한국추진공학회 2009년도 춘계학술대회 논문집 pp.299~302 2009 KSPE Spring Conference

# 진공 이젝터-디퓨져 시스템내의 비정상 유동 과정에 관한 연구

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# A Study on the Transient Flow Process in a Vacuum Ejector-Diffuser System

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## ABSTRACT

The objective of the present study is to analyze the transient flow through theejector system with the help of a computational fluid dynamics (CFD) method. An attempt is made to investigate the interesting and conflicting phenomenon of the infinite entrainment into the primary stream without an infinite mass supply from the secondary chamber. The results obtained show that the one and only condition in which an infinite mass entrainment can be possible in such types of ejectors is the generation of a re-circulation zone near the primary nozzle exit. The flow in the secondary chamber attains a state of dynamic equilibrium of pressures at the onset of the recirculation zone. A steady flow in the ejector system is valid only after this point.


Key Words: Ejector(액체로켓엔진), Secondary-chamber (액체산소), re-circulation(케로신), transient flow(가압식 공급)

## 1. INTRODUCTION

Ejector is a simple device which can transport a low-pressure secondary flow by using a high-pressure primary flow. In general, it consists of a primary driving nozzle, a mixing section, and a diffuser [1].

The ejector system entrains the secondary flow through a shear action generated by the primary jet. The efficiency of such an ejector system is relatively very low, compared to other fluid transport devices driven mainly by normal forces [2].

Until now, a large number of researches have been made to design and evaluate the ejector systems. In all these works, it is assumed that the ejector system has an infinite secondary chamber which can supply mass infinitely. Thus steady flow assumption has been successfully applied for the purpose of design or performance analysis of the ejector system. However, in almost all of the practical

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applications, the ejector system has a finite secondary chamber. There is always a finite mass to be dragged into the primary stream inside the ejector, regardless of the situations in which they are being used. This implies that steady flow should be possible only after the flow inside the secondary chamber has reached an equilibrium state. The objective of the present study is to analyze the transient flow through the ejector system. An attempt is made to investigate the interesting and conflicting phenomenon of the infinite entrainment of secondary stream into the primary stream without an infinite mass supply from the secondary chamber.

## 2. COMPUTATIONAL METHODOLOGY

Commercial software Fluent 6 is used to analyze the transient flow field. Typical ejector geometry and boundary conditions are shown in Fig.1. 2-D axi-symmetric solver is chosen with coupled implicit solver for both steady and unsteady simulations. The working gas is selected to be air. Initially, steady flow has been simulated with pressure inlet boundary condition (301325 Pa) at the primary nozzle inlet and pressure outlet conditions at secondary nozzle inlet (101325 Pa) and the ejector exit (101325 Pa). After the simulation has achieved convergence, the secondary flow inlet condition has been changed from pressure outlet to wall boundary condition in order to have a fixed volume secondary chamber, and correspondingly the solver is switched to unsteady one with a time step size of 10-7s.

## 3. RESULTS AND DISCUSSION

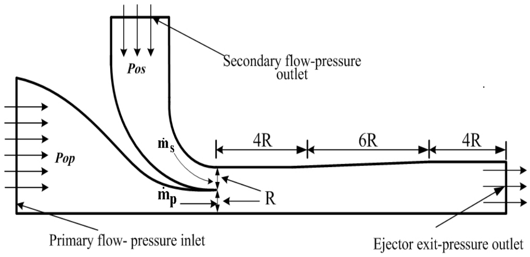


Fig. 1 Ejector geometry and boundary conditions

Figure.2 shows the static pressure history in the secondary chamber during transient starting process of the ejector. The term ps/p0s refers to the ratio of unsteady static pressure to the initial pressure in the secondary chamber. Point A refers to the state at an extremely small time interval after the start of transient flow. Figs.3 shows the mass flow history from the secondary chamber where and are primary and secondary mass flow rates, respectively. It can be noted that the flow reaches pressure equilibrium at point F in Fig.2 and an equilibrium state at which the secondary mass flow is zero in Fig.3 at the same time instant (1.0016 ms).. Consequent on the reduction in the secondary chamber pressure, the primary jet keeps on expanding. The unsteady flow quickly attains pressure equilibrium between the secondary chamber and the primary nozzle exit, owing to the small volume of the secondary chamber. It should be noted that at point F, though there is no pressure difference between the secondary chamber and the mixing section of the ejector, the flow field is not frozen. The fluid is still dynamic in the ejector and hence the point F is termed as "point of dynamic equilibrium of pressure"in Figs.2 & 3. At point F (t=1.0016 ms) where the flow has achieved the pressure equilibrium, it is seen that the area of re-circulation zone has sufficiently

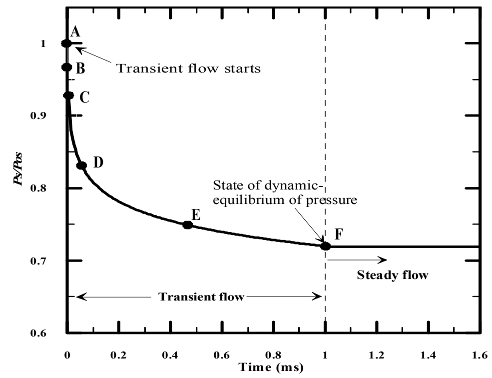


Fig. 2 Static pressure history in the secondary chamber

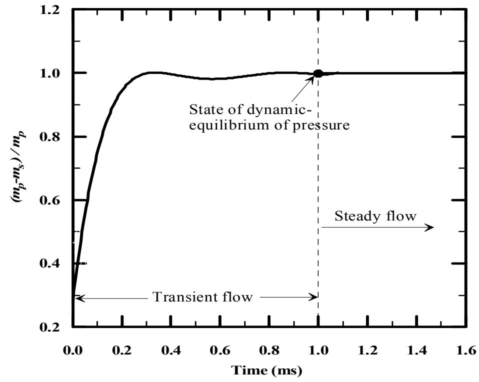


Fig. 3 Secondary mass flow history

increased and the fluid particles are turning 180o in order to have themselves entrained into the shear layer. This clarifies the point made early that the flow field is not at all frozen at this equilibrium point; but it undergoes dynamic changes even when the flow has achieved pressure equilibrium between the secondary chamber and the mixing section. This is the one and only condition in which the two conflicting flow conditions can be possible in a real flow situation. The conflicting conditions are the finite mass supply from the secondary chamber and the infinite mass entrainment into the shear layer as long as primary flow is present. It is worth noting that, though the fluid in the secondary chamber is stagnant, the fluid in the mixing section of the ejector is still dynamic, owing to the re-circulation. The recirculation zone appears in the flow field at a particular time instant. In order to make it clear how the recirculation zone is generated inside the ejector, ratio of axial shear stress ($\tau_w$) to the maximum axial wall shear stress ($\tau_{w,max}$), along the ejector wall is plotted at various time instants in Fig.4.

It can be seen that the first instant at which the recirculation zone appears in the flow field is around 0.05 ms after the start of transient flow, where the axial shear stress is negative in the divergent portion of the ejector. From that point onwards, the magnitude of the negative axial wall shear stress is increasing and it speak is moving upstream. This is in correlation with what has been observed early in the velocity vectors. The recirculation zone is moving upstream with reducing secondary chamber pressure with time. In a steady ejector system with constant pressure mixing section, the primary jet after exiting from the primary jet fans out and induces a converging duct for the induced flow. This hypothetical jet acts as a converging nozzle for the entrained flow which is hence accelerated further downstream. The entrained flow may or may not achieve sonic conditions, commonly known as "Fabri choke," depending on the primary jet characteristics. In the unsteady case, the pressure in the secondary chamber is continuously reduced due to a fixed chamber volume. As the secondary chamber pressure reduces with time, the primary jet characteristics are changed as it is expanded more and more. This makes the hypothetical convergent section (shown by dotted line in Fig.5) more converged as the

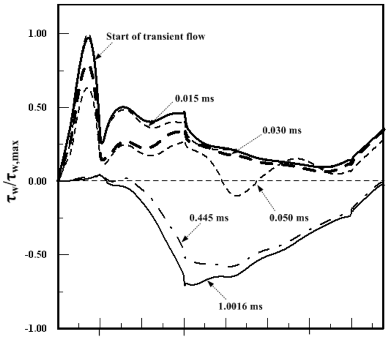


Fig. 4 Wall shear stress along ejector

primary flow develops in the radial direction when it becomes more and more expanded. The flow in this area is still subsonic, consequently leading to more reduction in the secondary flow pressure as it moves along the primary jet through the converging section. The entrained flow being subsonic has to increase its speed as it passes through the converging section. During this time, the expansion process of the primary jet continues and Mach discs becomes stronger downstream, and correspondingly, the pressure increases downstream of the minimum area of the hypothetical nozzle section. The flow has now to travel against a high adverse pressure gradient and the available kinetic energy of the entrained flow at this location is too small to overcome this pressure hill. This causes the inevitable flow separation and possible re-circulation at this location.

## CONCLUSIONS

At the pressure equilibrium state, a re-circulation zone appears in the vicinity of the primary nozzle exit. Due to this re-circulation zone, continuous mass entrainment into the primary jet prevails even when there is no flow from the secondary chamber. This is the one and only condition for the two conflicting phenomena can occur simultaneously, i.e, the finite mass flow from the secondary chamber and infinite mass entrainment into the primary jet. Moreover, during the transient period of the ejector flow, the primary jet characteristics are continuously changing owing to the reduction in pressure at the outlet of the primary nozzle. This will have a deterministic effect on the whole flow field. Thus the present analysis permits to identify what is happening inside the ejector and how the flow field behaves with respect to the transient changes during the starting process of such ejector systems.

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