International Journal of Advance Research in Engineering, Science & Technology(IJAREST),
ISSN(O):2393-9877, ISSN(P): 2394-2444,
Volume 2 ,Issue 4 , April-2015

Experimental Analysis of Convergent, Convergent Divergent nozzles at various mass flow rates for pressure ratio and pressure along the length of nozzle

Rakesh K. Bumataria[1], Darpan V. Patel[2], Sharvil D. Shah[3]
[1] *Mechanical Engineering Department, Parul Institute of Engineering and Technology (DS) Limda, Waghodia, Vadodara, Gujarat, India, E-mail: rakesh.bumataria@gmail.com*
[2] *Mechanical Engineering Department, Parul Institute of Engineering and Technology (DS) Limda, Waghodia, Vadodara, Gujarat, India, E-mail: darpanvpatel25@gmail.com*
[3] *Mechanical Engineering Department, Parul Institute of Engineering and Technology (DS) Limda, Waghodia, Vadodara, Gujarat, India, E-mail: shahsharvil74@gmail.com*

Abstract
In a wide variety of engineering applications, nozzles are encountered in systems as the downstream components of complete running assemblies. Due to prominent research in compressible fluid flow, experimental study has been carried out on specially design apparatus to analyses the performance and flow. Performance study contains with characteristics of one convergent and two divergent nozzles under various operating pressure ratio and with different nozzle profiles along the range of mass flow of fluid. Performance characteristics shows inlet and outlet condition by varying mass flow rate and change in pressure ratio along the length of nozzles.

Keywords- Convergent nozzle, Convergent divergent nozzle, subsonic flow, Mass flow rate, Pressure ratio

I. INTRODUCTION

We assume the steam nozzle to be a passage of varying cross section by means of which the energy of steam is converted into kinetic energy. The nozzle is so shaped that it will perform this conversion of energy with minimum loss. One may also define a nozzle as an opening through which steam is passed from a region of high pressure to one of lower pressure so as to derive additional velocity. It is chiefly used for producing a large velocity steam jet. In other words, its chief use is to produce a jet of steam for the purpose of driving steam turbines. The function of a nozzle in an impulse turbine is to admit steam to the active or moving parts of the turbine. In a reaction turbine the stationary nozzles admit steam to the moving parts which are also of nozzle shape and guide the steam from them.
A nozzle can be the flow accelerator in environmental control systems of commercial aircrafts which supplies fresh air at certain temperature and pressure to the passenger cabin; it can also be the essential part of the exhaust system of nuclear propulsion engines which utilize fusion reactions to generate energy and thrust. Regardless of the objective, the accurate prediction in design-oriented calculations of compressible nozzle flows is still a challenging task for the aerodynamicist and achieves increasing importance when the nozzle performance is significantly influenced by geometry, inlet conditions and sources of no isentropic character.
Variable area flow through nozzle in branch of compressible flow field employed two dimensional flow analyses. This can be simplified by making assumptions:

1. For simplicity, the gas is assumed to be an ideal gas.
2. The gas flow is isentropic (i.e., at constant entropy). As a result the flow is reversible (frictionless and no dissipative losses), and adiabatic (i.e., there is no heat gained or lost).
3. The gas flow is constant (i.e., steady) during the period of the propellant burn.
4. The gas flow is along a straight line from gas inlet to exhaust gas exit (i.e., along the nozzle's axis of symmetry)
5. The gas flow behavior is compressible since the flow is at very high velocities.

A. Convergent nozzles

Conical convergent nozzles have been widely used in subsonic jet engines as a means to convert pressure energy into kinetic energy because of their inherent simplicity in construction. A knowledge of the discharge coefficient and its variation with operating pressure ratio and convergence scmiangie is very important in the performance estimation of jet engines. Though there have been a number of attempts in the past to predict theoretically the variation of discharge coefficient, no simple, explicit and satisfactory expression has been obtained. However, experiments on the performance of conical jet nozzles in terms of flow and velocity coefficients were carried out systematically by Grey and WiLstedas early as 1948.

B. Convergent-divergent nozzles

A convergent-divergent nozzle (or de Laval nozzle, CD nozzle or con-di nozzle) is a tube that is pinched in the middle, making an hourglass-shape. It is used as a means of accelerating the flow of a gas passing through it to a supersonic speed. It is widely used in some types of steam turbine and is an essential part of the modern rocket engine and supersonic jet engines. Similar flow properties have been applied to jet streams within astrophysics. The nozzle was developed by Swedish inventor Gustaf de Laval in 1897 for use on an impulse steam turbine. This principle was used in a rocket engine by Robert Goddard, and very nearly all modern rocket engines that employ hot gas combustion use de Laval nozzles.

II EXPERIMENTAL SET-UP

The Nozzle Pressure Distribution unit has been specifically designed for experimental purpose. Until now experimental equipment for demonstrating and investigating the pressure distribution and mass flow rate in nozzles has usually used steam. This is because the quantity of air needed is beyond the capability of most of the air compressors usually installed. While steam is quite satisfactory for demonstrating the various effects in a nozzle, a boiler, with its heavy demand for energy, must be fired some time before the test is to start and a condenser with a cooling water supply etc is also needed. With these disadvantages in mind, this set up have designed the nozzle pressure distribution unit. This is bench top unit which uses compressed air at 7 to 9bar at the rate of 13 cfm. The power input needed to produce this quantity of air is only about 2.5kW, and there are no stands by losses. No additional services are required and the unit is ready for use as soon as the air is available.

Figure-1: Experimental nozzle apparatus for analysis

II APPARATUS SPECIFICATIONS

1. **Nozzles:**
i) One convergent (conical with six pressure trappings)
ii) One convergent divergent with five pressure trappings for design pressure ratio of 0.25
iii) One convergent divergent with eight pressure trappings for a design pressure ratio of 0.1

2. **Pressure gauge:**
i) Two 0 to 10 bar- to indicate air inlet and outlet pressures.
ii) Eight 1 to 10 bar- to indicate the pressure at the nozzle trappings.

3. **Valves:**
i) One needle valve- to give a fine control of air inlet pressure.
ii) One Gate valve – to control nozzle outlet pressure.

4. **Air filter/ Pressure regulator:**
To provide constant pressure, clean and water free air to the unit. This is to be installed between compressed air service and the unit must be drained regularly.

5. **Flow meter:**
Variable area type flow meter to indicate air flow at standard conditions.

6. **Thermometers:**
Two thermometers to indicate air temperature before and after nozzle.

IV. EXPERIMENTAL ANALYSES

[A] Convergent divergent nozzle (Nozzle-1)

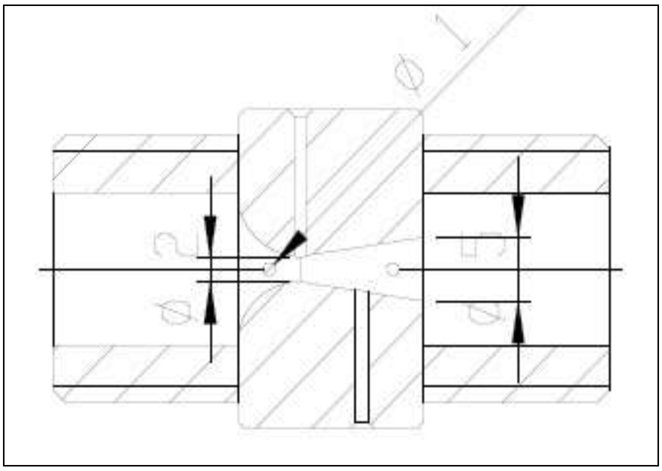

Figure-2: Convergent divergent nozzle with 5 pressure tapings

This convergent divergent nozzle contains Conical with five pressure trappings along the length of nozzle. Pressure tapings are used to measure local pressure at particular points along the nozzle.

(1) Pressure ratio for different mass flow rates

Figure 3 shows the variation of pressure ratio for different mass flow rate. Approximately up to pressure ratio 0.95 as pressure ratio decrease mass flow will increase rapidly. But after this pressure ratio mass flow change with pressure ratio is gradual.

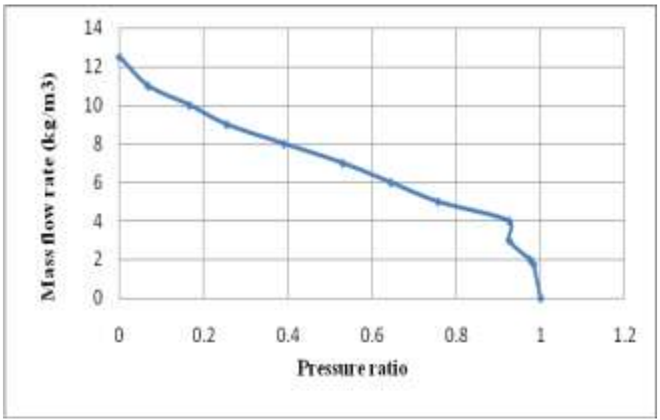

Figure-3: Mass flow vs pressure ratio for Convergent Divergent Nozzle with 5 pressure tapings

(2) Pressure ratio along the length of nozzle

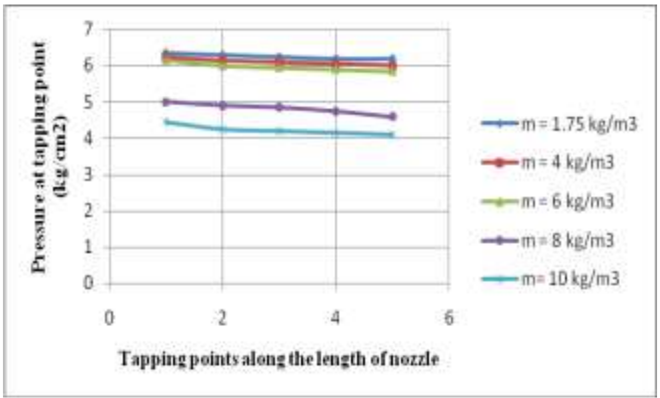

Figure-4: Pressure variation along the length of nozzle in convergent Divergent Nozzle with 5 pressure tapings

Figure 4 shows variation of pressure along the length of nozzle for different mass flow rate. This shows that as length increase pressure will decrease gradually. Also from this graph we can conclude that as mass flow increase pressure will decrease and also slop of pressure variation along the length will increase.

[B] Convergent divergent nozzle (Nozzle-2)

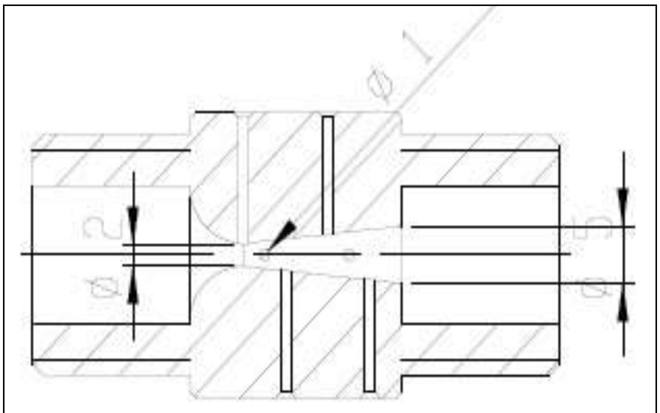

Figure-5: Convergent divergent nozzle with 8 pressure tapings

Specially designed convergent divergent nozzle with 8 pressure tapings is used to find more accurate pressure readings along the length of nozzle. Also this nozzle holds good for chocking phenomenon study. This nozzle is designed for 0.25 pressure ratio.

(1) Pressure ratio for different mass flow rates

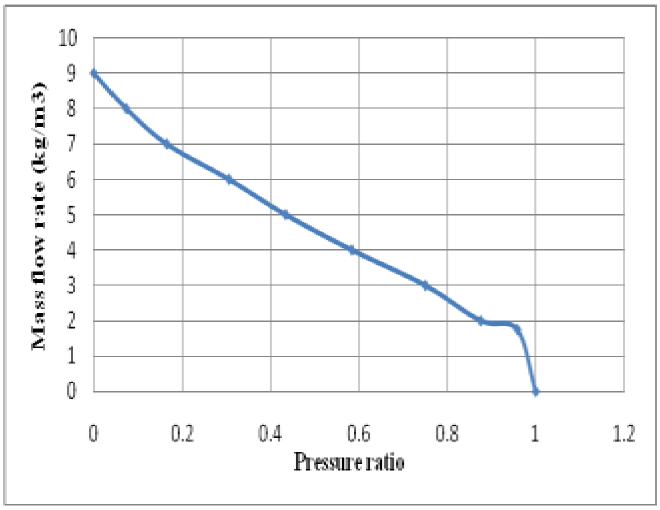

Figure-6: Mass flow vs pressure ratio for Convergent Divergent Nozzle with 8 pressure tapings

Figure 6 shows variation of pressure ratio with mass flow rate for convergent divergent nozzle. Results show that up to pressure ratio 0.95 mass flow increase rapidly with decrease in pressure ratio. From pressure ratio 0.95 to 0.88 mass flows will remain constant but after 0.88 pressures ratio mass flow will increase gradually as pressure ratio decrease.

(2) Pressure ratio along the length of nozzle

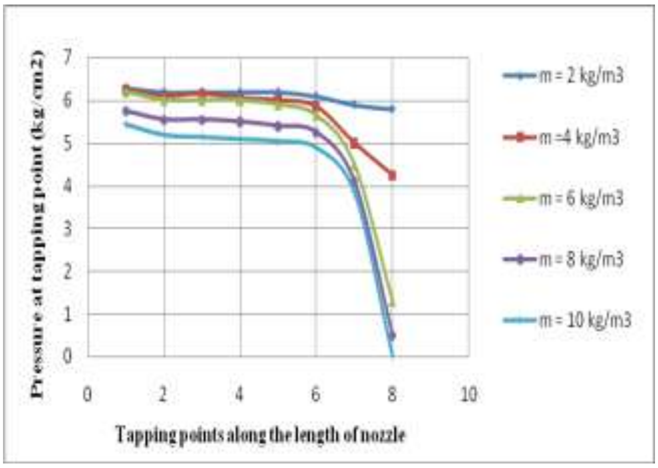

Figure-7: Pressure variation along the length of nozzle in convergent Divergent Nozzle with 8 pressure tapings

Figure 7 shows the pressure variation along the length of nozzle for different mass flow rates. As length increase pressure will gradually decrease up to taping point 6 and then pressure will rapidly decrease with increase in length. Also results shows that for more than 6 kg/m3 mass flow rate pressure variation after taping point 5 (five) is decreasing drastically.

[C] Convergent nozzle (Nozzle-3)

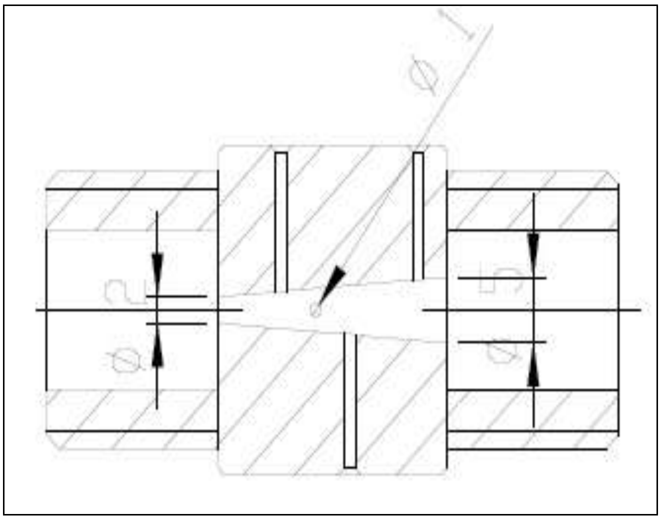

Figure-8: Convergent nozzle

Figure 8 shows convergent nozzle with 6 pressure taping for the study of mass flow variation along with pressure ration and pressure variation alon the length of nozzle by measuring pressures at different location along the length of nozzle. This nozzle is specially design for 0.1 pressure ratio.

(1) Pressure ratio for different mass flow rates

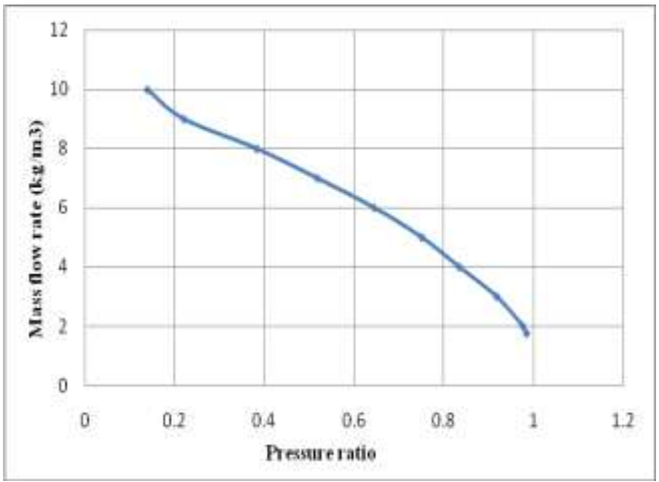

Figure-9: Mass flow vs pressure ratio for Convergent Nozzle with 6 pressure tapings

Figure 9 shows the variation pressure ratio by changing mass flow rate. Here results shows that for such a convergent nozzle pressure ratio change with changing mass flow rate behave nearly as a straight line. so as mass flow rate increase, pressure ratio decrease as a straight line.

(2) Pressure ratio along the length of nozzle

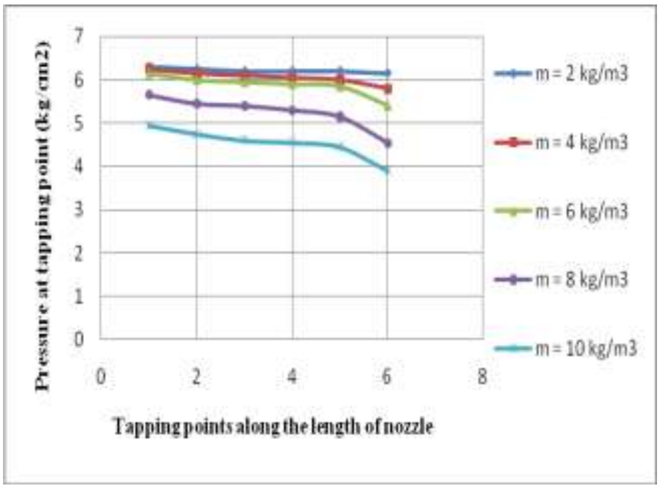

Figure-10: Pressure variation along the length of nozzle in convergent Nozzle with 6 pressure tapings

Figure 10 shows pressure variation along the length of nozzle for different mass flow rate. Here also results show that pressure slightly change with length u to taping point 5 and after this point it will decrease rapidly with length. Also this results show that pressure will decrease as mass flow increase.

CONCLUSION

Analysis of nozzle for different mass flow rate helps to predict behavior of nozzle. By analyzing change in pressure along the length of nozzle in all three nozzle is also used to predict behavior and energy conversation along the nozzle. Such experimental analysis also useful for comparison of actual performance with theoretical. Such types of results are guiding for selection of nozzle for different operations.

Reference

[1] Kapooria R K, Kumar S, Kasana K S, "Technological investigations and efficiency analysis of a steam heat exchange condenser: conceptual design of a hybrid steam condenser", Journal of Energy in South Africa, Vol. 19, No.3, August 2008.

[2] Pansari Kunal, Jilani S A K, "Analysis of the Performance and flow Characteristics of Convergent Divergent Nozzle", International Journal of Advances in Engineering & Technology, Vol.- 6, Issue-3, July 2013.

[3] Kayhani M H, Zarenezhad S, Lakzian E, Hashemian S M, "Numerical Investigation of 2D Condensation Steam Flow by Eulerian-Eulerian Method", "International Conference on Mechanical, Automobile and Robotics Engineering, Penang, Malaysia, 2012.

[4] Richards C R, "Entropy Temperature and Transmission Diagrams for Air", University of Illinois, Vol.X, No.15, January 1913.

[5] Hebbar K S, Sridhara K, Paranjpe P A, “Performance of Conical Jet Nozzles in Terms of Discharge Coefficient”, Journal of the Aeronautical Society of India, Vol-22, No-1, June 1969.

[6] S. Poorasadion, M. Alishiri, M. Saadatmand, “Cfd Investigation On The Steam Condensing Phenomena Inside Nozzle Of Steam Ejector” Idawc/Tian13, Tianjin, China.

[7] Yahya S M, “Fundamentals of Compressible flow with air craft and Rocket Propulsion”, New Age International Publication, 4^{th} Edition, 2010.