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DEVELOPMENT OF HIGH ALTITUDE TEST FACILITY FOR COLD JET SIMULATION

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Abstract

A High altitude test facility was developed in the Aerospace department, Karunya University for cold flow studies A High Altitude test facility was developed to study the jet plumes at high altitude , shock formation in a supersonic nozzle at different altitude condition above sea level and Jet interaction studies of single and multi-jets , cold and hot jets. The study basically involve the decent behavior of a nozzle. It provides altitude simulation for experimental purposes. Compressed air at high pressure is used to study the supersonic nozzle in vacuum conditions in the High Altitude Test Facility. The vacuum chamber can simulate altitude up to 32.5km. A scale model of supersonic conical nozzle of throat diameter 5mm and exit diameter 11mm was mounted inside the vacuum chamber of the high-altitude test facility. The experiment were performed at various decent conditions, static pressure along the nozzle was used to get the pressure profile using the 16 port electronic pressure scanner. CFD analysis was carried out for various inlet pressure condition, the results were found using isentropic relations are which validated with the experimental results. Air pressure decreases with increasing altitudes .A study of evacuation rate and the pressure rise with respect to time was also studied at different inlet conditions.

Keywords: CFD analysis, Isentropic relations, Electronic pressure scanner.

1. Introduction

Rocket engines and propulsion systems that are designed to operate in space often require testing under simulated altitude conditions. They often incorporate high expansion ratio nozzles for increased performance. When these nozzles are operated in an ambient pressure significantly higher than what they were designed for, there is flow separation from the nozzle wall, which results in lowering the thrust. Flow separation can cause nozzle burning and damage due to the formation of shock waves, unsymmetrical pressure distribution and excessive vibration at the separation point. Ignition characteristics of both solid and liquid propellants are significantly altered. Combustion instability triggered at engine start may be masked by ambient pressure ignitions. Convective heat transfer that readily exists at ambient pressure is nearly nonexistent in the space environment. Engines may overheat during this operation due to lack of convective cooling. All this posts a need for testing the nozzle at high altitude conditions. For studying the behavior of the nozzle for different altitude conditions a High altitude test facility was developed in Aerospace department , Karunya University. The High Altitude test facility was commissioned for studying the cold flow condition of a supersonic nozzle.

2. Experimental Setup

For developing the setup , a supersonic nozzle was to be designed and fabricated for the maximum test duration . The evacuation rate of the vacuum pump was considered to be the mass flow rate of the supersonic nozzle. The High Altitude Test facility of Karunya University is a vacuum simulation chamber that can simulate vacuum environments in the range of 0.9 to 1 mbar vacuum pressure . The High Altitude facility is a cost-efficient, secure and easy to handle configuration to perform tests and studies in the field of altitude simulation and flow separation of nozzles. The simulated altitude is approximately 32.5km in this facility. The vacuum chamber has a diameter of volume of 1.706 m^3 A vacuum pump was used for evacuating the chamber before the test. Suitable mountings were made to hold the high pressure nozzle in the test section of the vacuum chamber. The different vacuum level would give different altitudes . A positive displacement pump was used for this purpose. First it obtains a rough vacuum in the vessel before the momentum transfer pump is used to obtain a high vacuum . The specification of the vacuum pumps is of positive displacement type and the motor used of 3 phase induction type motor Pumping rate – 65 m^3/h Oil required – 2 litres. A two stage Reciprocating air Compressor was used to charge the high pressure reservoir. A High Pressure 2 stage Air cooled , Splash lubricated compressor with Displacement – 92.18 m^3/h and Free air delivery – 67.92 m^3/h was used .The working pressure of the compressor was 30kgf/cm^2 with Compressor speed of 1150 rpm. A compressed air dryer was used for removing water vapour from compressed air. This process concentrates atmospheric contaminants; including water vapour .This raises the dew point of the compressed air leading to condensation within the pipes. The air dryer is of Desiccant type with inlet flow rate of 127.42m^3/h Pressure of 6.86 to 12.3 bar and Temperature – 42^0C the Outlet conditions of the air dryer has Flow rate - 114.68 m^3/h Pressure – 6.67 to 12.1 bar and Temperature of 40^0 A Pressure drop of 0.2 bar Pressure was noted. A high Pressure vessel with closed container was installed to hold gases at a pressure substantially different from the ambient pressure .This Pressure Vessel was used to store the compressed dry air at high pressure for various operations to be executed in the high altitude test facility. The high pressure reservoir stored compressed air at high pressure with safe operating pressure of 20 bar. The volume of the reservoir is 6.28m^3

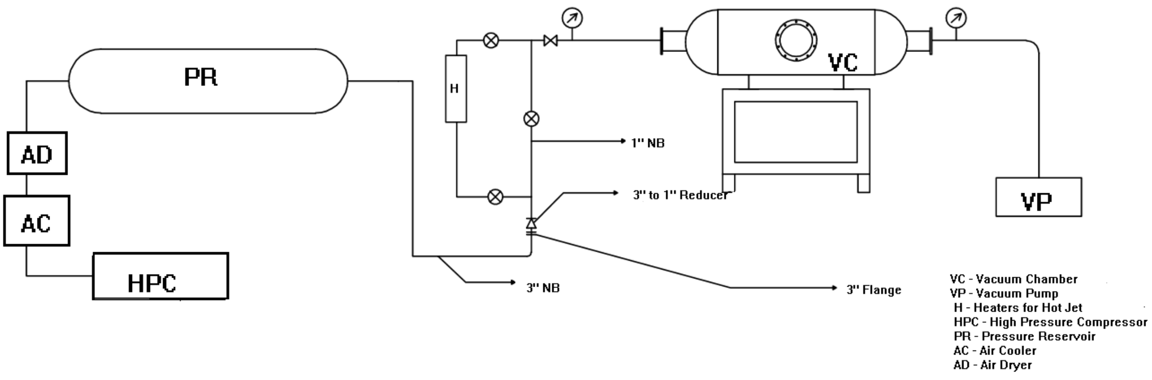

Figure 1: Experimental Setup

When High pressure is made to flow through the supersonic nozzle, the ambient pressure inside the vacuum chamber rises to higher values. A Pressure relief valve is used to maintain a controlled environment for the vacuum chamber which is calibrated for a pressure of 1.9 bar. In order to reduce the impact of vibration loads on the system

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due to the compressed air, we have mounted the conical nozzle with an internal rigid support structure. This will reduce the impact of vibrations. For the purpose of measuring the pressure across the different points on the contour of the nozzle, various holes of 1.5mm diameter were drilled on the surface of the nozzle. After this , the nozzle is mounted inside the vacuum chamber and silicon tubes of internal diameter 1.5mm are fixed over the steel tubes and are brought outside via the cross fittings . A 16 port electronic pressure scanner is used for measuring pressure from multiple ports simultaneously. These pressure scanners contain temperature compensated pressure sensor. The pressure gauge used is of Silicon Microstructure type with secondary storages. These ports are arranged in a manner that Port 1 can measure upto 150psi; Port 2,3,4-100psi; Port 5,6,7 -30psi; Port 8 to 16 measuring 15psi . The NI based interface connects the pressure scanner to the computer and the LAB VIEW software is used as GUI.

A supersonic nozzle was designed using conventional method. The nozzle exit angle was fixed to 15 degrees. The nozzle throat diameter was of 5 mm designed to operate at 10 bar inlet pressure. The material used to fabricate the nozzle is Stainless Steel, SS-304. The pipes used for plumbing are IBR seamless pipe made of high carbon steel. Standards flanges were used for the different joint .

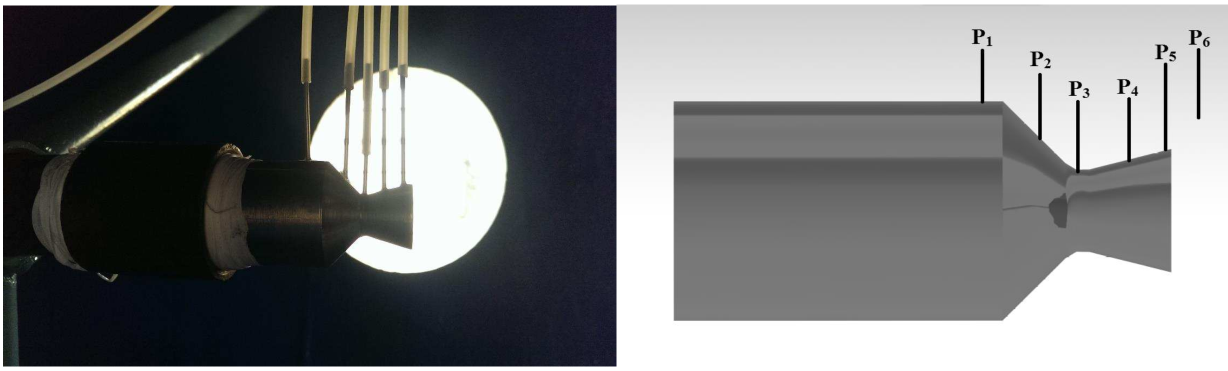

Figure 2 : P_1 - Inlet ;P_2 - Convergent section ;P_3 – Throat ;P_4- Divergent section ;P_5 – Exit ;P_6- Ambient (Vacuum chamber).

3. Results and discussion

A CFD analysis of the designed conical nozzle was carried out by generating an unstructured Quad-tri mesh using the dimensions of the nozzle in GAMBIT 2.4.6. Then the generated mesh was solved using FLUENT 6.3.26 and the results of various contours and vectors were obtained along with plots to see how the various isentropic parameters change as we go through the inlet to the throat and towards the exit of the nozzle . Then the respective boundary conditions were given for solving .

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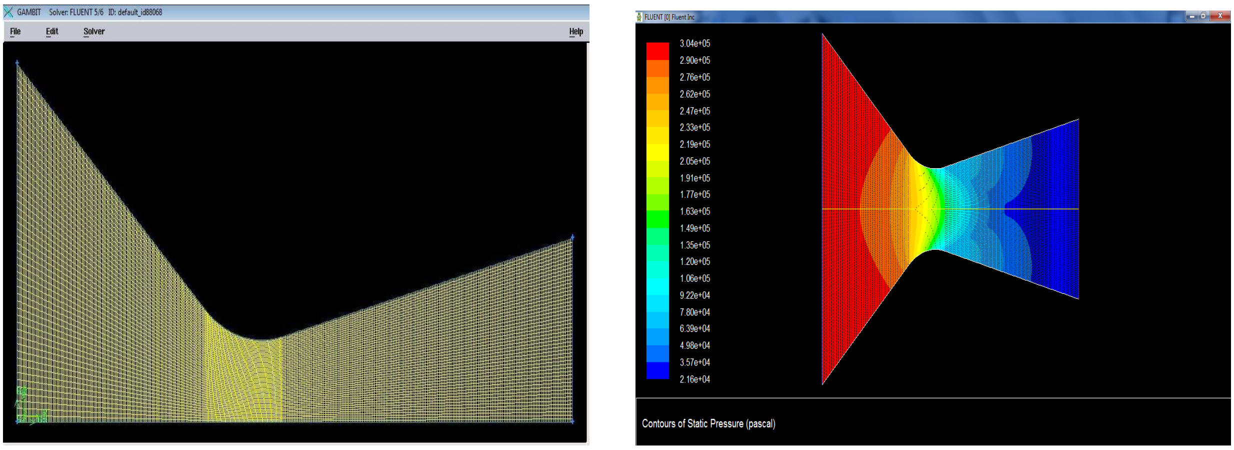


Figure 3 : (a) Nozzle mesh generated in GAMBIT 2.4.6 (b) Contour plot of Static Pressure

From the above pressure contour plot we could clearly observe that the pressure gradually started decreasing from the inlet , to medium at the throat and finally very less at the exit of the designed nozzle .[2]

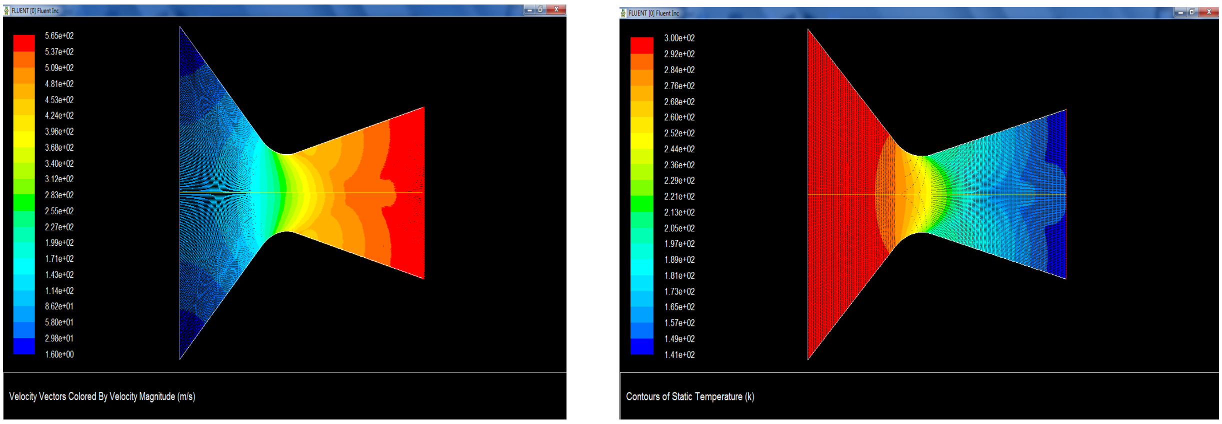


Figure 4 : (a) Vector plot of Velocity Magnitude (b) Contour plot of Static Temperature

According to the previously proved theories we have observed that from the velocity vector plot, the conical nozzle showed signs of velocity increasing from the inlet through the throat to the maximum value of the velocity at the exit . Through the CFD analysis the conical nozzle showed that the temperature kept decreasing downstream and there were freezing temperatures at the nozzle exit .

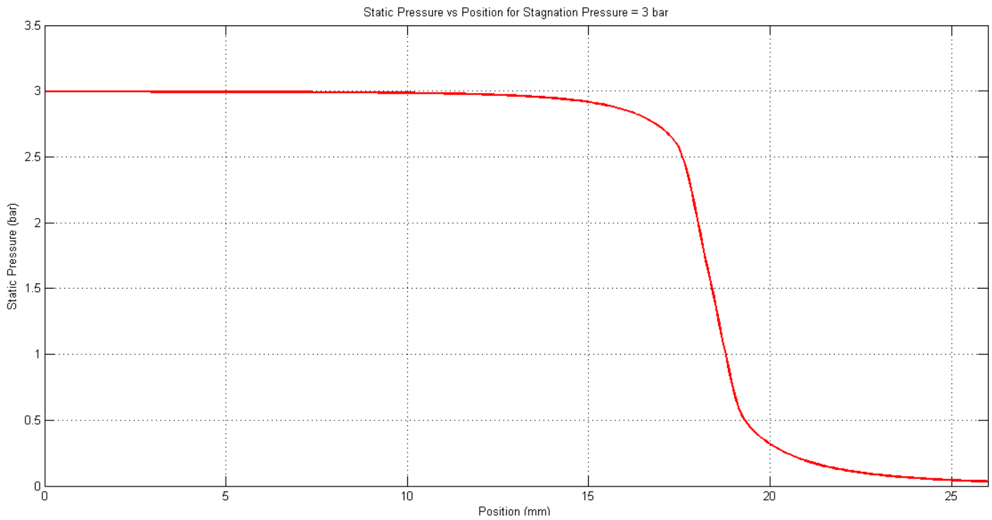


Figure 5 : Static Pressure vs Position for Stagnation Pressure of 3 bar

For the purpose of theoretically calculating the static pressure , temperature and velocity at each and every cross section of the conical nozzle all the way from the inlet , throat and the exit . We plot the curves to validate these parameters with respect to the position downstream of the nozzle. A suitable programming language was used and the results were programmed using the MATLAB R2008b .

We have plotted the various graphs for Pressure, Temperature and Velocity.

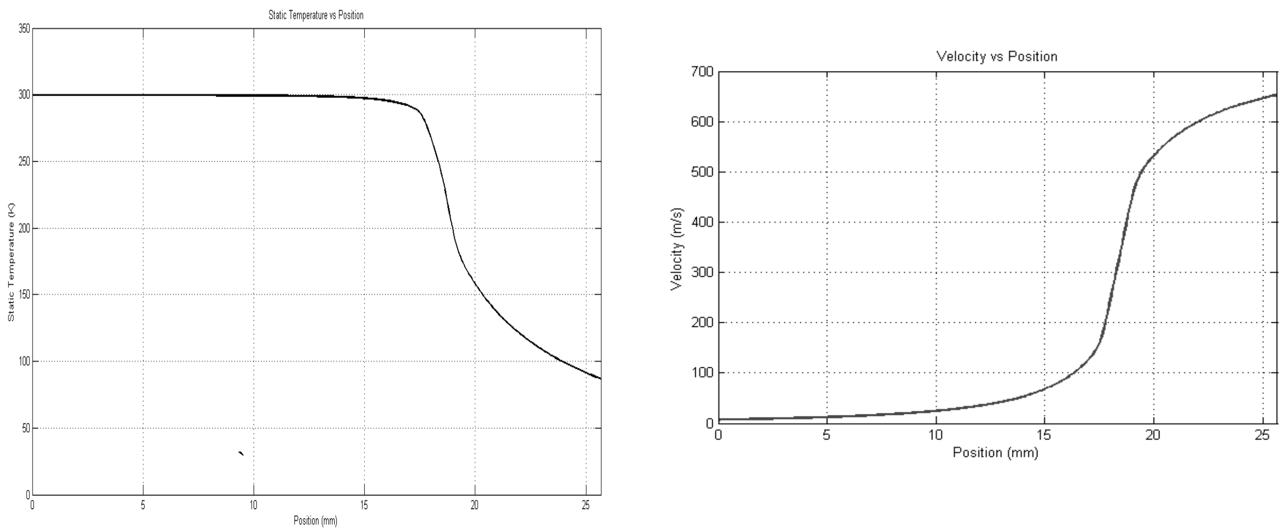


Figure6 (a) Static Temperature vs Position (b) Velocity vs Position

For conducting any experiment in vacuum chamber, it is very important to calculate the run time for the test . The run time is dependent on the pressure rise in the chamber for every inlet stagnation pressure . It is also important to note the time it takes for vacuum chamber to get filled from 0.001bar to 1 bar , which gives the run time of the experiment . Here the rise in pressure the chamber for various stagnation pressure is plotted using the MATLAB R2008b. We have got the following plots from which we know that the measured run time for 5 bar and 10 bar inlet stagnation pressure is 1minute 37 seconds and 46 seconds respectively.

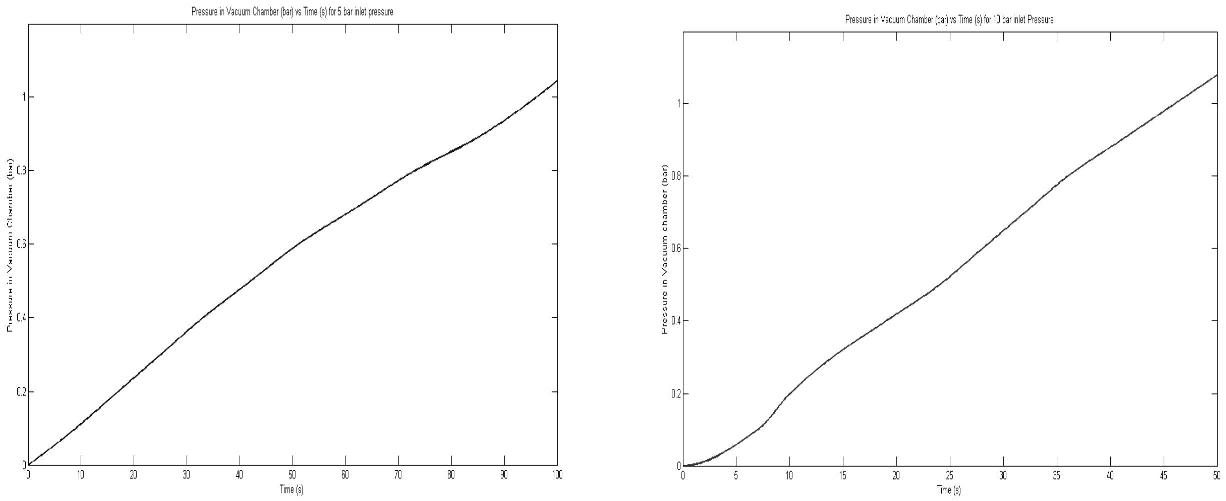


Figure 7 : (a) Pressure rise in the vacuum chamber for 5 bar inlet pressure (b) Pressure rise in the vacuum chamber for 10 bar inlet pressure

By placing the pressure port along the nozzle.An experimental pressure profile was created using a 16 port electronic pressure scanner.

4. Conclusion

At different values of stagnation pressure, the pressure at different pressure points was measured using a 16 port electronic pressure scanner along the length of nozzle from the inlet to the exit measuring the time interval of 0.1 seconds . The ratio of exit pressure to the ambient pressure (P_5/P_6) is plotted with time and the regions of under expansion and over expansion are noted along with the line where the nozzle is correctly expanded. The graphs for these values are plotted using MATLAB R2008b. The graph shows that the design value matches with the practical datas

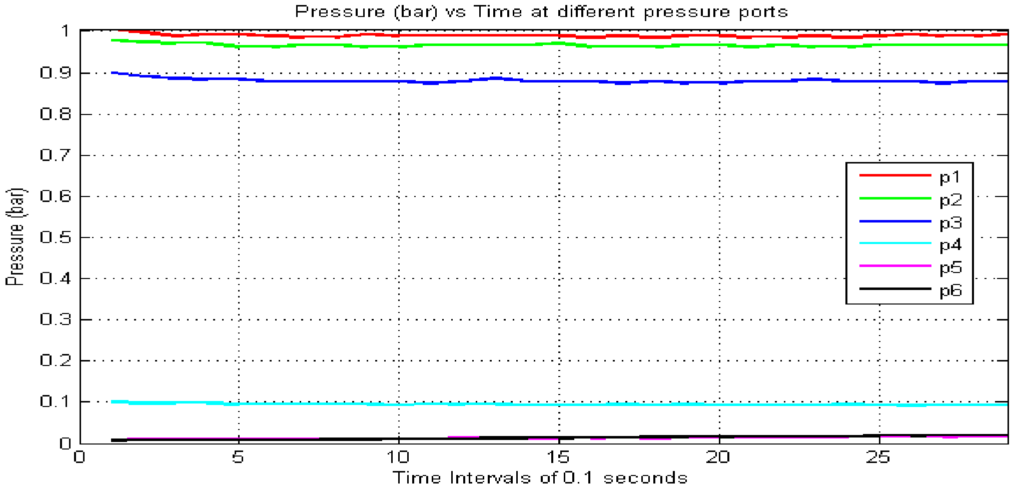
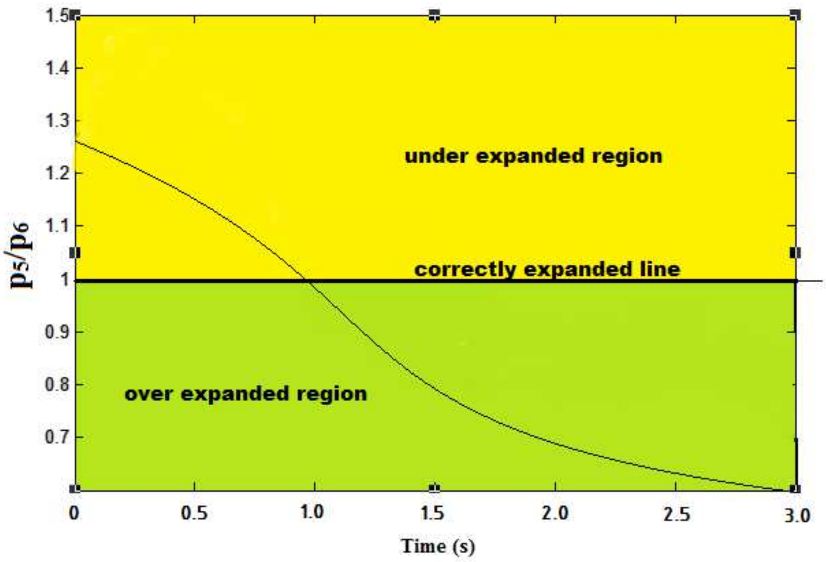


Figure 9: Pressure at different pressure port



From the above graph we can interpret that the ambient pressure P6 slowly shows signs of increase , mainly due to the pressure build up in the chamber.The results of theoretical and experimental datas are found to match.

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