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Study on the Performance of a Variable Geometry Ejector

JIN Xu[a], CHEN Zuozhou [b], DANG Chaobin [b]*, HIHARA Eiji [b]*

[a] School of Energy and Power Engineering, Northeast Electric Power Univesity, Jilin, 132012, China
[b] Institute of Environmental Studies, Graduate School of Frontier Sciences, The University of Tokyo, 5-1-5 Kashiwanoha, Kashiwa-shi, Chiba 277-8563, Japan

Abstract

In this research, experimental investigation has been conducted on the variable geometry ejector performance in order to use the unstable solar heat as the driving energy on the ejector refrigeration system. A supersonic nozzle and a subsonic nozzle were adopted in the ejector to verify the influence of nozzle configuration on the ejector performance. In the experiment, the generating temperature were regulated between 60 ºC to 80 ºC. The nozzle throat opening were adjusted to achieve the highest ejector performance. The results show a close relationship between the driving flow condition and the ejector performance. A supersonic nozzle can provide high ejector performance when the driving flow reaches ideally-expanded condition at the optimum nozzle opening for the ejector performance. Meanwhile, a subsonic nozzle provides stable performance under a various range of configuration regulation. Therefore, the nozzle configuration should be selected based on operating condition. In addition, the variable geometry ejector can ensure a stable performance for the ejector refrigeration system with unstable energy input. The results are significant for improvement of ejector performance in solar energy utilization.

Keywords: Ejector, Variable geometry, R134a, Solar

1. Introduction

Large-scale applications of refrigeration and heat pump systems consume a huge amount of energy, and bring environmental problems. Heat-driven refrigeration systems have the potential to alleviate the energy burden by using low grade energy such as solar heat. Ejector refrigeration system has the potential to use solar energy, it also owns advantages such as simple-structured, easy maintenance, and eco-friendly. Sokolov and Hershgal [1] proposed the first solar-powered compression enhanced ejector air conditioner as shown in Fig.1, and claimed that this hybrid system can effectively enhance the system performance using solar energy.

* DANG Chaobin. Tel.: +81-04-7136-6467
E-mail address: dangcb@k.u-tokyo.ac.jp.

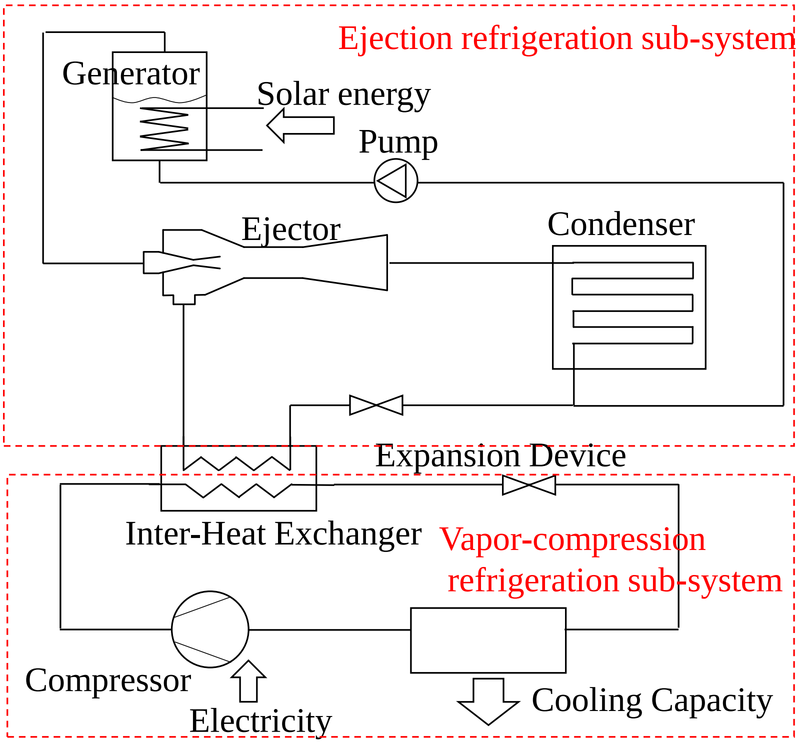


Fig. 1 Ejection-compression hybrid system

Since the solar energy is unstable, the variable geometry ejector has been then proposed to provide stable performance with unstable solar energy input. Yapici *et al.* [2] investigated the ejector-to-throat area ratio of the ejector, and claimed that an optimum ejector configuration exists for each operating condition. By regulating the ejector configuration, the variable geometry ejector provides stable performance even with unstable heat input.

As shown in Eq. (1), AR_{mt} is the area ratio between the mixing section A_m and the nozzle throat A_t. The variable geometry ejector (VGE) enables the regulation of AR_{mt} by inserting a needle into the nozzle throat as shown in Fig. 2. The change of nozzle location inside the nozzle throat yields AR_{mt} regulation of the ejector.

$$AR_{mt} = A_m / A_t \tag{1}$$

Another parameter AR_{et} refers to the nozzle configuration as shown by Eq. (2). It is the area ratio between the nozzle exit area A_e and throat area A_t of a supersonic nozzle. AR_{et} decides the velocity and pressure of the driving flow at the nozzle exit.

$$AR_{et} = A_e / A_t \tag{2}$$

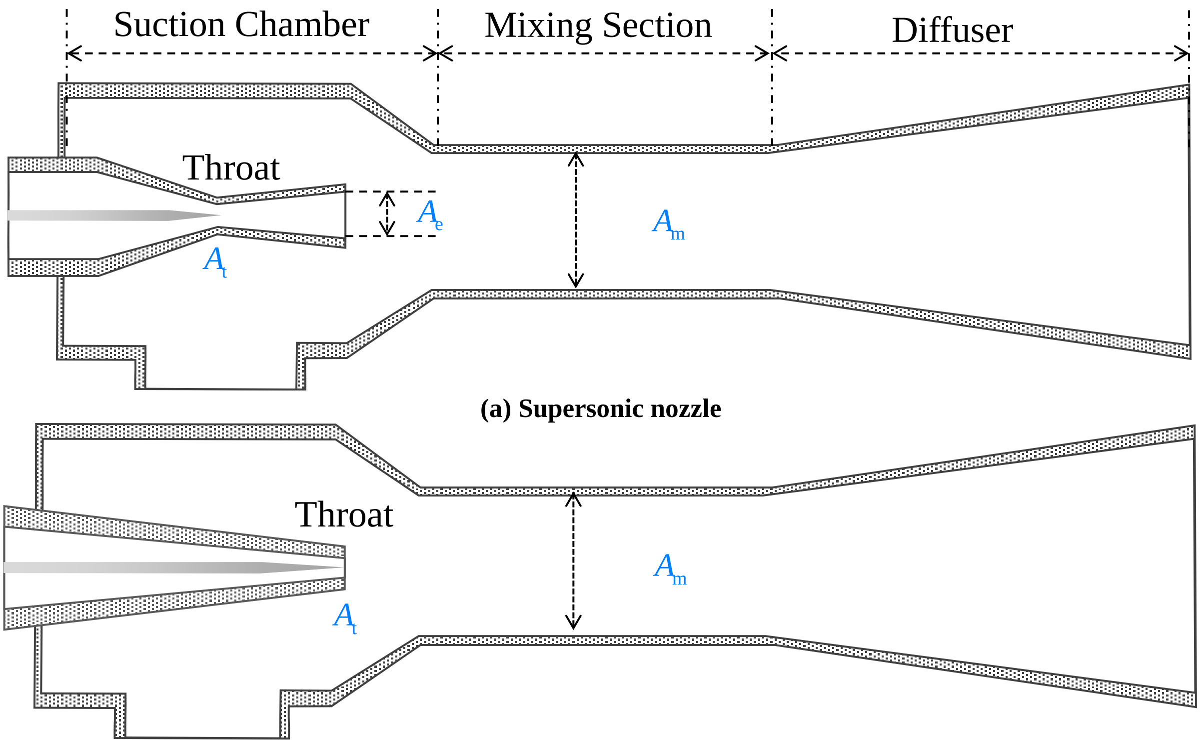


Fig. 2 Schematic of a variable geometry ejector

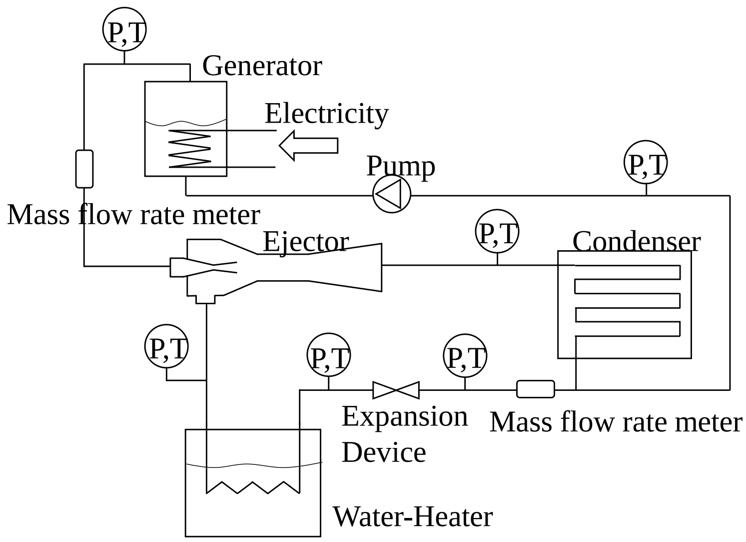
A study conducted by Huang *et al.* [3] showed that the isentropic expansion assumption could be adopted to describe the driving flow development inside the ejector. This assumption is valid when a stable heat source is provided with a well-designed nozzle. However, the isentropic expansion of driving flow is not guaranteed when both the heat source temperature and the nozzle configuration are changeable. To discuss the influence of driving flow expansion on the ejector performance, a supersonic nozzle and a subsonic nozzle are adopted in the variable geometry ejector in the experiment as shown in Fig. 4 (a) and (b). A supersonic nozzle has a convergent-divergent duct, and is able to convert the driving flow into a low pressure supersonic flow. A subsonic nozzle has only a convergent duct, thus the driving flow could only be converted to the local sonic speed.

In the current study, experimental investigation was conduct to discuss the influence of nozzle configuration on the ejector performance, a supersonic nozzle and a subsonic nozzle are employed in the ejector. In addition, the performance of the variable geometry ejector with changeable heat source temperature was experimentally verified.

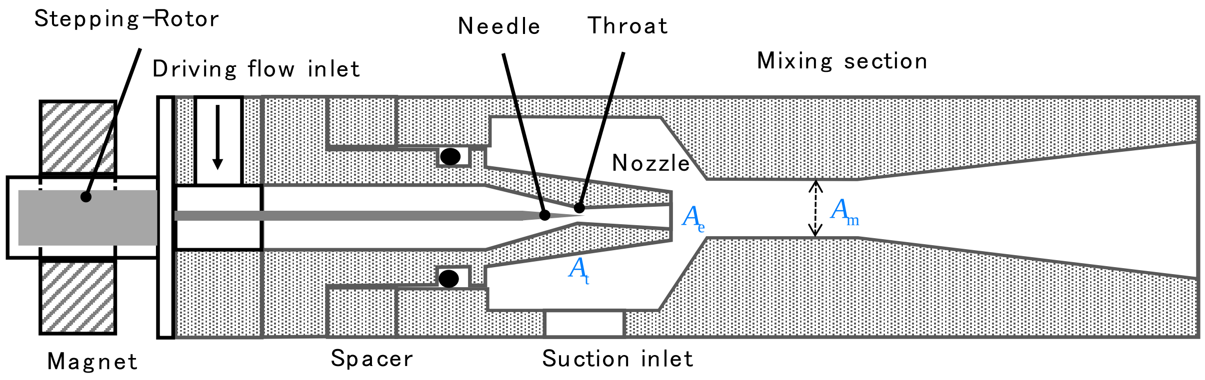
2. Experimental Setup

Fig.3 (a) shows a schematic of the experimental apparatus. An ejector refrigeration system has been constructed to test the performance of the variable geometry ejector. The driving flow is produced in the generator, and enters the ejector from the nozzle inlet. Meanwhile, the suction flow enters the ejector from the evaporator. The two flows mix inside the ejector, and jet into the condenser. R134a was selected as the working fluid.

The locations of thermo-couples and pressure sensors are shown in Fig.3 (a). The mass flow rates of the driving and suction flow are measured by Coriolis mass flow meters located at the generator and evaporator outlets. Signal from the sensors is acquired by CADAC21 post-acquisition data acquisition instruments, and transferred to a computer for data processing.



(a) Ejector refrigeration system



(b) Control device for variable geometry ejector

Fig. 3 Experimental setup

A schematic of the variable geometry ejector is shown in Fig. 3 (b). A needle connected to a stepping-rotor is employed to regulate the nozzle throat area. By a digital controller, the needle location inside the nozzle could be adjusted, the nozzle opening (σ_n) could be then regulated from 100 % to 0 %. The main parameters regarding to the variable geometry ejector configuration are presented in Table. 1.

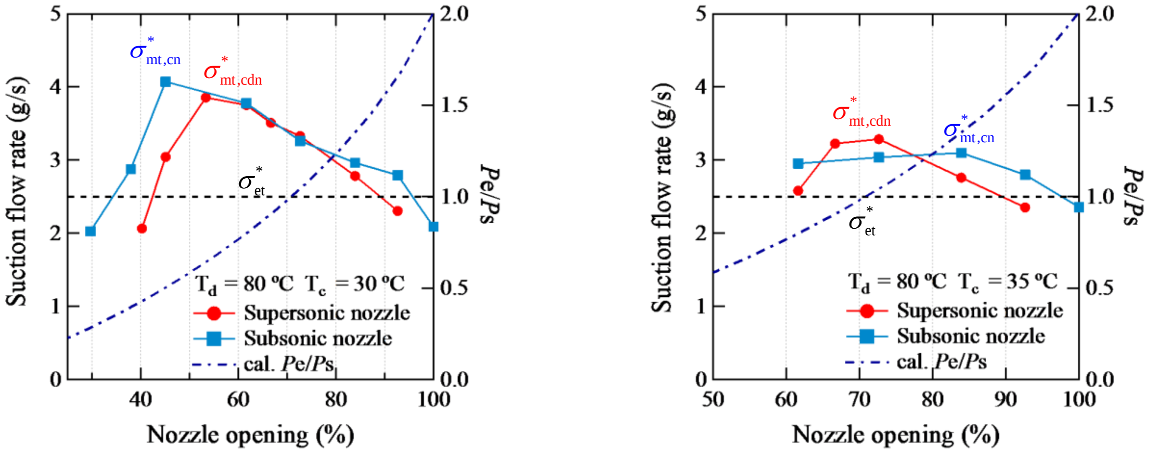
Table 1 Geometries of the ejector

Unit: mm	Supersonic nozzle	Subsonic nozzle
Nozzle throat diameter	1.30	1.30
Nozzle exit diameter	1.36	N/A
	Ejector	
Mixing section diameter	2.08	
Mixing section length	10.0	

3. Results and Discussion

3.1. Nozzle comparison

The influence of nozzle opening (σ_n) on the VGE performance is discussed in this section. The results obtained from the supersonic nozzle and subsonic nozzle were brought into comparison. The generator and evaporator temperature during the experiment were kept at 80 ºC and 20 ºC, respectively. The suction flow rate is presented in the *y*-axis in the figures as the evaluation criteria for the ejector performance. By regulating the nozzle opening, the ejector performance varies, and the experimental results are shown in Fig. 4. It could be observed that for both nozzles, as the nozzle opening decreased from 100 %, the suction flow rate increased firstly and then decrease after a peak performance point. The nozzle opening of the peak performance was around 50 % when the condenser temperature was 30 ºC, and increased to around 70 % when the condenser temperature was 35 ºC. The subsonic nozzle achieved higher performance when the condenser temperature was 30 ºC, while the supersonic nozzle achieved higher performance when the condenser temperature was 35 ºC.



(a) Performance comparison when condensing temperature is 30 ºC

(b) Performance comparison when condensing temperature is 35 ºC

Fig. 4 Performance with different nozzle structures

In addition, calculation has been conducted on the driving flow pressure at the nozzle exit (P_e) based on the nozzle structure (AR_{et}) to discuss the driving flow status from the nozzle exit. The pressure difference between the driving flow (P_e) and suction flow (P_s) indicates the driving flow development process from the nozzle exit. There are three status for the driving flow for a supersonic nozzle: over-expanded ($P_e / P_s < 1$), ideally-expanded ($P_e / P_s \approx 1$), and under-expanded ($P_e / P_s > 1$). The calculation results are appended to Fig. 4. Meanwhile, the driving flow status for a subsonic nozzle could only be under-expanded.

$$AR_{et} = \frac{1}{M_e}\sqrt{\left(\frac{2}{\gamma+1}\left(1+\frac{(\gamma-1)}{2}M_e^2\right)\right)^{(\gamma+1)/(\gamma-1)}} \tag{3}$$

$$P_e = P_d\left(1+M_e^2(\gamma-1)/2\right)^{\gamma/(\gamma-1)} \tag{4}$$

σ_{mt}^{*} and σ_{et}^{*} are highlighted in Fig. 4, which are defined as the critical nozzle opening to achieve AR_{mt}^{*} (optimum ejector-to-throat area ratio) and AR_{et}^{*} (optimum exit-to-throat area ratio), respectively. When AR_{mt}^{*} was achieved, the ejector performance reached its highest value, on the other hand, AR_{et}^{*} indicates that the driving flow is in ideally-expanded condition where the irreversible energy loss caused by shockwave is mostly supressed. σ_{mt}^{*} is obtained from the experiment results, and σ_{et}^{*} is a calculated value when $P_{\mathrm{e}} / P_{\mathrm{s}} = 1$. The relationship between the nozzle opening and the area ratios are shown in Eq. (5) and Eq. (6), where $AR_{\mathrm{et,0}}$ and $AR_{\mathrm{mt,0}}$ represent the initial ejector and nozzle configuration.

$$AR_{\mathrm{et}}^{*} = AR_{\mathrm{et,0}} / \sigma_{\mathrm{et}}^{*} \tag{5}$$

$$AR_{\mathrm{mt}}^{*} = AR_{\mathrm{mt,0}} / \sigma_{\mathrm{mt}}^{*} \tag{6}$$

Fig. 4 (a) show the performance variation with nozzle opening when the condenser temperature of the system was set to 30 ºC. The optimum ejector-to-throat area ratio (AR_{mt}^{*}) was achieved when σ_{mt}^{*} is around 50 %. The optimum ejector configuration is achieved when the driving flow is in over-expanded condition ($P_{\mathrm{e}} / P_{\mathrm{s}} < 1$). In this circumstance, shockwave is assumed to occur in the driving flow and causes irreversible energy losses. Meanwhile, the driving flow at a subsonic nozzle exit is kept in under-expanded condition, therefore, the optimum performance of the supersonic nozzle falls below the performance obtained by the subsonic nozzle.

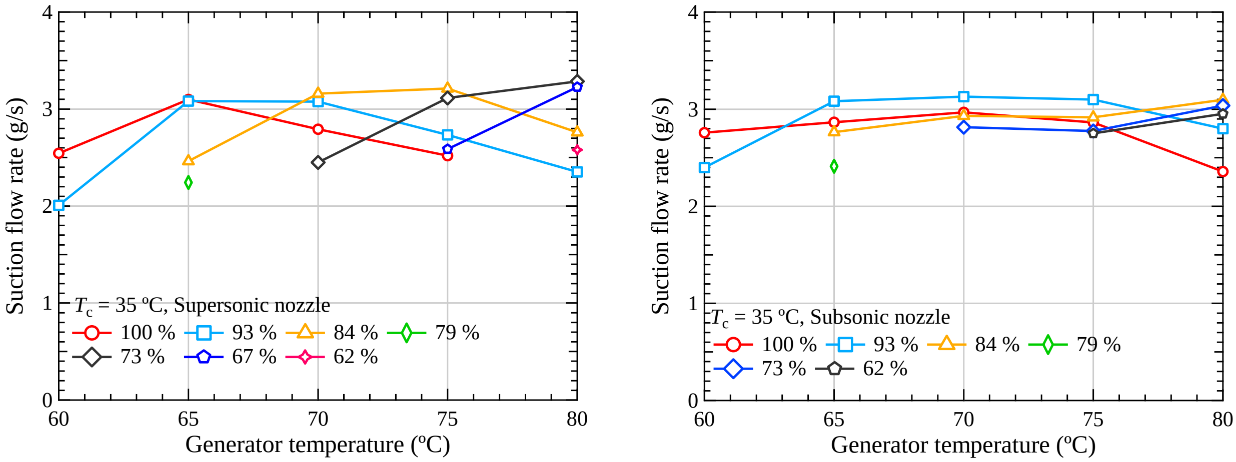
Fig.4 (b) show the performance variation of the VGE when the condensing temperature is kept at 35 ºC. σ_{mt}^{*} increases to around 70 %. It could be observed that for the supersonic nozzle, σ_{et}^{*} and σ_{mt}^{*} are achieved synchronously, which indicates the driving flow is in ideally-expanded condition while the ejector configuration is most appropriate for the operating condition. The supersonic nozzle VGE achieved higher performance than the subsonic nozzle in Fig. 4 (b).

The results in Fig. 4 show that nozzle configuration have significant influence on the ejector performance. An optimized supersonic nozzle can be adopted to achieve high performance, yet special attention should be paid to avoid shockwave occurrence.

3.2. Adjustment of a VGE

Fig. 5 shows the performance of the VGE while the generating temperature changes from 60 to 80 ºC. The evaporating and condensing temperatures are kept at 20 ºC and 35 ºC. Fig. 5 (a) and (b) show the performance obtained by the supersonic nozzle and the subsonic nozzle, respectively. By the needle location regulation, the appropriate nozzle opening for each generating temperature could be achieved. Therefore, the performance of a VGE could be kept stable with unstable heat source temperature. It could be further observed that the supersonic nozzle provides increasing performance while the generating temperature increases. Meanwhile, the subsonic nozzle provides constant performance with generating temperature change.

From the current case, the advantage of adopting the VGE in the ejector refrigeration system has been experimentally verified that stable performance could be provided even with unstable energy input temperature.



(a) VGE with a supersonic nozzle

(b) VGE with a subsonic nozzle

Fig. 5 Performance optimization under various generating temperatures

4. Results and Discussion

In the current study, experimental investigation has been conducted to discuss the performance characteristics of a variable geometry ejector. The main conclusions are listed:

1. A variable geometry ejector is capable to achieve optimum performance in a wide range of operating conditions, thus it could be adopted to maintain a stable performance for the solar-driven ejector-refrigeration system.
2. Well-designed supersonic nozzle can achieved high performance compared to subsonic nozzle, yet special attention should be paid to the nozzle failure during adjustment.

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