Numerical Investigation on The Effect Pressure on Flow Characteristics in Converging Diverging Nozzle

Saleh Etaig* and Gamal Hashem, University of Benghazi

Abstract:- The present work investigates the effect of the pressure on the flow characteristics in a converging diverging nozzle. The finite volume method was used to solve the governing equations with the boundary conditions; a wide range of inlet pressure was tested to investigate the flow characteristics in the nozzle as well as the throat. It was found that the pressure coefficient increases with the increase in the inlet pressure and decreases with the flow in the nozzle, however, the decrease is considerable in the converging section while the decrease in the diverging section is insignificant.

Keywords:- *Compressible Flow; Mach Number; Converging Diverging Nozzle***.**

I. INTRODUCTION

The study of the compressible flow attracted many researches for a quite long time due to its wide range of applications, Oswatitsch and Rothstein [1] presented a pioneer work on describing a new method for prediction of gas flow pattern of converging diverging nozzle in a two dimensional case. Liao and Lucas [2] performed a 3D numerical study to investigate the flashing in a vertical converging diverging nozzle. Simoneau [3] measured the chock flow rates and pressure distribution in a converging diverging nozzle. Lemonnier and Selmer [4] conducted an experimental investigation on the two phase components flow in a converging diverging nozzle. Berana et al [5] studied the shock waves two phase supersonic flow of Co2 in a converging diverging nozzle. Yazdani etal [6] presented a numerical modelling of supersonic two phase flow of conventional refrigerants in converging diverging nozzle. Bartosiewicz et al [7] highlighted experimentally and numerically the evaluation of the performance of six well known turbulence models in a supersonic ejectors. Gupta et al [8] investigated experimentally the mixing characteristics of the ejector having an area ratio of 2 in the critical flow regime for a range of stagnation pressure ratios varying between 5.49 and 11.12 and a primary Mach number of 1.5, 2.0, and 2.5. Chunnanond et al [9] constructed a 3 kW cooling capacity steam ejector refrigerator, they measured the static pressure along the ejector axis at various operating conditions, Pereira et al [10] performed an experimental investigation with variable geometry ejectors, they found that The performance improvements compared to a fixed geometry ejector. Chong et al [11] presented an experimental and numerical analysis of supersonic ejectors, they highlighted that the pressures before the second shock position remain constant during the critical mode. Dvorak and Safarik [12] investigated the supersonic and transonic flow for two dimensional model ejector, they observed a good agreement between the numerical and experimental results. Mazzelli et al [13] performed a numerical and experimental analysis on supersonic air ejectors to evaluate the applicability of conventional computational techniques, they highlighted the good on-design agreement across 2D and 3D models, however, off-design needs 3D simulations. Ding li et al [14] analyzed the real fluid flows in converging diverging nozzles. Noren et al [15] performed an experimental and numerical study on converging diverging nozzle with cross flow injection. Nakagawa et al [16] measured the temperature and pressure throughout the nozzle. Banasiak et al [17] presented a numerical and experimental study to investigate the influence of the two-phase ejector geometry on the performance of the R744 heat pump**.** Mason et al [18] investigated the effect of throat contouring on two dimensional converging diverging nozzle with static conditions, they found that that throat contouring increases the value of discharge coefficient but has no significant effect on internal thrust ratio except in cases of internal flow separation. Ishii et al [19] studied the characteristics of bubbly flow through a vertical, two-dimensional, converging–diverging nozzle, they highlighted that numerical results obtained by using the proposed system of model equations agree well with the experiments.

The aim of the present work is to investigate the flow characteristics in a converging diverging nozzle with a wide range of inlet pressure.

II. PROBLEM DESCRIPTION

The geometry investigated in the present work is illustrated in Figure1. The dimension shown in the Figure: x, y, z, L and K are: 25mm, 35 mm, 50 mm, 75mm and 10 mm respectively. The working fluid is air; the inlet pressure tested is 30 kpa, 40 kpa, 50 kpa and 60 kpa.

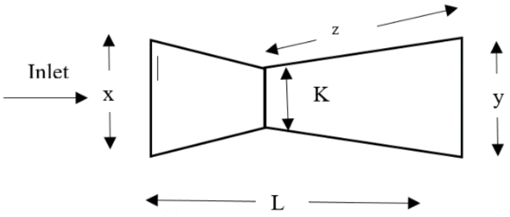

Fig 1 Problem Geometry

III. GOVERNING EQUATIONS

The governing equations were solved in the present study are continuity, momentum equation and energy equation and can be written as

Continuity equation

$$\nabla(\rho\vec{v}) = 0 \qquad (1)$$

Momentum equation

$$\nabla(\rho\vec{v})\vec{v} = -\nabla p + \nabla(\tau) + \rho g + F \qquad (2)$$

Energy equation

$$\nabla(\vec{v}(\rho E + P)) = \nabla\left(K_{eff}\nabla T - \sum h_j J_j + (\tau\vec{v})\right) \qquad (3)$$

Mach number can be computed as:

$$Ma = \frac{V}{a} \qquad (4)$$

Where a is the speed velocity and can be expressed as:

$$a = \sqrt{\gamma RT} \qquad (5)$$

IV. NUMERICAL PROCEDURE

The finite volume was used to solve the governing equations as well as the boundary conditions. The domain was divided into 248460 cells, the second order upwind scheme was employed to discretize all the terms. To solve the pressure-velocity coupled equations, the SIMPLEC algorithm was selected. The convergence criteria is to reduce the maximum residual below 10^{-5}. After solving the governing equations, quantities of fluid dynamics can be determined

V. RESULTS AND DISCUSSIONS

In this section, the results are presented and discussed, the variation of speed of sound number within the nozzle is studied and the results are shown in Figure 2. It can be seen that the speed of sound is maximum in the throat and decreases in the inlet of the converging section and the outlet of the diverging section. It was also noted that the increase in the inlet pressure lead to lower speed of sound in the throat, however, this trend is opposite in both diverging and converging sections, this is attributed to the chock waves.

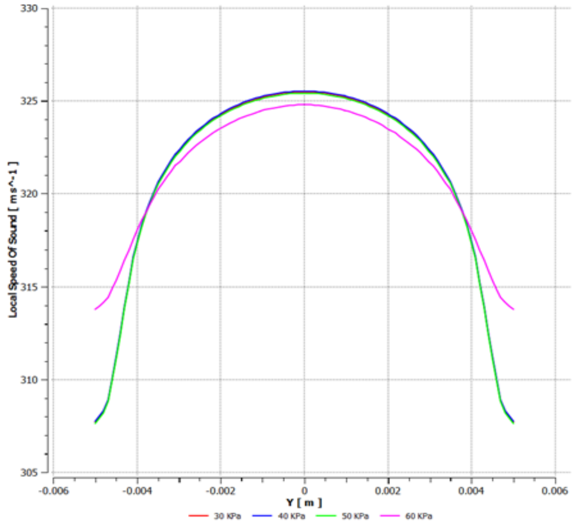

Fig 2 The variation of speed of sound within the nozzle

The variation of Mach number with the inlet pressure in the nozzle was also investigated and the results are depicted in Figure 3. The results show that the flow is supersonic in the inlet of the converging section and the outlet of the diverging section. The increase in the inlet pressure was accompanied with a decrease in Mach number in the throat while an increase in Mach number was notice in the inlet and outlet of the nozzle. It is also worth to mention that for 30-50 kpa pressure range, the change in Mach number was insignificant; unlike in the case 60 kpa, the effect was noticeable.

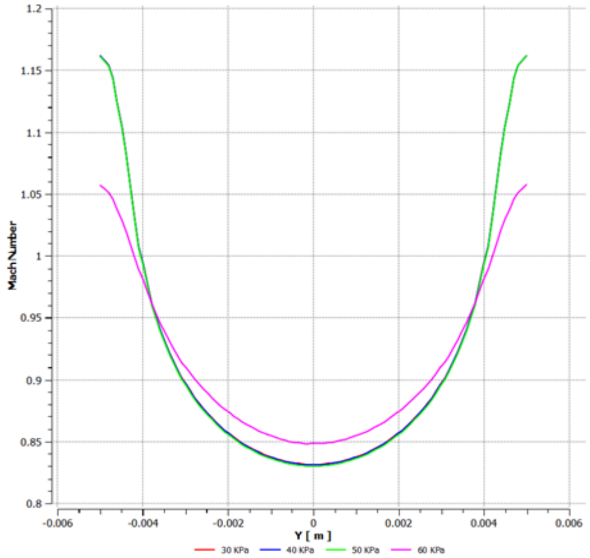

Fig 3 Variation of Mach nmuer in the nozzle

The pressure coefficient variation in the nozzle is studied and the results are illustrated in Figure 4. It can be clearly seen the pressure coefficient increases with the increase in the inlet pressure. However, the pressure coefficient decreases in the converging diverging nozzle. This decrease is sharp in the converging nozzle while the decrease is independent of the inlet pressure in the divergent nozzle and remains unchanged.

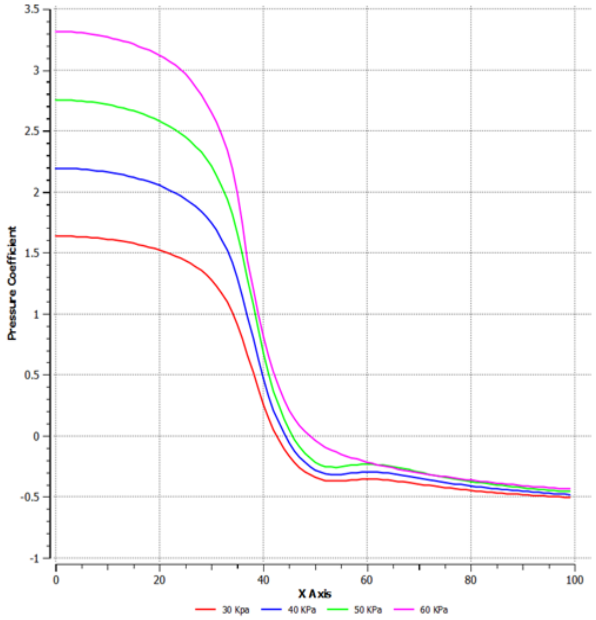

Fig 4 Variation of the pressure coefficient in the nozzle

To gain a better understanding of flow characteristics in the nozzle, variation of temperature in the nozzle was investigated and the results are shown in Figure 5. The temperature dropped sharply within the nozzle; however, it is independent of the inlet pressure except in the throat

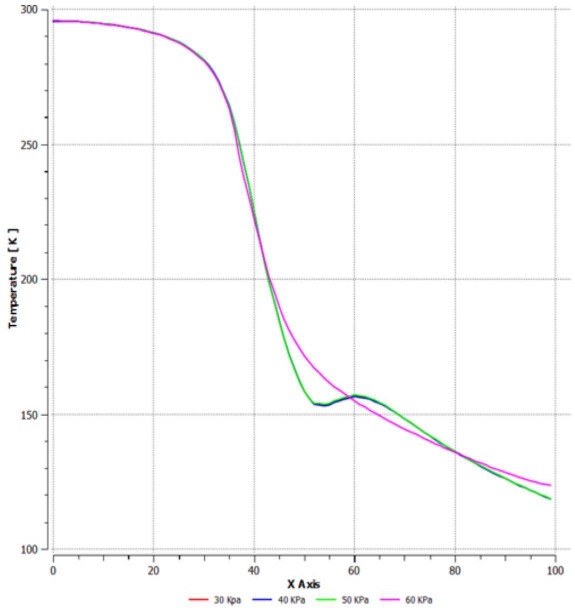

Fig 5 Variation of Temperature in the nozzle with pressure inlet

The study of the change in the enthalpy is crucial in the nozzle, the results of variation of enthalpy in the domain was explored and the results are presented in Figure 6.

It can be seen that the total enthalpy does not vary with the inlet pressure in the converging section. This variation is substantial in the diverging section. The increase in the inlet pressure led to a sharp increase in the enthalpy.

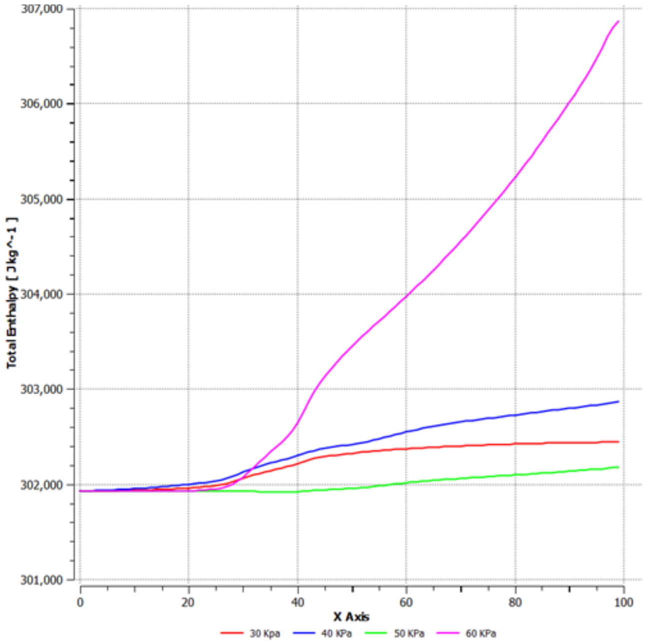

Fig 6 Variation of enthalpy in the nozzle

The contours of the speed of sound is shown in Figure 7. The contours display the distribution of the speed of sound in the converging diverging nozzle. The speed of sound is maximum in the converging section and reduces remarkably in the nozzle where it reaches its minimum value in the exit. This trend is seen for all inlet pressure range tested in the present study. The pressure contours for inlet range tested are illustrated in Figure 8. The pressure is maximum in the converging nozzle, and minimum in the diverging nozzle. The contours also show the distribution of the pressure in the throat, which interpret the chock wave and the critical values of pressure in the throat. It is evident that the pressure declined in the x direction for the divergent nozzle.

In addition to the pressure, the temperature contours are also investigated and the distribution of temperature is introduced in Figure 9. It can be seen that the temperature is maximum at the converging nozzle, however, in the throat and the diverging section, the temperature dropped significantly.

This drop is profound in the higher inlet pressure (60 kpa), the effect of inlet pressure on the temperature is dominant in the divergent section.

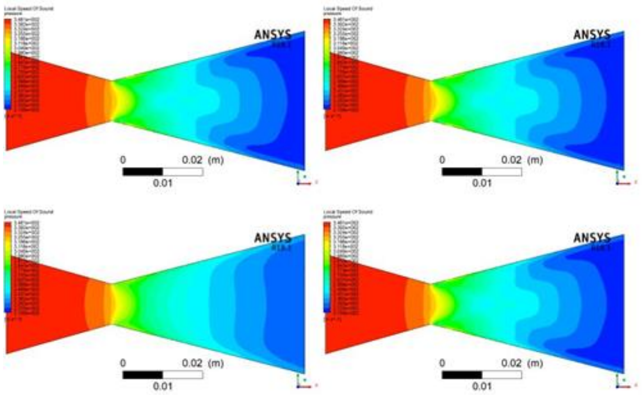

Fig 7 The contours of the speed of sound

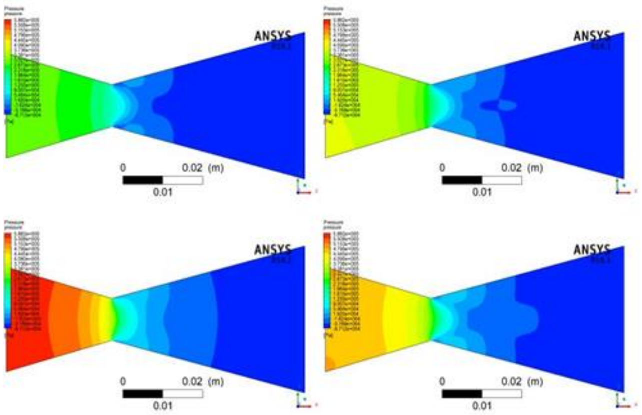

Fig 8 The pressure contours for various range pressure inlet

In order to understand the flow characteristics in the converging diverging nozzle, the velocity vectors are presented in this work and shown in Fig. 10

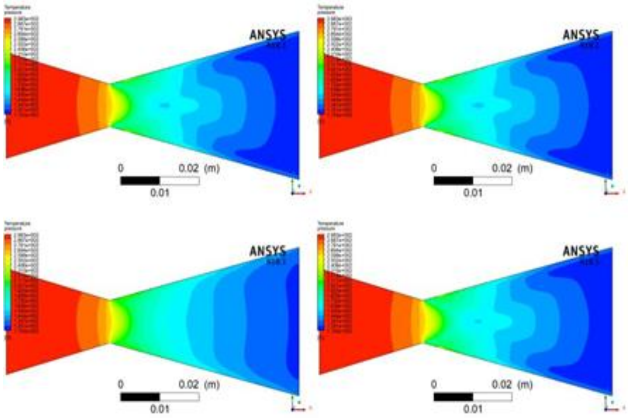

Fig 9 Contours of Temperature

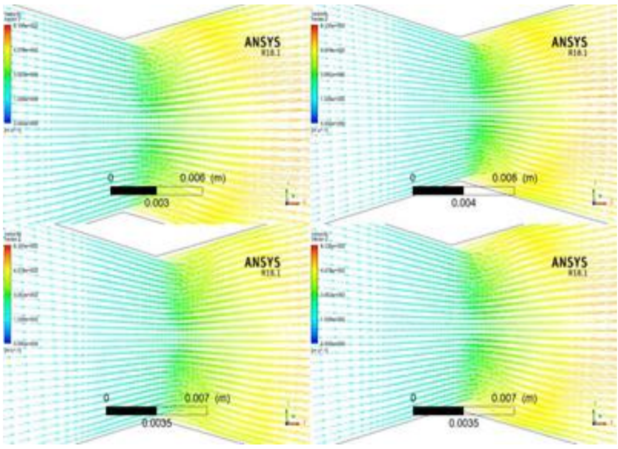

Fig 10 Velocity vectors in the converging diverging nozzle

VI. CONCLUSION

In the present work, the flow characteristics in a converging diverging nozzle was tested and analyzed. The effect of the pressure in the nozzle as well as the throat was explored. A various range of pressure (30 kpa -60 kpa) was investigated and the results were shown and discussed.

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BIOGRAPHIES

[1]. Saleh Etaig has received Bsc degree in Mechanical Engineering from University of Benghazi, in 1996. He got Msc degree from University of Manchester, UK in 2007. Later, he got PhD degree in Mechanical Engineering from the Northumbria University at Newcastle, UK in 2017, He is currently work as an assistant professor at the mechanical Engineering Department in the Faculty of Engineering at University of Benghazi/Libya.

[2]. Gamal Hashem has received Bsc degree in Mechanical Engineering from University of Benghazi, in 1999. He got Msc degree from University of Benghazi in 2007. Later, he got PhD degree in Mechanical Engineering from the Northumbria University at Newcastle, UK in 2016, He is currently work as an assistant professor at the mechanical Engineering Department in the Faculty of Engineering at University of Benghazi/Libya