CHAPTER 2

EXPERIMENTAL SETUP AND CONDITIONS

2.1 EXPERIMENTAL SETUP

The purpose of the experiments is to obtain a jet trajectory equation and concentration decay equation estimating the pressure drop for practical application. In addition, the optimum jet angle is also studied by experiment. The experimental investigation was carried out in a clear venturi-jet mixer made of acrylic fibre material of size 20 x 11 mm. The mixers were manufactured from rod of acrylic using a high precision CAD-CAM system for the flow and mixing could be seen. The internal flow passage in the mixer was carefully polished to remove any internal steps/ seams.

Figure 2.1 Schematic of venturi-jet mixer with initial jet angle 45°
Figure 2.1 shows the geometry of one of the mixers used in the present study, with initial jet angle 45° and a round jet nozzle with internal diameter of 1mm mounted in throat of venturi. The mixer has a contraction ratio of 0.3025 corresponding to exit-plane area of 314.16mm\(^2\). The contraction provides smooth uniform flow in the throat section of mixer.

An optimised converging cone angle of 17° and diverging cone angle of 8.5° for maximum entrainment of suction fluid proposed by Ahmed et al. (2005) is used in the present study.

Process venturi systems are designed in such a way that under normal flow conditions the motive fluid attains a constant, near-absolute vacuum in the restriction. The difference between the low pressure inside the venturi restriction and the higher atmospheric pressure in the ambient surroundings provides the required energy for the venturi to draw in the injectate as indicated in defining sketch of the mixer (Figure 2.2).

![Figure 2.2 Defining sketch of venturi-jet mixer](image)

The distance between the jet exit and the tracer fluid in container is 10cm for undisturbed flow of tracer. Water for cross flow is supplied by a
suitable centrifugal pump. After filtering and regulating, the cross flow is metered by a flow measuring device.

The tracer enters automatically into the throat through the transverse jet attached at 1D from the leading edge of the throat and mixes with cross flow in the downstream of injection point.

The test facility shown in Figure 2.3 is used to investigate the effects of the various jet injection angles and operating conditions as given in Table 2.1:

**Table 2.1 Jet injection angles and operating conditions of the present work**

<table>
<thead>
<tr>
<th>Flow conditions</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initial jet injection angle</td>
<td>$45^\circ - 135^\circ$</td>
</tr>
<tr>
<td>Cross flow velocity</td>
<td>4.3844 – 7.8917m/s</td>
</tr>
<tr>
<td>Initial jet velocity</td>
<td>2.9958 – 5.8272 m/s</td>
</tr>
<tr>
<td>Velocity ratio</td>
<td>0.6833 – 0.8117</td>
</tr>
<tr>
<td>Motive cross flow pressure</td>
<td>109.32 – 140.82 kPa (abs)</td>
</tr>
<tr>
<td>Throat vacuum pressure</td>
<td>92.65 – 77.35 kPa (abs)</td>
</tr>
</tbody>
</table>

**Figure 2.3 Schematic representation of experimental apparatus**
2.2 CROSS FLOW AND JET FLUIDS

For the experiments, a tracer solution of potassium-di-chromate with concentration of 0.3% is prepared by dissolving dry potassium dichromate in distilled water at ambient temperature.

Water with no tracer concentration is used as cross flow in the mixer. The tracer fluid had the same viscosity as the main fluid. The other properties of tracer liquid determined and are equal to the properties of water with a difference of ± 2%.

2.3 EXPERIMENTAL PROCEDURE

In each test run, the mass flow of cross flow is adjusted to give the desired crossflow Reynolds number (Re$_{cf}$) value of 5800, 6960, 8120, 9280 and 10440. Based on hydraulic diameter the Reynolds number (Re) is set as 3191, 3830, 4464, 5106, and 5745.

Each test run is composed of two parts. First the flow of jet and pressure drop is measured for the desired Re. Second the concentration of tracer is measured with the help of spectrophotometer for downstream distances to throat diameter with nominal Reynolds number for a wide range of injection angles.

A digital spectrophotometer is used throughout all the experiments to measure the local scalar concentration $c$, operates between wavelength of 360nm and 960nm. The spectral resolution and wavelength are set as 1 and 460nm. The accuracy and repeatability of the instrument is ± 3nm.

In the present investigation, the concentration of tracer is measured along the normalised stream-wise direction for 5d, 10d, 15d, 20d, 25d and 30d. The pressure drop across the venturi-jet mixer is determined with
differential manometer. The flow of cross flow and jet are measured with flow metering device.

All the experiments are performed at ambient temperature. Twenty five experiments are conducted in which the jet injection angle $\theta$ varied $45^\circ$ - $135^\circ$ and the cross flow Reynolds number based on throat diameter $Re_{cf}$ varied 58002-104403.

Figure 2.4 Solid models of venturi-jet mixers with various jet injection angles
Figure 2.3 shows solid models of venturi-jet mixers with various injection angles used for the present work. The estimation of uncertainty is done based on Moffat (1988). The uncertainty for a single measurement on the experimentally calculated result, for only that one measurement can be found using Equation (2.1).

\[
\frac{\partial R}{\partial X_i} = \frac{\partial R}{\partial X_1} \int X_1
\]  

(2.1)

When more independent variables are used in the function R, the individual terms are combined by root-sum-square method and given in Equation (2.2).

\[
\frac{\partial R}{\partial X} \left\{ \sum_i^N \left( \frac{\partial R}{\partial X_i} \right)^2 \right\}^{\frac{1}{2}}
\]  

(2.2)

The following equation is used to consider the relative errors in the individual factors denoted by \( x_i \).

\[
w(u,v,D,h,\ldots) = \left[ \left( x_1 \right)^2 + \left( x_2 \right)^2 + \ldots + \left( x_n \right)^2 \right]^{\frac{1}{2}}
\]  

(2.3)

Reynolds Number uncertainties can be calculated by combinations of Equations (2.4) and (2.5). Equation (2.6) is the resultant equation obtained after combining Equations (2.4) and (2.5).

\[
Re = \frac{vD}{\gamma}
\]  

(2.4)

\[
w_{Re} = \left[ \left( \frac{\partial Re}{\partial v} \right)^2 + \left( \frac{\partial Re}{\partial D} \right)^2 + \left( \frac{\partial Re}{\partial h} \right)^2 \right]
\]  

(2.5)
\[
\frac{w \text{Re}}{\text{Re}} = \left[ \left( \frac{w v}{v} \right)^2 + \left( \frac{w D}{D} \right)^2 + \left( \frac{w \gamma}{\gamma} \right)^2 \right]^{\frac{1}{2}} \tag{2.6}
\]

Sherwood number uncertainties can be calculated by combinations of Equations (2.7) and (2.8).

\[
\text{Sh} = \frac{h_m d}{D_{AB}} \tag{2.7}
\]

\[
w_{\text{Sh}} = \left[ \left( \frac{\partial \text{Sh}}{\partial h_m} w_m \right)^2 + \left( \frac{\partial \text{Sh}}{\partial d} w_d \right)^2 + \left( \frac{\partial \text{Sh}}{\partial D_{AB}} w_{D_{AB}} \right)^2 \right]^{\frac{1}{2}} \tag{2.8}
\]

\[
w_{\text{Sh}} = \left[ \left( \frac{w h_m}{h_m} \right)^2 + \left( \frac{w d}{d} \right)^2 + \left( \frac{w D_{AB}}{D_{AB}} \right)^2 \right]^{\frac{1}{2}} \tag{2.9}
\]

Similarly velocity ratio uncertainties can be calculated by combinations of Equations (2.10) and (2.11).

\[
R = \frac{u}{v} \tag{2.10}
\]

\[
w_{R} = \left[ \left( \frac{\partial R}{\partial w} w \right)^2 + \left( \frac{\partial R}{\partial v} w \right)^2 \right]^{\frac{1}{2}} \tag{2.11}
\]

\[
w_{R} = \left[ \left( \frac{w u}{u} \right)^2 + \left( \frac{w v}{v} \right)^2 \right]^{\frac{1}{2}} \tag{2.12}
\]

Each of the measured physical properties consists of non dimensional parameters. The uncertainties of the non dimensional parameters for each of the measured physical properties are given in Table 2.2. Maximum
values of uncertainty calculations for Re, Sh, and R are 6.5%, 7.8% and 11.5% respectively.

Table 2.2 Uncertainties value for the relevant variable

<table>
<thead>
<tr>
<th>Variable</th>
<th>Uncertainty (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water density, $\rho_{cf}$</td>
<td>1.4</td>
</tr>
<tr>
<td>Tracer density, $\rho_j$</td>
<td>1.8</td>
</tr>
<tr>
<td>Diameter, D</td>
<td>1.2</td>
</tr>
<tr>
<td>Dynamic viscosity of water, $\mu_{cf}$</td>
<td>2.6</td>
</tr>
<tr>
<td>Dynamic viscosity of tracer, $\mu_j$</td>
<td>2.9</td>
</tr>
<tr>
<td>Water flow rate, m</td>
<td>4.2</td>
</tr>
<tr>
<td>Pressure drop, $\Delta p$</td>
<td>4.4</td>
</tr>
</tbody>
</table>

The flow conditions are characterised by means of three global non-dimensional parameters:

$$\text{Re} = \frac{vD}{\gamma}; \text{Sh} = \frac{h_{mf}d}{D_{AB}}; \text{R} = \frac{u}{v}$$