Experiment 4

FLOW THROUGH A NOZZLE

1.0 OBJECTIVE

- To study the pressure distribution through a nozzle for different inlet pressures and different flow rates, critical pressure, velocity, mass flow rate of air at the throat.

2.0 INTRODUCTION & THEORETICAL BACKGROUND

A nozzle is a steady state-flow device; whose purpose is to create a high-velocity fluid stream at the expense of its pressure. Nozzles are commonly utilized in jet engines, rockets, space crafts, and even garden hoses. The cross-sectional area of a nozzle decreases in the flow direction for subsonic flows, and increases for supersonic flows, as seen in Figure 1. The rate of heat transfer between the fluid flowing through a nozzle and the surroundings is usually very small ($\dot{Q} \cong 0$), there is little or no change in potential energy($\Delta p \cong 0$), and the process involves no work($\dot{W} = 0$).

Mach Number M: The Mach number is a dimensionless value useful for analyzing fluid flow dynamics. The Mach number can be expressed as *M = v / c*
Where M = Mach number, *v = fluid flow speed (m/s), c = speed of sound = 343 (m/s).*
Mach number < *1*, the flow is **subsonic**
Mach number = *1*, the flow is **transonic**
Mach number > *1*, the flow is **supersonic**
If the Mach number > *5*, the flow is **hypersonic** (See Figure 1)

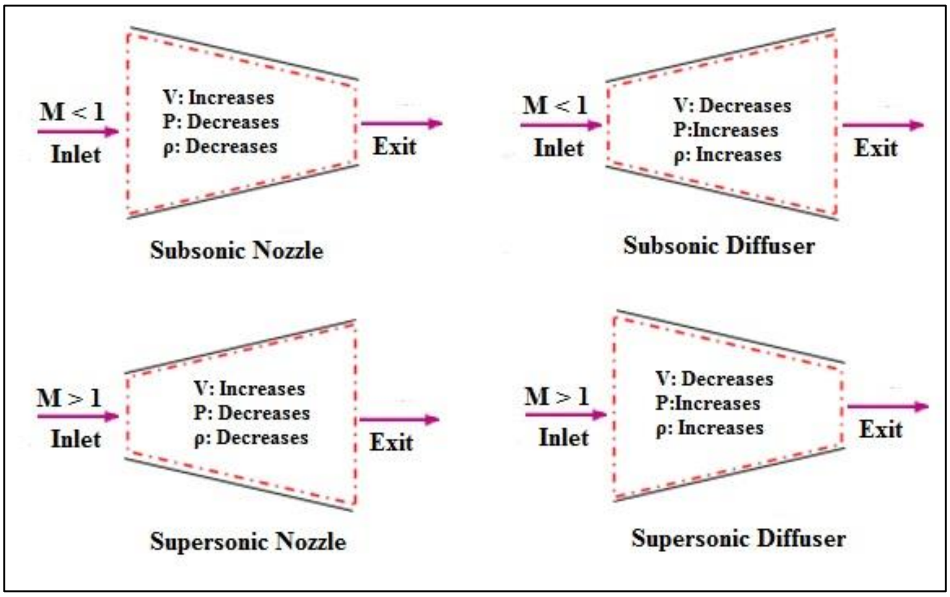

Fig. 1: Shapes of nozzles and diffusers in subsonic and supersonic regimes

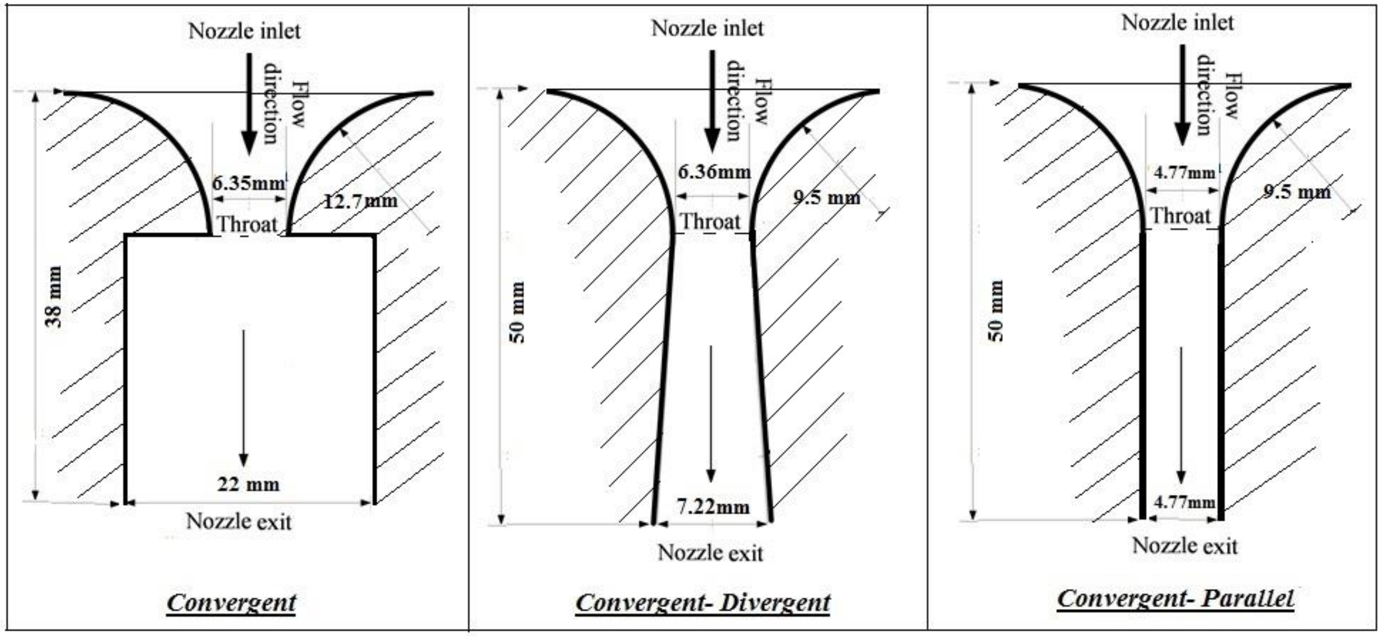

Fig. 2: Nozzle Profiles

TECHNICAL DATA

Nozzle Type	Throat diameter
Convergent:	**6.35 mm**
Convergent–Divergent:	**6.36 mm**
Convergent–Parallel:	**4.77 mm**

Probe diameter: **3.33 mm**

The flow of ideal gas through three different nozzles is shown in Figure 3 & 4. The nozzle discharges into a plenum chamber, in which the pressure is P_b can be regulated. Let P_e be the exit pressure just at the exit cross-section of the nozzle. When P_b is reduced, gas is drawn through the nozzle. As P_b is reduced more, the mass flow rate of gas increases and the velocity increase. The value of the velocity is the highest at the minimum area, and this can't be higher than the critical value i.e. when the velocity reaches the velocity of sound.

At this state the pressure is at its critical value, P*, which is given by:

$\frac{P^*}{P_o} = \left(\frac{2}{k+1}\right)^{\frac{k}{k-1}}$	(1)

Where P* is the critical pressure kPa

P_o is the stagnation pressure kPa

k is the specific heat ratio

For air k = 1.4, and thus $P^* = 0.528 \times P_o$

For conditions other than the critical condition, the velocity at the throat is given by:

$V_t = \sqrt{\frac{2kRT_o}{k-1}\left[1-\left(\frac{P_t}{P_o}\right)^{\frac{k-1}{k}}\right]} \quad m/s$	(2)

Where T_o and P_o are the temperature and pressure in the nozzle chest, and P_t is the pressure at the throat.

While the mass flow rate at the throat is given by:

$\dot{m}_t = A_t * P_o * \left(\frac{P_t}{P_o}\right)^{\frac{1}{k}} \sqrt{\frac{2k}{(k-1)*R*T_o} * \left[1-\left(\frac{P_t}{P_o}\right)^{\frac{k-1}{k}}\right]} \quad kg/s$	(3)

Where:

$Throat\ Area = A_t = \frac{\pi}{4}(d_n^2 - d_p^2), \quad m^2$	(4)

In this relation the pressure is in kPa, T_o *in K and* R = 0.287 kJ/kgK

3.0 APPARATUS

A General View and schematic layout of the apparatus is shown in figure 3 and figure 4. Air is admitted to a cast iron pressure chest by way of adjustable vales. A nozzle of highly finished brass is screwed into a seating in the base of the chest and the air or steam expands through the nozzle. To enable the pressure distribution through the nozzle to be plotted, a search tube or probe of stainless steel may be traversed along the axis of the nozzle. A small cross hole in the search tube connects with a high grade pressure gauge which registers the pressure at any point in the nozzle. The search tube is traversed by rotating a calibrated dial and pressures are usually recorded at intervals of 2.5 mm. A pointer moves with the search tube past a replica of the nozzle profile in order to indicate the point in the nozzle at which the pressure is being measured. The nozzle discharges into a vertical pipe of large bore fitted with a throttling valve for controlling the downstream pressure. Other instruments include a second pressure gauge for recording the pressure in the chest (Po) and a thermometer for indicating the temperature of air in the chest. (See Figure 3)

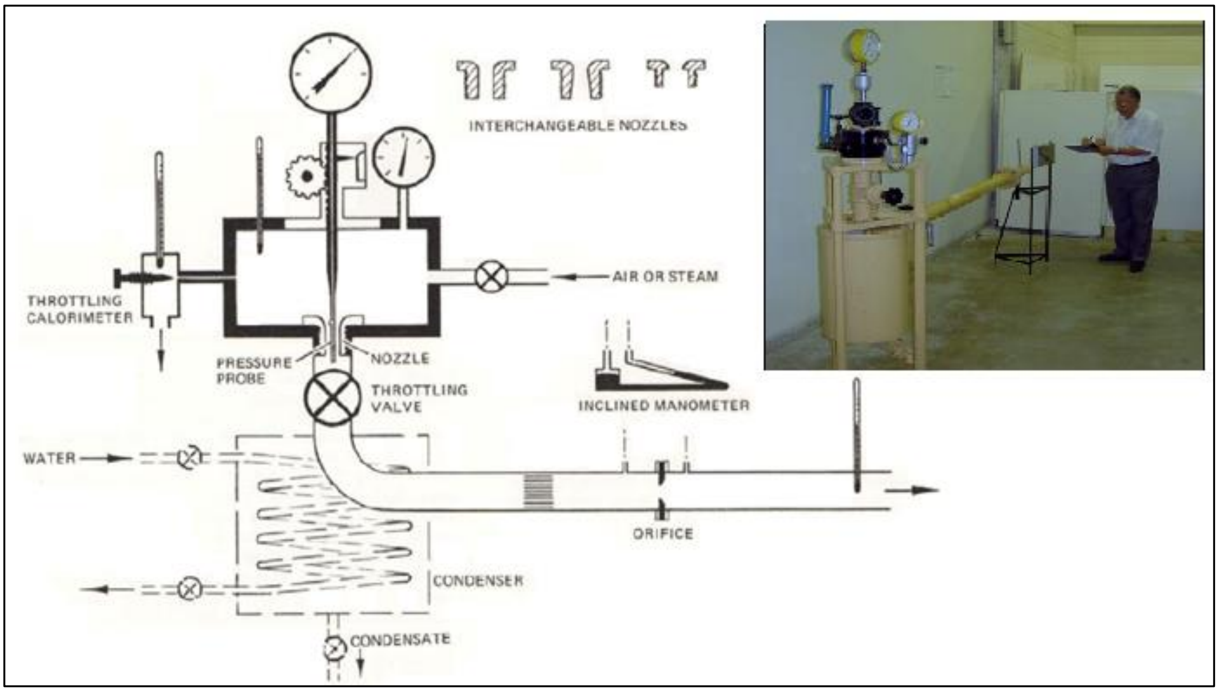

Fig. 3: Nozzle Flow Apparatus

4.0 PROCEDURE

1. Before starting, record the inlet air temperature and the barometer pressure.
2. Open the back pressure valve and return the search tube (pressure probe) to its upper limit, the pressure gauge should indicate the inlet chest pressure.
3. Open the inlet throttling valve by adjusting the chest gage pressure to 300 kPa.
4. Start record the probe pressure at several locations along the nozzle axis by rotating the calibrated dial, the probe is traversed in increments of 2.5 mm
5. The selected inlet chest pressure should remain constant during the experiment, so Chest pressure to be observed and re-adjusted to initial setting if necessary.
6. Record probe pressure at each of the locations shown on the nozzle.
7. At the end of the traverse, search tube should be returned to the upper position.
8. Repeat for other values of chest pressure, 400, and 500 kPa.
9. Check that the pressure at the throat is not lower than that for the condition of choking (critical condition).

Note: there is tendency for the inlet chest pressure to change in the course of the experiment (this may occur when the apparatus is being supplied with air by a compressor of insufficient capacity) a student should be placed in charge of the inlet throttling valve, with the task of maintaining a constant inlet chest pressure by adjusting the throttling valve as necessary.

5.0 OBSERVATIONS

Table 1: DATA OBSERVED

Atmospheric Pressure =______kPa Atmospheric Temperature = ________ ℃

Part	Probe Position	X/L	Chest pressure P_o (gage)		
			P_o = ------- kPa	P_o = ------- kPa	P_o = -------- kPa
			Position Pressure, Pp, kPa		
Nozzle	7	0.0			
	8	0.25			
	9	0.5			
	10	0.75			
	11	1.0			
Parallel Section	12	1.25			
	13	1.5			
	14	1.75			
	15	2.0			
	16	2.25			
	17	2.5			
	18	2.75			
	19	3.0			
	20	3.25			
	21	3.5			
	22	3.75			
	23	4.0			
	24	4.25			
	25	4.5			
	26	4.75			
	27	5.0			
Outside	28	5.25			
	29	5.5			
	30	5.75			
	31	6.0			
	32	6.25			

Note that: **Position (7): is the entrance of the nozzle**

Position (11): is the location of the throat and exit of nozzle

Position (27): is the end of the parallel section

L = Nozzle length (10 mm), X= Probe increment = 2.5mm, X/L = 0.0, 0.25, 0.50 …6.25mm

6.0 DATA ANALYSIS

When the velocity of air reaches the velocity of sound where Mach number =1, the pressure is at its critical value, P*, which is given by:

$$\frac{P^*}{P_o} = \left(\frac{2}{k+1}\right)^{\frac{k}{k-1}}$$

P* is the critical pressure

P_o is the stagnation pressure

K is the specific heat ratio

For air k = 1.4, and thus $P^* = 0.528 \times P_o$

For conditions other than the critical condition, the velocity at the throat is given by:

$$V_t = \sqrt{\frac{2kRT_o}{k-1}\left[1 - \left(\frac{P_t}{P_o}\right)^{\frac{k-1}{k}}\right]} \quad m/s$$

T_o and P_o are the temperature and pressure in the nozzle chest, and P_t is the pressure at the throat.

The mass flow rate at the throat is given by:

$$\dot{m}_t = A_t * P_o * \left(\frac{P_t}{P_o}\right)^{\frac{1}{k}} \sqrt{\frac{2k}{(k-1) * R * T_o} * \left[1 - \left(\frac{P_t}{P_o}\right)^{\frac{k-1}{k}}\right]} \quad kg/s$$

$$Throat\ Area = A_t = \frac{\pi}{4}\left(d_n^2 - d_p^2\right), \quad m^2$$

In this relation the pressure is in KPa, T_o *in K and* R = 0.287 kJ/kg K

7.0 RESULTS & DISCUSSION

Table 2: SUMMARY OF RESULTS

Throat Area = ________________ m^2					
Chest pressure, kpa, (abs.)	**Throat Pressure, kpa, (abs.)**	**Mass Flow Rate @ Throat kg/s**	**Velocity @ throat m/s**	**Pressure Ratio**	**Critical Pressure, kpa, (abs.)**

1. For different values of chest pressure, plot the absolute pressure with the probe position along the nozzle (X/L).
2. For different values of pressure ratio across the nozzle, plot the mass flow rate with the pressure ratio.
3. All the results were recorded and tabulated under the results table.
4. Write your own opinions about the results.
5. What might be the possible causes of errors in this experiment? Discuss about whether the results are acceptable or not?
6. The diameter of the pressure probe is 3.33 mm, what is the effect of the probe diameter on the measured pressure distribution? Does it really represent the pressure distribution in the nozzle or a different one?
7. What is the percentage error involved in calculating the mass flow rate?
8. How would you explain the pressure drop downstream of the nozzle exit?
9. What can be done to improve the apparatus or the test procedure?

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