design of supersonic ejectors and may be helpful for further applications in boosting natural gas production.

1. Introduction

The use of ejectors is not new with respect to compressible fluids. Ejectors are simple mechanical devices, which can employ a high pressure motive stream to entrain and accelerate a low pressure secondary stream. Ejectors were first used by LeBlanc in France before 1901. Their first wave of popularity came in the early 1930s, particularly for use in air conditioners. Today, in light of the exhaustible nature of fossil energy sources and with ever-increasing awareness of the need to protect the environment, in addition to pressures to do so, ejectors have become the focus of renewed interest in many scientific areas. They have been widely used in the engineering fields, such as "jet augmentor wings" in the aerospace area [1,2] and heat pumps in district-heating systems [3]. Additionally, due to the problems of global warming and ozone depletion, one of the most popular applications is steam jet refrigeration [4–6].

Our primary interest in this paper is the use of supersonic ejectors in boosting the production of low pressure natural gas. Generally, the production and pressure of gas wells gradually decrease with extended production lifetime, or, what is more serious, these wells may even be abandoned. Thus, it is important to maintain the production and to obtain the maximum recovery from gas wells when their pressures fall below the pipeline pressure or the pressure of the processing system. To maintain the production of low pressure wells, natural gas compressors have conventionally been used; these compressors are bulky and costly to operate and maintain. In contrast, supersonic ejectors have several advantages, such as the lack of moving parts, the relatively low capital cost, the simplicity of operation, the reliability and the low maintenance cost. The most important benefit is that ejectors can be powered by the energy of the high pressure gas well itself, which is usually wasted through choke valves, to boost the natural gas production. Despite

* Corresponding author. Tel./fax: +86 29 82665741.
E-mail address: dtchong@mail.xjtu.edu.cn (D. Chong).

1359-4311/$ – see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.applthermaleng.2013.04.036

Nomenclature

d	diameter (m)
G	natural gas volume flow rate under standard conditions ($\times 10^4$ m^3 per day)
L	length (m)
m	natural gas mass flow rate (kg/s)
N	pressure ratio (%)
NXP	primary nozzle exit position
P	pressure (MPa)
R	mixing tube length to diameter ratio
RNG	renormalization group
S	generalised source
t	time (s)
u	entrainment ratio (%)
Pi	axial pressure (MPa)

Greek symbols

Γ	generalised diffusion coefficient
ε	turbulent dissipation rate (m^2/s^3)
θ	inclination (deg)
κ	turbulent kinetic energy (m^2/s^2)
ρ	density (kg/m^3)
ν	specific volume (m^3/kg)
ϕ	generalised variables

Subscripts

c	back pressure
d	diffuser
H	high motive pressure
L	low induced pressure
mc	mixing chamber
mt	mixing tube
t	throat of the primary nozzle

the fact that natural gas ejectors have so many advantages for boosting the productivity of low pressure natural gas wells, they are not widely used in the natural gas industry because of their demonstrated low performance under present conditions. Because both the operational conditions and geometries significantly affect the ejector performance, a deeper understanding of ejector working principles and entrainment features is essential for improving the performance of the overall system.

The effect of geometry on the ejector performance has been analysed by different researchers. First, Keenan et al. [7] proposed a 1-D constant pressure mixing ejector theory for analysing the ejector performance. Later, this model was improved by considering a real gas and thermodynamic irreversibility [8]. Munday and Bagster [9] postulated a fictive throat or "effective area" located at some location inside the mixing chamber. They assumed that the primary flow fans out without mixing the induced flow after it is discharged from the exit of the nozzle, and the mixing of the two flows begins with a uniform pressure after the hypothetical throat. Based on their assumptions, Huang et al. [10] further assumed that constant pressure mixing occurs inside the constant area section of the ejector and then set up a model to predict the performance when the ejector is at critical operation. These theoretical models are helpful in analysing the influence of certain ejector geometries, such as the mixing tube diameter, on the ejector performance. However, the effects of other important geometries, such as the primary nozzle exit position (NXP) and the mixing tube length to diameter ratio R ($R = L_{mt}/d_{mt}$), are not reflected in those theoretical models due to the limitations associated with the 1-D flow simplification.

Due to the significance of these effects (NXP and R) on the ejector performance, many researchers have paid attention to investigate NXP and R. Keenan et al. [8] and Huang and Chen [11] experimentally investigated the effect of NXP on ejector performance and reported that the entrainment ratio decreased as the primary nozzle was moved away from the mixing tube. However, Aphornratana and Eames [12] indicated that the entrainment ratio increased as the primary nozzle was moved away from the mixing tube. Based on their numerical results, Rusly et al. [13] reported only a small influence of NXP on the entrainment ratio. Pianthong et al. [14] investigated the performance of an ejector with NXP varying from −15 mm to 10 mm, and their numerical results showed that the entrainment ratio increased slightly as the NXP was moved further from the inlet section. However, an increasing number of researchers recognises that there is an optimal NXP for obtaining optimal operation [15]. For the parameter R, the experimental results from Havelka et al. [16] showed that the entrainment ratio increased as R was increased and then reached a plateau when the ratio was larger than 6; the same conclusion was obtained by the numerical results in Ref. [17]. However, the numerical results of Pianthong et al. [14] and Varga et al. [18] indicated that the constant area section length had no influence on the entrainment ratio but influenced the value of the critical back pressure. From these studies, it is clear that the optimum NXP and mixing tube length varied with the operational condition, and it is difficult to find a universal value that meets all of the conditions.

As mentioned above, many investigations have been carried out to study the effects of geometrical factors on the ejector performance in various applications, but the studies on natural gas ejectors are relatively sparse. Sarshar et al. [19,20] indicated that the jet pumps were proven to be a cost effective manner in which to boost production and recovery from low pressure gas wells. In their experimental results, the entrainment ratio reached 78% when the high pressure, low pressure and discharged pressure were 5.5 MPa, 1.6 MPa and 2.0 MPa, respectively. Melancon [21] and Andreussi [22] also investigated its operational mechanism and economics. Recently, Chong et al. [23] carried out geometrical optimisation on the design condition to obtain the maximum pressure ratio. Chen et al. [24] made the geometrical optimisation to gain the maximum entrainment ratio on the design operation, and the effect of diffuser on the performance also involved which was ignored in Ref. [23].

In the application of a natural gas ejector, there are two important parameters; namely, they are the entrainment ratio and the pressure ratio, with the definitions given as follows:

$$\text{Entrainment ratio}: \ u = m_L/m_H \tag{1}$$

$$\begin{aligned}\text{Pressure ratio}: \ N &= (P_c - P_L)/(P_H - P_c) \\ &= (P_H - P_L)/(P_H - P_c) - 1\end{aligned} \tag{2}$$

As mentioned above, it is highly desirable to obtain the maximum total recovery from all gas wells and to maintain their production in the industry. Thus, an important issue is the boosting of production from lower pressure gas wells. This means that the optimum operation of an ejector should be defined as (1) the maximum entrainment ratio and (2) the maximum pressure ratio. However, previous studies mainly were focused on the maximum entrainment ratio. To deepen the understanding of ejector performance, the present paper is focused on the effects of the geometrical factors, NXP and R, on the entrainment ratio and pressure ratio.