Figure 1: Schematic of a typical gauging nozzle showing dimensions.

a) 1 – 4 are flow stations.

b) P – T are points showing the different sections for pressure drop analysis (PQ – convergent section, QR – area under the rim, RS – divergent section, ST – tube section).
Figure 2: Schematic of a conical cell showing the ratios of dimensions. 
\(\frac{D_p}{D_j} = 8, \frac{L_j}{D_j} = 1, \frac{S_j}{D_j} = 0.35, \frac{G_j}{D_j} = 0.1, \beta = 168.9^\circ\)
Figure 3: Comparison of predicted streamlines at $Re = 685$.  
(a) – this work, (b) – Miranda & Campos (1999).
Figure 4: Comparison of radial velocities at one point within the conical cell, $R = 2.65, Z = 0.034$. Solid line – this work; squares – experimental data (Miranda & Campos, 1999); dotted line – numerical predictions (finite difference, Miranda & Campos, 1999).
Figure 5: Comparison of streamline predictions for impinging laminar submerged jet at $Re = 25$, defined at the jet exit. (a) – this work, (b) – Deshpande & Vaishnav (1982).
Figure 6: Comparison of predictions of the maximum dimensionless wall shear stress for an impinging laminar jet. Solid line – this work; dotted line – Deshpande & Vaishnav (1982).
Figure 7: Computational models for different inlet boundary conditions. Boundary tags I to VI are shown in brackets. (a) – Model 1, (b) – Model 2, (c) – Model 3.
Figure 8: Dimensionless coordinates of the gauging nozzle ($R_{tube} = 1$).
Figure 9: Grid refinement in the region near the nozzle for a typical simulation case.
Figure 10: Streamlines at $Re_t = 260$ and $h/d_t = 0.125$ showing three distinct flow regions. 
\((a)\) – Model 1, \((b)\) – Model 2, \((c)\) – Model 3, \((d)\) – Suction region.
Figure 10 (d): Suction region

Undisturbed-flow region

Recirculation region

Nozzle

Suction region

10 (c): Model 3
Figure 11(a): Streamlines from Model 1 at $h/d_t = 0.2$ and $Re_t = 160$ (left) and 200 (right).
Figure 11(b): Streamlines from Model 1 at $h/d_i = 0.2$ and $Re_i = 8$ (left) and 20 (right).
Figure 12: Comparison of hydrostatic head for gauging flows (water).
Symbols - simulation $s_s$; solid line - experimental $s$. 
Figure 13(a): Discharge coefficient versus $Re_t$.
Solid lines – this work; A – $h/d_t = 0.65$, B – $h/d_t = 0.20$, C – $h/d_t = 0.10$; symbols – experimental data, black – this work, grey – (Tuladhar, 2001); squares – $h/d_t = 0.65$, triangles – $h/d_t = 0.20$, circles – $h/d_t = 0.10$; dotted lines – empirical model from Tuladhar et al. (2000) – equation (19); B* – $h/d_t = 0.20$, C* – $h/d_t = 0.10$.
Nozzle: $d_t = 1$ mm, $d = 4$ mm, $w = 0.5$ mm, $\lambda = 0.1$ mm and $\alpha = 45^\circ$. 
Figure 13(b): Asymptotic discharge coefficient versus $Re_t$, high $Re_t$ range.
Solid lines – this work; $A - h/d_t = 0.65$, $B - h/d_t = 0.20$, $C - h/d_t = 0.10$; symbols – experimental data, black – this work, grey – (Tuladhar, 2001); squares – $h/d_t = 0.65$, triangles – $h/d_t = 0.20$, circles – $h/d_t = 0.10$; dotted lines – empirical model from Tuladhar et al. (2000) – equation (19); $B^* - h/d_t = 0.20$, $C^* - h/d_t = 0.10$.
Nozzle: $d_t = 1$ mm, $d = 4$ mm, $w = 0.5$ mm, $\lambda = 0.1$ mm and $\alpha = 45^\circ$. 
Figure 14 (a): Pressure drop analysis, $h/d_t = 0.10$. 
Figure 14 (b): Pressure drop analysis, $h/d_t = 0.20$. 
Figure 14 (c): Pressure drop analysis, $h/d_t = 0.65$. 

[Diagram showing pressure drop analysis with % values for ST, RS, QR, PQ at different Re values: 4, 20, 400]
Figure 15: Discharge coefficient versus $Re_t$ for CMC solutions.
Solid lines – this work; $D$ – $h/d_t = 0.34$, $E$ – $h/d_t = 0.18$, $F$ – $h/d_t = 0.10$; symbols – experimental data (Colombo and Steynor, 2002); squares – $h/d_t = 0.34$, triangles – $h/d_t = 0.18$, circles – $h/d_t = 0.10$; dotted lines – empirical model from Tuladhar (2001) – equation (26); $D^*$ – 0.34, $E^*$ – $h/d_t = 0.18$, $F^*$ – $h/d_t = 0.10$.
Nozzle: $d_t = 2$ mm, $d = 4$ mm, $w = 0.2$ mm, $\lambda = 0.1$ mm and $\alpha = 30^\circ$. 
Figure 16(a): Dimensionless shear stress distributions on the gauged surface. Case: $Re_t = 260$, $h/d_t = 0.125$. Thick solid line, Model 1; thin solid line, $\tau_{wall}$ residuals (dimensionless) from Model 2 (equation (27)); dotted line, $\tau_{wall}$ residuals (dimensionless) from Model 3 (equation (28)).
Nozzle: $d_t = 1.0 \text{ mm}$, $d = 4.0 \text{ mm}$, $\lambda = 0.1 \text{ mm}$ and $w = 0.5 \text{ mm}$. 
Figure 16(b): Dimensionless normal stress distributions on the gauged surface. Case: \( Re_t = 260, h/d_t = 0.125 \).
Thick solid line, Model 1; thin solid line, \(-P_{\text{wall}}\) residuals (dimensionless) for Model 2 (equation (27)); dotted line, \(-P_{\text{wall}}\) residuals (dimensionless) for Model 3 (equation (28)).
Nozzle: \( d_t = 1.0 \, \text{mm}, d = 4.0 \, \text{mm}, \lambda = 0.1 \, \text{mm} \) and \( w = 0.5 \, \text{mm} \).
Figure 17(a): Shear stress distributions on the gauged surface, Case: $h/d_i = 0.10$. Solid line, $Re_i = 904$; dotted line, $Re_i = 4$.

Inner radius of nozzle rim, $R_i = 0.25$
Outer radius of nozzle rim, $R_o = 0.50$
Figure 17(b): Normal stress distributions on the gauged surface, Case: $h/d_i = 0.10$.
Solid line, $Re_i = 904$; dotted line, $Re_i = 4$.

Inner radius of the nozzle rim, $R_i = 0.25$
Outer radius of the nozzle rim, $R_o = 0.50$
Figure 18: Maximum wall shear stress versus $Re_t$ (water).
Identification of data sets: $A - s = 340$ mm; $B - s = 200$ mm; $C - s = 140$ mm.
Figure 19(a): Shear and normal stress distributions on the gauged surface, Case: $Re_t = 20$, $h/d_t = 0.20$.
Nozzle: $d_t = 1.0$ mm, $d = 4.0$ mm, $\lambda = 0.1$ mm and $w = 0.5$ mm.
Grey solid line, $\alpha = 60^\circ$, black solid line, $\alpha = 45^\circ$, dotted line, $\alpha = 30^\circ$. 

Inner radius of nozzle rim, $r_i = 0.5$ mm
Figure 19(b): Shear and normal stress distributions on the gauged surface, Case: $Re_t = 400$, $h/d_t = 0.20$.
Nozzle: $d_i = 1.0$ mm, $d = 4.0$ mm, $\lambda = 0.1$ mm and $w = 0.5$ mm.
Grey solid line, $\alpha = 60^\circ$, black solid line, $\alpha = 45^\circ$, dotted line, $\alpha = 30^\circ$. 

Inner radius of nozzle rim, $r_i = 0.5$ mm
Figure 20(a): Shear stress distributions on the gauged surface, Case: $Re_t = 20$, $h/d_t = 0.20$.

Nozzle: $d_t = 1.0$ mm, $d = 4.0$ mm, $\lambda = 0.1$ mm and $\alpha = 45^\circ$.

Grey solid line, $w = 1.0$ mm, black solid line, $w = 0.5$ mm, dotted line, $w = 0.25$ mm.
Inner radius of nozzle rim, $r_i = 0.5$ mm

Figure 20(b): Shear stress distributions on the gauged surface, Case: $Re_t = 400$, $h/d_t = 0.20$.

Nozzle: $d_i = 1.0$ mm, $d = 4.0$ mm, $\lambda = 0.1$ mm and $\alpha = 45^\circ$.

Grey solid line, $w = 1.0$ mm, black solid line, $w = 0.5$ mm, dotted line, $w = 0.25$ mm.
Figure 20(c): Normal stress distributions on the gauged surface, Case: $Re = 20$, $h/d_t = 0.20$.

Nozzle: $d_t = 1.0$ mm, $d = 4.0$ mm, $\lambda = 0.1$ mm and $\alpha = 45^\circ$.

Grey solid line, $w = 1.0$ mm, black solid line, $w = 0.5$ mm, dotted line, $w = 0.25$ mm.
Figure 20 (d): Normal stress distributions on the gauged surface, Case: \(Re_i = 400, \ h/d_i = 0.20.\)

Nozzle: \(d_i = 1.0 \text{ mm}, \ d = 4.0 \text{ mm}, \ \lambda = 0.1 \text{ mm} \) and \(\alpha = 45^\circ.\)

Grey solid line, \(w = 1.0 \text{ mm},\) black solid line – \(w = 0.5 \text{ mm},\) dotted line – \(w = 0.25 \text{ mm}.\)
Figure 21 (a): Shear stress distributions on the gauged surface, Case: \( Re_t = 20, h/d_t = 0.20 \).

Nozzle: \( d_t = 1.0 \text{ mm}, w = 0.5 \text{ mm}, \lambda = 0.1 \text{ mm} \) and \( \alpha = 45^\circ \).

Grey solid line, \( d = 8.0 \text{ mm} \), black solid line, \( d = 4.0 \text{ mm} \).
Figure 21 (b): Shear stress distributions on the gauged surface, Case: $Re_i = 400$, $h/d_i = 0.20$. Nozzle: $d_i = 1.0$ mm, $w = 0.5$ mm, $\lambda = 0.1$ mm and $\alpha = 45^\circ$. Grey solid line, $d = 8.0$ mm, black solid line, $d = 4.0$ mm.
<table>
<thead>
<tr>
<th>$h/d_t$</th>
<th>$0 \leq Re_t \leq 200$</th>
<th>$201 \leq Re_t \leq 1000$</th>
<th>$1001 \leq Re_t \leq 1500$</th>
<th>$1501 \leq Re_t \leq 2200$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$0.07 \leq h/d_t \leq 0.10$</td>
<td>$30 \times R_{tube}$</td>
<td>$90 \times R_{tube}$</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>$0.11 \leq h/d_t \leq 0.20$</td>
<td>$30 \times R_{tube}$</td>
<td>$100 \times R_{tube}$</td>
<td>$130 \times R_{tube}$</td>
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<tr>
<td>$0.21 \leq h/d_t \leq 0.30$</td>
<td>$30 \times R_{tube}$</td>
<td>$90 \times R_{tube}$</td>
<td>$110 \times R_{tube}$</td>
<td>$130 \times R_{tube}$</td>
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<tr>
<td>$0.31 \leq h/d_t \leq 0.50$</td>
<td>$20 \times R_{tube}$</td>
<td>$70 \times R_{tube}$</td>
<td>$100 \times R_{tube}$</td>
<td>$110 \times R_{tube}$</td>
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<tr>
<td>$0.51 \leq h/d_t \leq 0.65$</td>
<td>$20 \times R_{tube}$</td>
<td>$70 \times R_{tube}$</td>
<td>$100 \times R_{tube}$</td>
<td>$110 \times R_{tube}$</td>
</tr>
</tbody>
</table>

Table 1: Summary of the values of $L_1$ used in the simulations.
<table>
<thead>
<tr>
<th>Sucrose solution (w/w %)</th>
<th>Viscosity (kg/ms)</th>
<th>Experimental</th>
<th>Mathlouthi and Genotelle (1995)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>0.00145</td>
<td>0.00140</td>
</tr>
<tr>
<td>15%</td>
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<td>0.00224</td>
<td>0.00215</td>
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<tr>
<td>25%</td>
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<td>0.00373</td>
<td>0.00374</td>
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</tbody>
</table>

Table 2: Summary of the viscosities for sucrose solutions at 25°C.
<table>
<thead>
<tr>
<th>CMC solution (w/w %)</th>
<th>$n$</th>
<th>$k$</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.8% high viscosity</td>
<td>0.59</td>
<td>0.60</td>
</tr>
<tr>
<td>0.5% high viscosity</td>
<td>0.61</td>
<td>0.40</td>
</tr>
<tr>
<td>0.3% high viscosity</td>
<td>0.67</td>
<td>0.18</td>
</tr>
<tr>
<td>0.8% low viscosity</td>
<td>0.85</td>
<td>0.033</td>
</tr>
<tr>
<td>0.5% low viscosity</td>
<td>0.93</td>
<td>0.0106</td>
</tr>
<tr>
<td>0.3% low viscosity</td>
<td>0.98</td>
<td>0.0044</td>
</tr>
</tbody>
</table>

Table 3: Summary of the rheological parameters for CMC solution at 25°C (Colombo & Steynor, 2002).