

## Study on the performance characteristics of the ejector along the driving nozzle exit position

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**ABSTRACT:** Most industrial processes use a significant amount of thermal energy, mostly by burning fossil fuels. Some part of the energy released in combustion is inevitably rejected to the surroundings as waste. This waste heat can be utilized in certain types of refrigeration system such a jet refrigeration cycle. The influence of the ejector system depends on a mixing by the shearing action between the primary flow and the secondary flow, the pressure loss by the shock wave at the ejector throat, the pressure recovery of a diffuser and etc. And the shape of the component elements for comprising influence is the important design parameters. Thus, in this study the condition that it can maintain the optimum operation state of the ejector system according to a change including the aspect ratio of the exit position of the driving nozzle and the length of the ejector throat length.

**Keywords:** diffuser, ejector, driving nozzle, supersonic flow, ejector throat

### NOMENCLATURE

A: area ( $\text{m}^2$ )  
D: mixing section diameter (m)  
P: static pressure (Pa)  
Q: mass flow rate (kg/h)  
 $R_p$ : pressure lift ratio  
 $R_A$ : nozzle throat area ratio  
U: mean velocity (m/s)  
 $\alpha$ : mass flow rate constant  
 $\varepsilon$ : expansion constant  
 $v$ : specific volume ( $\text{m}^3/\text{kg}$ )  
 $\rho$ : density ( $\text{kg}/\text{m}^3$ )

### 1. INTRODUCTION

Supersonic ejectors are simple mechanical components, which generally

allow to performing the mixing and/or the recompression of two fluid streams. The fluid with the highest total energy is the motive or primary stream, while the other, with the lowest total energy is the secondary or the induced stream. Operation of such systems is also quite simple: the motive stream (high pressure and temperature) flows through a convergent divergent nozzle to reach supersonic velocity. By an entrainment-induced effect, the secondary stream is drawn into the flow and accelerated. Mixing and recompression of the resulting stream then occurs in a mixing chamber, where complex interactions take place between the mixing layer and shocks.

An ejector has no rotating parts or the no motion parts and the malfunction can be small and it can transport the large amount of fluid by the small size. For these reasons, the ejector system is variously applied over the whole industry including the chemistry field, the air conditioning system, the natural gas manufacturing device, etc.

The ejector design can be classified into two categories according to the position of the nozzle [1]. For the nozzle with its exit located within the constant-area section of an ejector, the mixing of the primary and the entrained flows occurs inside the constant-area section and the ejector is known as “constant-area mixing ejector”. For the nozzle with its exit located within the suction chamber which is in front of the constant-area section, the ejector is referred as “constant-pressure mixing ejector”. For this kind of ejector, it was assumed that the mixing of the primary and the entrained streams occurs in the suction chamber with a uniform or constant pressure [2].

It is known that the constant-pressure ejector has a better performance than the constant-area ejector and is thus widely used. Therefore, we focus on the design of a “constant-pressure ejector” in the present study, but with a new concept that the mixing occurs within the constant-area section. The constant-pressure mixing theory of ejector developed by Keenan et al. [2] was frequently used in the analysis of constant-pressure ejector [3, 4, 5]. Keenan et al. [2] assumed that the pressures of the primary and the entrained flows at the exit of the nozzle have an identical pressure. Mixing of the two streams begins there with a uniform pressure, i.e. constant pressure, until the inlet of the constant-area section.

The influence of the ejector system depends on a mixing by the shearing action between the primary flow and the secondary flow, the pressure loss by the shock wave at the ejector throat, the pressure recovery of a diffuser. And the shape of the component elements for comprising influence is the important design parameters [6, 7, 8].

Thus, in this study the condition that it can maintain the optimum operation state of the ejector system according to a change including the aspect ratio of the exit position of the driving nozzle and the length of the ejector throat length.

## 2. Experimental study

By using the air as the working fluid, a system comprised of the atmospheric open type and an experiment was progressed in order to grasp the operation mechanics and characteristic of an ejector.

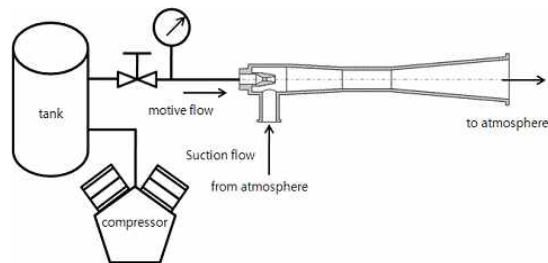


**Figure 1:** Schematic diagram of experimental system.

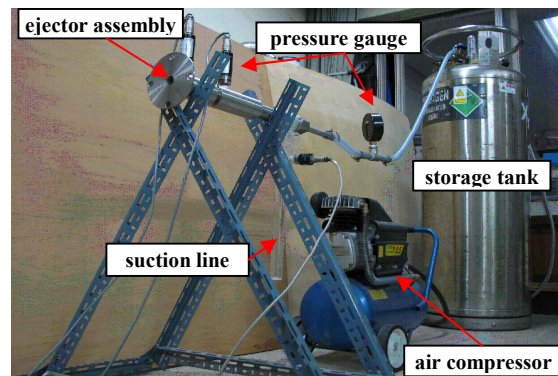


**Figure 2:** Experimental apparatus set-up.

**Table I:** Dimension of ejector assembly.

|                  | Length(mm) | Diameter(mm) | Angle(°) |
|------------------|------------|--------------|----------|
| Constant area    | 100 (L3)   | 10 (D1)      | -        |
| Diffuser         | 75( L2)    | 10→20.5      | 4 (A1)   |
| Discharge        | 180 (L4)   | 20.5         | -        |
| Ejector assembly | 436 (L1)   | -            | -        |

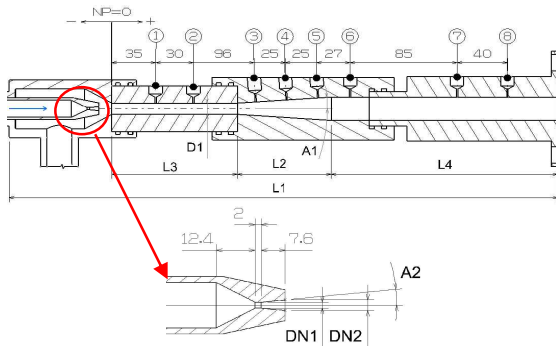


**Figure 3:** Schematic diagram of test ejector.

**Table II:** Dimension of driving nozzle.

|                             | DN1<br>(mm)                                   | DN2<br>(mm) | A2<br>(°) | Nozzle<br>area ratio |
|-----------------------------|-----------------------------------------------|-------------|-----------|----------------------|
| Nozzle 1                    | 2                                             | 3.5         | 5.5       | 3.06                 |
| Nozzle 2                    | 3.5                                           | 5.5         | 7.5       | 2.45                 |
| Nozzle 3                    | 2.65                                          | 4.5         | 7         | 2.88                 |
| Operation<br>pressure ratio | 1(196kPa), 2(294kPa),<br>3(392kPa), 4(490kPa) |             |           |                      |

Fig. 1 shows the schematic diagram of experimental system and fig. 2 shows the experimental apparatus set-up. Fig. 3 showed schematic diagram of the ejector and showed the dimension of the ejector in the table 1. Driving nozzles made 3 types and the detailed dimension showed in the table 2.

Along the wall of the ejector, a static pressure at each operating condition was tapped and measured using a pressure transducer show in fig. 3. This information was used to create the plots of the static pressure distribution along the ejector and they became the significant information for the validation of the simulated CFD ejector models.

The straight section was secured between the storage tank and nozzle in order to maintain the balance of the supplied flow with a nozzle. A pressure was changed to the same interval (196, 294, 392 and 490kPa) and we experimented in order to grasp the performance characteristics according to a pressure. The position of driving nozzle was varied in difference locations according to mixing tube diameter (0.5d, 1d, 2d, 3d, 4.15d, 5d and 6d).

Fig. 4 shows static pressure profiles along the ejector axis for various nozzle types. In figure nozzle 1 showed at the maximum pressure recovery is not occurred in the diffuser and it is occurred in the constant area section. And this phenomenon is longer than a diffuser throat diameter and the length of diffuser throat is determined as a thing by the pressure increase by the wall friction. And then shows nozzle 2, it can observe that the pressure of the flow passing through the nozzle exit is choked in excess of the critical pressure. Therefore, the nozzle 2 was confirmed that the sufficient suction force is obtained from the low operation pressure ratio. Fig. 6 shows relationship between the operation pressure ratio and pressure lift ratio. Show in figure, the operation pressure ratio rises same time the pressure lift ratio rise too. Especially, nozzle 2 can look at to drastically rise.

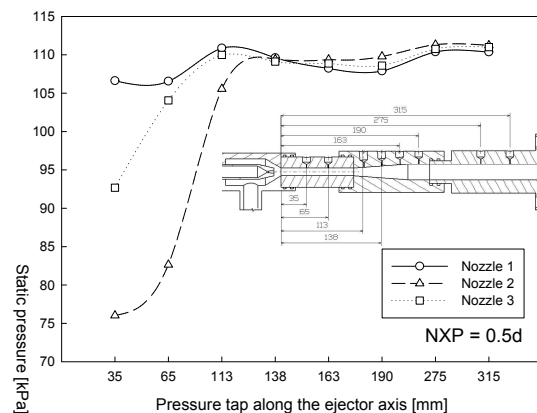


**Figure 4:** Comparison of static pressure distributions.

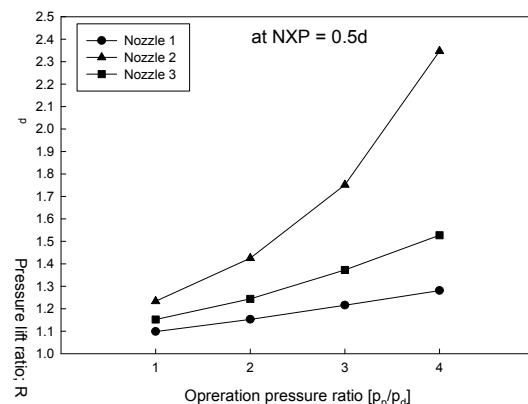


**Figure 5:** Relationship between  $P_p/P_d$  and  $R_p$ .

### 3. CFD analysis

In order to simulate this particular situation, Gambit 2.2 and FLUENT 6.3 were used as the grid generator and the CFD solver, respectively.

As proposed, Gambit version 2.2 was used to create the calculation domain and grid elements of the model. The mesh and model were created in a two-dimension (2-D) domain. However, the axisymmetric solver was applied and therefore, the three dimensional effect (3-D) was taken into account in the simulation.

The geometries of the calculation domain of the modeled air ejectors were taken from those which were used in the experiment. Their significant dimensions have already been described in the previous section. The mesh was made of about 40,000 structured quadrilateral elements, as shown in Fig. 6.

The concentration of grid density was focused on the areas where significant phenomena were expected.

FLUENT 6.3 is a commercial CFD software package which utilizes the control-volume-based techniques to convert governing equations to algebraic equations that can be solved numerically.

As the supersonic flow field was expected, the flow was thought to be a turbulent compressible flow. The “*realizable  $k-\varepsilon$  model*” was selected to govern the turbulence characteristic.

This model was the improved version of the conventional “*standard  $k-\varepsilon$  model*”. It is believed that the “*realizable  $k-\varepsilon$  model*” is able to predict a more accurate spreading rate of a round jet [9]. Moreover, it was likely to provide a superior performance of the flows involving rotation, boundary layer under strong adverse pressure gradient and separation as presented in our ejector model.

The non-linear governing equations were solved using the “*coupled-implicit*” solver.

The near wall treatment was left as the “*standard wall function*”, which gave reasonably accurate results for the wall bounded with very high Reynolds number

flow.

Fig. 7 showed static pressure profiles along the ejector axis. By using the results of an experiment and CFD analysis, figure take compared the static pressure distribution about the nozzle 2.

The result of an experiment and numerical analysis for quantitatively quite well coincides with over the inside ejector propagate if we look at in figure. And then the error of an experiment and numerical analysis is satisfied within 5%.

Fig. 8 showed with the error rate of an experiment and numerical analysis with 10% the error line.

Fig. 9 shows the distributions of Mach number for various NXP (nozzle exit position). Particularly, in case of the NXP is positioned in the mixing section entrance.

Fig. 10 shows Static pressure distributions along the ejector axis and fig. 11 shows the entrainment ratio according to variable conditions. In the figures, the condition that the positions of a nozzle exit with the mixing chamber entrance most excellently shows an entrainment ratio. And of a then is 0.08.

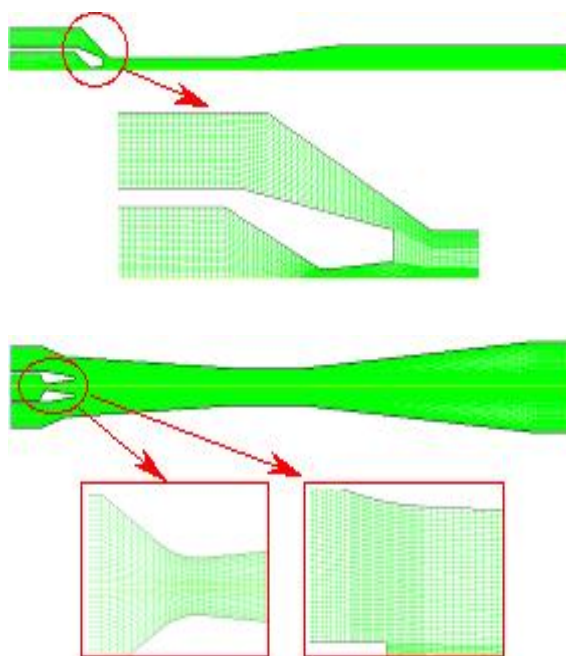


**Figure 6:** Grid system of CFD model.

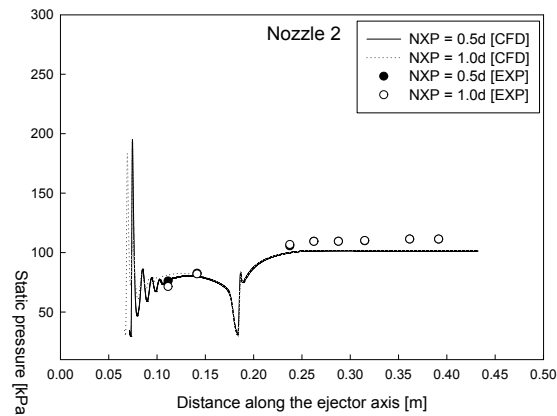


**Figure 7:** Static pressure profiles along the ejector axis.

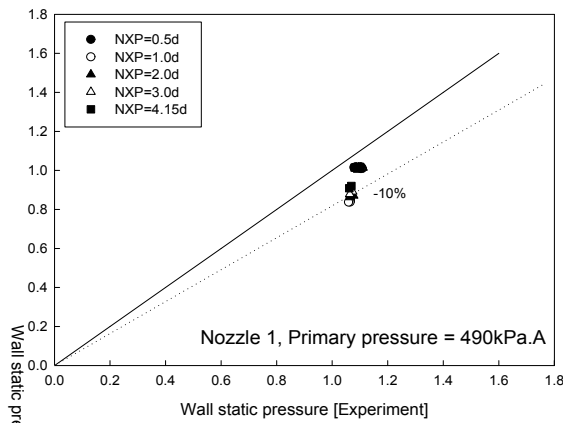


**Figure 8:** Comparison between the experimental and CFD results of static pressure for various NXP.

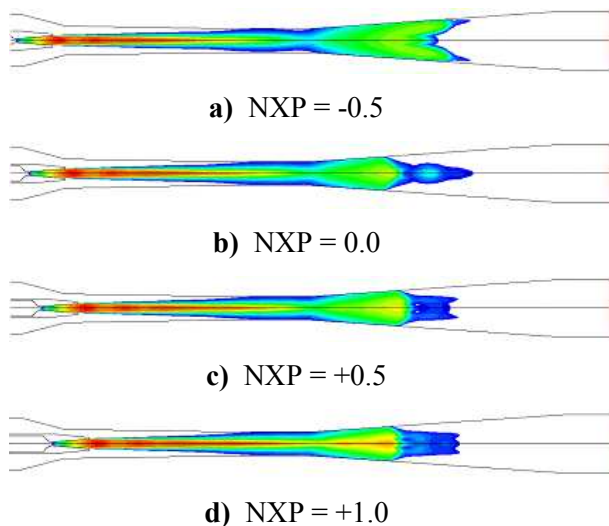


**Figure 9:** Comparison of Mach number distributions along the nozzle exit position.

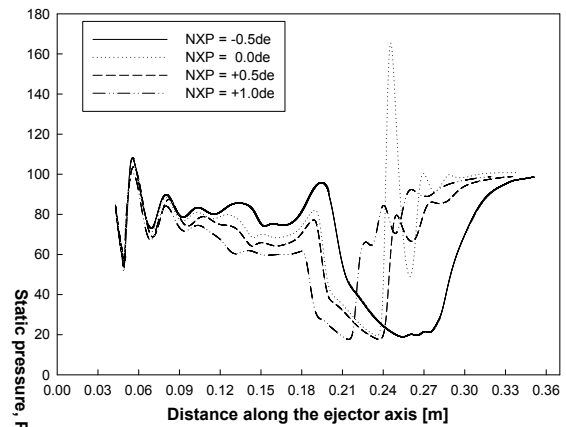


**Figure 10:** Static pressure distributions along the ejector axis.

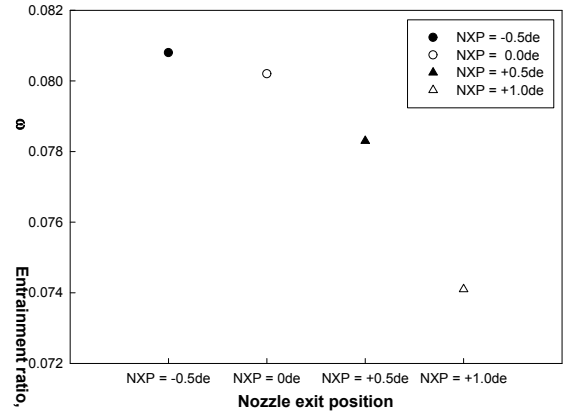


**Figure 11:** Entrainment ratio of variation model.

## 5. CONCLUSION

The following take was obtained as results of performance an experiment and numerical analysis about the exit position of the driving nozzle and the length of the ejector throat and etc.

The trend of the driving nozzle could confirm that a flow was stabilized and a performance is improved as it drew to the constant area section entrance.

We confirmed in the ejector system operation that the minimum operation pressure ratio was 4 or greater and the normal operation could be made.

The ejector throat there was with number to the maximum extent it makes an efficiency to select the quadruple of less of the throat diameter and when the length was

two times, the ejector of this research showed the optimum performance.

The condition that the positions of a nozzle exit with the mixing chamber entrance most excellently shows an entrainment ratio. And of a then is 0.08.

## ACKNOWLEDGEMENT

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