CHAPTER VI

EFFECT OF AXI-SYMMETRIC CAVITIES
IN COAXIAL SUPersonic STREAMS

6.1 INTRODUCTION

Experiments discussed in the last two chapters bring out the potential of the clover nozzle as a device for enhancing mixing in a mixing tube without cavity. Literature survey revealed the scope of introducing some cavities for better mixing performance. Here in this chapter some cavities were provided inside the mixing tube expecting better performance. Mixing analysis was done by changing the cavities inside the mixing tube. For this experimental study a conical and a three lobed clover nozzle were designed and fabricated. A high pressure compressor is made available with storage capacity of 3000 liters (1000 Liters x 3 tanks) capable of giving 40 bar pressure. The detail of changes made in the previous experimental set up is included as appendix-II. The experimental procedure is the same as that used in the chapter V.

6.2 MIXING TUBE

The mixing tube is made of mild steel rod with cavities (which are axi-symmetric) inside. The length ‘l’ and depth ‘d’ of these cavities is as per designed values.
The diameter (D) of the mixing tube is same as that of the exit diameter of the secondary nozzle.

![Diagram of mixing tube with anisymmetric cavity](image)

**Fig. 6.1**

<table>
<thead>
<tr>
<th>Sl. No.</th>
<th>d</th>
<th>1/d</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>10</td>
<td>6</td>
</tr>
<tr>
<td>2</td>
<td>10</td>
<td>10</td>
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</tbody>
</table>

Table - 6.1 Specifications of mixing tube

### 6.3 RESULTS AND DISCUSSION

#### 6.3.1 Momentum Mixing

The coaxial jets enter into the supersonic combustor with different momentum and stagnation pressure. The momentum flux distribution at the exit of the supersonic combustor in the radial direction is a measure of extent of bulk mixing. The momentum flux is calculated as 

\[ \mu = \frac{1}{2} \rho \frac{1 + \gamma M_x^2}{\gamma - 1} \]

where \( \rho \) is the static pressure and \( M_x \) is the Mach number calculated from measured values of stagnation pressure. The L/D ratio at which momentum flux attains uniformity
indicates the axial distance where the mixing is complete. In the case of clover nozzles, to check the extent of mixing in the transverse planes, the measurements are done along radial lines in major and minor planes.

6.3.1.1 Momentum Mixing in Clover Nozzle

**Fig.6.2 Momentum mixing in clover nozzle**

**Fig.6.3 Momentum mixing in clover nozzle**
By observing the above two graphs, it is clear that the curve is more flatter for L/D=5 as compared to L/D=4 for clover nozzle. This indicates the completion of mixing at L/D=5.

6.3.1.2 Momentum Mixing in Circular Nozzle

![Graph showing momentum mixing in circular nozzle for L/D=4 and L/D=5](image)

**Fig. 6.4 Momentum mixing in circular nozzle**

![Graph showing comparison of momentum mixing for L/D=4 and L/D=5](image)

**Fig. 6.5 Comparison of momentum mixing**
The above figures shows momentum flux distribution occurring in mixing tube when circular (conventional convergent divergent) nozzles are employed. Here notable thing is as \( r/R \) is increasing from 0.5 the curve has a sudden drop which indicates poor mixing between primary and secondary streams. Not only that the momentum flux values at \( r/R = 1 \) is lower as compared to that for clover nozzles. This also points the lesser mixing.

The following graph show the momentum mixing for circular and clover nozzles without a cavity for L/D ratio of 5.

![Graph showing comparison of momentum mixing](image)

Fig. 6.6 Comparison of momentum mixing

The following graph shows the comparison of circular and clover nozzles for the same aspect ratio of cavity.
Fig. 6.7 Comparison of momentum mixing

Fig. 6.8 Comparison of momentum mixing

Fig. 6.9 Comparison of momentum mixing

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Comparing two nozzles for different L/D and l/d ratios the capability of mixing enhancement by cavities is clear. Clover nozzles have more uniform momentum flux distribution due to the fact that flow redirections occurring to the primary and secondary streams. The upper lobe redirect the flow outward while lower lobe makes it inward. This creates a circulation which gradually develops into vortices. It can also be seen that cavity with l/d=1.0 provides better mixing as compared with l/d=1.66.

6.3.2 Degree of Mixing

The figure 6.11 shows degree of mixing of clover and circular nozzles for an L/D ratio of 5 and l/d ratio of 1. It is arranged in descending order of degree of mixing. From this figure it is clear that degree of mixing for clover nozzles with cavity is more than circular one. This proves that clover nozzles with cavities achieve nearly complete mixing.
in a three dimensional flow field, within a short mixing chamber. This helps in reducing the overall bulk and weight of the propulsion system.

![Comparison of degree of mixing](image)

**Fig. 6.11 Comparison of degree of mixing**

### 6.3.3 Pressure Drop Factor

To find the drop in stagnation pressure a factor called pressure drop factor (PDF) is defined. The primary and secondary streams enter the mixing tube with different stagnation pressures. Hence PDF is defined as the difference between the weighted average stagnation pressures at the inlet and axial station considered, normalized by weighted average of inlet stagnation pressures.

The additional stagnation pressure loss in the case of clover nozzle with cavity is due to the enhanced mixing and increased viscous losses due to increased surface area compared to circular nozzle. The present study combines both active and passive methods for mixing enhancement of air and fuel. Mixing performance of two nozzles with different cavities in mixing tubes has been quantitatively and
Fig. 6.12 Comparison of pressure drop factor

qualitatively assessed based on radial momentum flux distribution. From the present study it is clear that clover nozzle with a cavity l/d of one provide better lateral mixing of supersonic streams in a comparatively short length (L/D=5) of mixing chamber. The stagnation pressure loss associated with the introduction of cavities is found to be more but it is compensated by the increased mixing.