CHAPTER 4
EXPERIMENTAL RESULTS AND PARAMETRIC STUDY

The results of the experiments can be studied with the help of graphs \( \dot{m}_p \) with respect to \( S \), for various values of the geometric parameters.

4.1 EFFECT OF DISTANCE \( S \)

The distance between the primary and secondary nozzle is a very important parameter for the design of the air-solid injector feeder. As the primary nozzle is moved axially from \( S = 0 \) a significant increase in \( \dot{m}_p \) occurs as shown in Figures 4.1, 4.3 and 4.5. This is because more and more material are entrained in the jet. However, owing to the divergence of air jet, the velocity of the jet decreases downstream. Hence the effect of changing \( S \) can be explained as shown in Figure 4.2. In the experimental set up the material is getting choked when \( S \) exceeds 23.0 mm. For this experimental set up \( S = 20.0 \) mm is found to be a good choice. However, this result cannot be generalised. For a general case, it is worth experimenting on the actual design to fix this parameter, since \( \dot{m}_p \) keeps on increasing with \( S \) and suddenly choking occurs.

4.2 EFFECT OF INLET TUBE-ANGLE (\( 2\alpha \))

The inlet tube angle (\( 2\alpha \)) of the secondary nozzle is another important parameter which influences the mass flow rate of materials. The variation of \( \dot{m}_p \) with respect to \( S \), for different values of \( \alpha \) is shown in Figure 4.1. As inferred from the figure, the mass flow rate of material increases as the inlet tube angle is increased. Among the five inlet tubes used, \( \dot{m}_p \) is significantly high for the tube having \( \alpha = 15.0^\circ \). The diameter of the secondary nozzle inlet tube is kept at 50.0 mm. Hence as the angle \( \alpha \) is increased, the length \( L_1 \) decreases.
Increasing $\alpha$ beyond $15^\circ$ may reduce the overall length of the nozzle. This suggested value of $\alpha = 15^\circ$ agrees fairly well with the corresponding value of $\alpha$ for jet pumps [15].

4.3 EFFECT OF MIXING TUBE LENGTH ($L_m$)

The next important parameter to be considered is the length of the mixing tube ($L_m$). Figure 4.3 depicts the variation of $\dot{m}_p$ with respect to $S$ for different values of $L_m$. The relation between $\dot{m}_p/\dot{m}_a$ and static pressure for different $L_m/d_m$ is plotted in Figure 4.4 for $S = 13.0$ mm and $d_m = 19.0$ mm. There is gradual increase of flow rate of material until $L_m/d_m = 8.0$ and then there is a decrease. In the range $L_m/d_m$ 7 to 9 there is marginal increase in the static pressure. From the mass flow rate of material consideration the mixing tube length in the range 7 to 9 $d_m$ is a good choice. Moreover, it lies within the range of 5 to 10 $d_m$ used for jet pumps[15].

4.4 EFFECT OF MIXING TUBE DIAMETER ($d_m$)

The variation of $\dot{m}_p$ with respect to $S$ for different values of the mixing tube diameters is given in Figures 4.5 and 4.6 for $L_m = 150.0$ and $180.0$ mm respectively. The difference in $\dot{m}_p$, while using $d_m = 19.0$ and $22.5$ mm is not very much significant. However when $S$ is large an increase in $\dot{m}_p$ occurs for $d_m = 22.5$ mm. The value of $d_m$ in the range 0.7 to 0.8 $d_m$ gives rise to maximum flow rate of material.

4.5 EFFECT OF DIFFUSER ANGLE ($\beta$)

The variation of diffuser angle with respect to $S$ for different diffuser angles is shown in Figures 4.7, 4.8 and 4.9. Figures 4.7 and 4.9 show the relationship, for $L_1 = 55.0$ mm and $73.4$ mm respectively, other parameters are shown in figures. The relationship plotted in Figure 4.8 is also for the same geometric parameters as the above, except for $L_1 = 55.0$ mm and $L_m = 180.0$ mm. The mass flow rate of material is found to increase as the angle $\beta$ is decreased. Since $d_m$ is also fixed around 0.7 to 0.8 $d_m$ any decrease of the angle $\beta$ below $2^\circ$ will result in unduly long diffuser.
4.6 EFFECT OF PRIMARY NOZZLE DIAMETER (\(d_p\))

Figures 4.10 and 4.11 show the variation of \(m_p\) with respect to \(S\) for \(L_m = 150.0\) and \(180.0\) mm for different values of the primary nozzle throat diameters. When \(d_p\) is decreased the velocity of the injecting air increases resulting in more material rate. However, conveying the materials with higher velocities of air may become one among the causes for particle degradation. While conveying, the degradation of the material must be as far as possible within tolerable limit based on judgement. Hence this parameter, \(d_p\) is more dependent on the characteristics of the material. For the experiments conducted \(d_p = 10.0\) mm was good, based on mass flow rate and degradation of material consideration.

4.7 EFFECT OF MASS FLOW RATE OF AIR (\(\dot{m}_a\))

Figures 4.12 and 4.13 show the variation of \(m_p\) with respect to \(S\) for various values of mass flow rate of air. Figure 4.12 shows the relationship for \(L_m = 150.0\) mm while the Figure 4.13 is for \(L_m = 180.0\) mm with all other parameters kept as same. The mass flow rate is usually fixed based on the quantity of material to be transported and conveyor pipe diameter.

4.8 STATIC PRESSURE

It is observed that there is a substantial increase in static pressure during the flow of materials through the secondary nozzle inlet tube as depicted in Figure 4.14. There is a decrease in static pressure as the material is conveyed through the mixing tube, which may be attributed to the particle acceleration and wall friction. If the mixing tube is too long, the frictional losses will be high, which in turn may reduce final recovery of pressure in the diffuser tube. There is only a marginal increase in static pressure in the diffuser tube. If the conveyor is operated at a higher rate of air flow, a considerable increase in pressure in the diffuser may be expected. There is also possibility of static pressure built up at some distance
away from the diffuser tube end. Figures 4.14 and 4.15 show the static pressure distribution along the secondary nozzle by choosing $d_m = 19.0$ mm and $L_m = 150.0$ and 180.0 mm with all the other parameters being the same. The static pressure distribution along the secondary nozzle by changing $d_m$ to 22.5 mm $L_1$ to 51.0 mm, $L_0$ to 82.3 mm and keeping both values of $L_m$ and other parameters same as above is depicted in Figures 4.16 and 4.17.

4.9 VARIATION OF $L_m$, $d_D$ AND $\dot{m}_a$ FOR RAGI

From the experimental studies made with wheat, the values of $L_1 = 15^\circ$, $L_m = 7$ to 10 $d_m$ and $\beta = 2^\circ$ appeared to be a better choice. Hence these values have been used to conduct experiments on ragi. Figure 4.18 shows the relation between $\dot{m}_p$ with respect to $S$ for $L_m = 150.0$ and 180.0 mm.

The relation between $\dot{m}_p$ versus $S$ for different $d_p$ are shown in Figures 4.19 and 4.20 respectively. The Figure 4.19 is for $L_m = 150.0$ mm and that of Figure 4.20 for $L_m = 180.0$ mm with all other parameters being the same. As mentioned earlier, this parameter is more dependent on the characteristics of the material.

The relation between $\dot{m}_p/\dot{m}_a$ with respect to $S$ for different $\dot{m}_a$ is depicted in Figures 4.21, 4.22 and 4.23. Figure 4.24 shows the variation of $\dot{m}_p$ with respect to $S$ for wheat and ragi for the same geometric parameters and $\dot{m}_a$. It is found that the mass flow rate of ragi is comparatively less than that of wheat. There is an increase of flow rate of material for higher flow rates of air.

4.10 SPECIAL CASES OF FEEDER

Apart from the secondary nozzle having the inlet, mixing and diffuser tubes, to have an idea on the mass flow rate of material two special cases have been considered. If $L_m = 0$, it becomes a convergent-divergent nozzle and if $\alpha = \beta = 0$, it is a straight tube ($d_m$ was made equal to $d_0$). The effect of mass flow rate of material for
different $S$ for the two cases are depicted in Figures 4.25 and 4.26. The flow rate of material in both the special cases is found to be less than that of a secondary nozzle having inlet, mixing and diffuser tubes.

4.11 EFFECT OF FLUIDIZATION

The study of the effect of the flow rate of material with fluidization of the feeder is confined to wheat only. The effect of $\dot{m}_a$ with respect to $S$, with and without fluidization of the feeder is depicted in Figures 4.27 to 4.31. In Figure 4.27 the relation is shown for $L_m = 150.0$ mm whereas in Figure 4.28 it is for $180.0$ mm for $d_p = 10.0$ mm and all other parameters kept same. The same relationship is shown in Figure 4.29 taking $L_m = 180$ mm and $d_p = 8.3$ mm. The relationship shown in Figure 4.30 is for $d_p = 14.0$ mm and $L_m = 150.0$ mm. The relationship shown in the Figures 4.27 to 4.30 is for $d_m = 19.0$ mm. The variation shown in Figure 4.31 is for $d_m = 22.5$ mm, $L_m = 180.0$ mm and $d_p = 10.0$ mm; other geometric parameters are shown in the figure. During fluidization, it is found that $\dot{m}_a$ depends on $\dot{m}_a$ also in addition to the parameters $L_i$, $L_m$, $L_o$, $d_m$, $d_p$, $d_a$ and $S$. The ratios of $\dot{m}_{aux}/\dot{m}_a$ are 0.1822, 0.2066 and 0.2725. It is found that higher ratio of $\dot{m}_{aux}/\dot{m}_a$ will give rise to increased flow rate of material.

4.11.1 Static Pressure during fluidization

The static pressure distribution along the length of the secondary nozzle with and without fluidization of the injector feeder is shown in Figures 4.32, 4.33 and 4.34. In Figure 4.32 the relation is shown for $L_m = 150.0$ mm $S = 13.0$ mm and $d_m = 19.0$ mm and that in Figure 4.33 for $L_m = 180.0$ mm with other parameters being the same. In Figure 4.34 the relation is shown for $L_m = 180.0$ mm, $S = 13.0$ mm, $L_i = 51.0$ mm, $L_o = 82.3$ mm, $d_m = 22.5$ mm and other values of the parameters same as before. Even when the feeder is fluidized it is observed that there is a substantial increase in static pressure during the flow through inlet tube and decrease in static pressure.
along the mixing tube length. This decrease in pressure may be attributed to the particle acceleration and wall friction. The increase in static pressure along the diffuser is only marginal. Further it is observed that when the feeder is fluidized with higher $m_{aux}$ there is a reduction in the static pressure along the length of the secondary nozzle.
FIGURE 4.1 VARIATION OF $\dot{m}_p$ VERSUS $S$ FOR DIFFERENT $L_i$
When $S = 0$, very small quantity of material is conveyed by sucking.

More and more materials are entrained by the jet. Further velocity of air near the secondary nozzle is sufficient to accelerate the particles.

Velocity of air near the secondary nozzle is insufficient to accelerate the particles. Hence material get choked.

**FIGURE 4.2 EFFECT OF $m_p$ VERSUS $S$**
FIGURE 4.3 VARIATION OF $m_p$ VERSUS $S$ FOR DIFFERENT $L_m$
FIGURE 4.4: RELATION BETWEEN $m_p/m_a$ VERSUS $L_m/d_m$ AND PRESSURE RECOVERY VERSUS $L_m/d_m$ FOR $S = 13.0$ mm

MAT: WHEAT

$L_1 = 55.0$ mm  $d_p = 10.0$ mm
$L_0 = 85.5$ mm  $m_a = 1.764$ kg/min
$d_m = 19.0$ mm

FIGURE 4.4: RELATION BETWEEN $m_p/m_a$ VERSUS $L_m/d_m$ AND PRESSURE RECOVERY VERSUS $L_m/d_m$ FOR $S = 13.0$ mm
FIGURE 4.5 VARIATION OF $m_p$ VERSUS $S$ FOR DIFFERENT $d_m$
FIGURE 4.6 VARIATION OF $m_p$ VERSUS S FOR DIFFERENT $d_m$
FIGURE 4.7 VARIATION OF $\dot{m}_p$ VERSUS $S$ FOR DIFFERENT $L_0$

MAT: WHEAT

- $L_0 = 105.1$ mm ($\beta = 1.907°$)
- $85.5$ mm ($\beta = 2.940°$)
- $71.2$ mm ($\beta = 3.456°$)

$L_i = 55.0$ mm, $d_p = 10.0$ mm, $L_m = 150.0$ mm, $\dot{m}_a = 1.764$ kg/min, $d_m = 19.0$ mm
FIGURE 4.8 VARIATION OF $\dot{m}_p$ VERSUS $S$ FOR DIFFERENT $L_0$
FIGURE 4.9 VARIATION OF $\dot{m}_p$ VERSUS $S$ FOR DIFFERENT $L_0$
FIGURE 4.10 VARIATION OF $m_p$ VERSUS $S$ FOR DIFFERENT $d_p$

MAT: WHEAT

$L_i = 55.0 \text{ mm}$
$D_m = 19.0 \text{ mm}$
$L_m = 150.0 \text{ mm}$
$m_s = 1.416 \text{ kg/min}$
$L_0 = 105.1 \text{ mm}$
FIGURE 4.11 VARIATION OF $m_p$ VERSUS $S$ FOR DIFFERENT $d_p$

MAT: WHEAT

$L_1 = 55.0$ mm, $d_m = 19.0$ mm
$L_2 = 180.0$ mm, $m_a = 1.416$ kg/min
$L_3 = 105.1$ mm
FIGURE 4.12 VARIATION OF \( \dot{m}_p \) VERSUS S FOR DIFFERENT \( \dot{m}_a \)

- - - EXPERIMENTAL CURVE
- - - FITTED CURVE

MAT: WHEAT
\[
\begin{align*}
L_1 &= 55.0 \text{ mm} & d_m &= 19.0 \text{ mm} \\
L_m &= 150.0 \text{ mm} & d_p &= 10.0 \text{ mm} \\
L_o &= 105.1 \text{ mm}
\end{align*}
\]
FIGURE 4.13 VARIATION OF $m_p$ VERSUS $S$ FOR DIFFERENT $m_a$

MAT: WHEAT

$L_1 = 55.0 \text{ mm} \quad d_m = 19.0 \text{ mm}$
$L_m = 180.0 \text{ mm} \quad \phi = 10.0 \text{ mm}$
$L_0 = 105.1 \text{ mm}$
FIGURE 4.15 STATIC PRESSURE DISTRIBUTION FOR DIFFERENT S
FIGURE 4.16 STATIC PRESSURE DISTRIBUTION FOR DIFFERENT S

MAT: WHEAT

\[ L_1 = 51.0 \text{ mm} \quad d_m = 22.5 \text{ mm} \]
\[ L_m = 150.0 \text{ mm} \quad d_p = 100.0 \text{ mm} \]
\[ L_a = 82.3 \text{ mm} \quad \dot{m}_a = 1.764 \text{ kg/min} \]

<table>
<thead>
<tr>
<th>SYMBOL</th>
<th>( S ), mm</th>
</tr>
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<tbody>
<tr>
<td>( O )</td>
<td>0.0</td>
</tr>
<tr>
<td>( V )</td>
<td>8.0</td>
</tr>
<tr>
<td>( D )</td>
<td>18.0</td>
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FIGURE 4.17 STATIC PRESSURE DISTRIBUTION FOR DIFFERENT S
FIGURE 4.18 RELATION BETWEEN $m_p$ VERSUS $S$ FOR DIFFERENT $L_m$
FIGURE 4.19 RELATION BETWEEN $m_p$ VERSUS $S$ FOR DIFFERENT $d_p$. 

MAT: RAGI

$L_i = 55.0 \text{ mm} \quad d_m = 19.0 \text{ mm}$ 
$L_m = 150.0 \text{ mm} \quad m_s = 1.416 \text{ kg/min}$ 
$L_o = 105.1 \text{ mm}$ 

$dp = 8.3 \text{ mm}$ 
$14.0 \text{ mm}$ 
$10.0 \text{ mm}$
FIGURE 4.20 RELATION BETWEEN $m_p$ VERSUS $S$ FOR DIFFERENT $d_p$
FIGURE 4.21 VARIATION OF $\frac{m_p}{m_a}$ VERSUS S FOR DIFFERENT $m_a$
FIGURE 4.22 VARIATION OF $\frac{m_p}{m_a}$ VERSUS S FOR DIFFERENT $m_a$
MAT: RAGI

$L_i = 55.0 \text{ mm}$  $d_m = 19.0 \text{ mm}$

$L_m = 150.0 \text{ mm}$  $d_p = 8.3 \text{ mm}$

$L_o = 105.1 \text{ mm}$

SYMBOL $m_a$, kg/min

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<th>$m_a$, kg/min</th>
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<tr>
<td>$\bigcirc$</td>
<td>1.416</td>
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<tr>
<td>$\square$</td>
<td>1.242</td>
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FIGURE 4.23 RELATIONSHIP BETWEEN $m_p/m_a$ VERSUS $S$
FOR DIFFERENT $m_a$
Figure 4.24 Variation of $m_p$ versus $S$ for wheat and ragi for different $m_a$.

MAT: WHEAT AND RAGI

$S_f = \begin{array}{c}
20 \\
25 \\
30
\end{array}$

$WHEAT$
$RAGI$

$\text{FIGURE 4.24 VARIATION OF } m_p \text{ VERSUS } S \text{ FOR WHEAT AND RAGI FOR DIFFERENT } m_a$
**FIGURE 4.25 VARIATION OF $m_p$ VERSUS $S$ FOR CONVERGENT-DIVERGENT SECONDARY NOZZLE**

**TABLE**

<table>
<thead>
<tr>
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<th>$L_{1, \text{mm}}$</th>
<th>$L_{m, \text{mm}}$</th>
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<tbody>
<tr>
<td>O</td>
<td>55.0</td>
<td>71.6</td>
</tr>
<tr>
<td>V</td>
<td>55.0</td>
<td>88.9</td>
</tr>
<tr>
<td>D</td>
<td>61.1</td>
<td>71.6</td>
</tr>
<tr>
<td>X</td>
<td>61.1</td>
<td>88.9</td>
</tr>
</tbody>
</table>

MAT: WHEAT

$m_a = 1.764$ kg/min
FIGURE 4.26 VARIATION OF $\dot{m}_p$ VERSUS $S$ FOR STRAIGHT TUBE
FIGURE 4.27 VARIATION OF $m_p$ VERSUS $S$ FOR DIFFERENT $m_{aux}$
FIGURE 4.28 VARIATION OF $m_p \text{ VERSUS } S$ FOR DIFFERENT AUX. PIPE MASS FLOW RATE

<table>
<thead>
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<th>SYMBOL</th>
<th>AUX. PIPE</th>
<th>AIR FLOW RATE, kg/min</th>
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<tr>
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<tr>
<td>▽</td>
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<tr>
<td>□</td>
<td>0.2926</td>
<td></td>
</tr>
<tr>
<td>X</td>
<td>0.3860</td>
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</table>

MAT. : WHEAT

$L_1 = 55.0 \text{ mm } d_0 = 10.0 \text{ mm}$
$L_m = 180.0 \text{ mm } d_m = 19.0 \text{ mm}$
$L_0 = 105.1 \text{ mm } m_a = 1.416 \text{ kg/min}$
FIGURE 4.29 VARIATION OF $m_p$ VERSUS S FOR DIFFERENT $m_{aux}$
FIGURE 4.30 VARIATION OF $m_p$ VERSUS S FOR DIFFERENT $m_{aux}$

**MAT: WHEAT**

- $L_i = 55.0$ mm  $d_m = 19.0$ mm
- $L_m = 150.0$ mm  $d_p = 14.0$ mm
- $L_o = 105.1$ mm  $m_a = 1.416$ kg/min

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<th>SYMBOL</th>
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<tr>
<td>O</td>
<td>0.0000</td>
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<td>0.2926</td>
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<tr>
<td>□</td>
<td>0.2580</td>
</tr>
<tr>
<td>▼</td>
<td>0.3860</td>
</tr>
</tbody>
</table>

---

WITHOUT FLUIDIZATION
WITH FLUIDIZATION
FIGURE 4.31 VARIATION OF $\dot{m}_p$ VERSUS $S$ FOR DIFFERENT $m_{aux}$

MAT: WHEAT
$L_i = 51.0$ mm $d_m = 22.5$ mm
$L_m = 180.0$ mm $d_p = 10.0$ mm
$L_0 = 82.3$ mm $m_a = 1.416$ kg/min

<table>
<thead>
<tr>
<th>SYMBOL</th>
<th>$m_{aux}$, kg/min</th>
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<tbody>
<tr>
<td>O</td>
<td>0.0000</td>
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<tr>
<td>▽</td>
<td>0.2580</td>
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<tr>
<td>□</td>
<td>0.2926</td>
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<tr>
<td>X</td>
<td>0.3866</td>
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</table>

**FIGURE 4.31 VARIATION OF $\dot{m}_p$ VERSUS $S$ FOR DIFFERENT $m_{aux}$**
FIGURE 4.32 STATIC PRESSURE DISTRIBUTION FOR S = 13.0 mm

- - - WITHOUT FLUIDIZATION

WITH FLUIDIZATION

L_i = 55.0 mm  \quad d_m = 19.0 mm
L_m = 150.0 mm  \quad \phi = 100.0 mm
L_o = 105.1 mm  \quad S = 13.0 mm
Figure 4.33 Static Pressure Distribution for S = 13.0 mm

MAT: WHEAT

- - - WITHOUT FLUIDIZATION
--- WITH FLUIDIZATION

L1 = 55.0 mm  d_m = 19.0 mm
Lm = 180.0 mm  d_p = 10.0 mm
L2 = 105.1 mm  S = 13.0 mm

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<thead>
<tr>
<th>SYMBOL</th>
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<tbody>
<tr>
<td>O</td>
<td>0.0000</td>
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<td>▼</td>
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<td>0.2928</td>
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<tr>
<td>X</td>
<td>0.3860</td>
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FIGURE 4.34 STATIC PRESSURE DISTRIBUTION FOR $S = 13.0$ mm

MAT: WHEAT

- WITHOUT FLUIDIZATION
- WITH FLUIDIZATION

$L_1 = 51.0$ mm  $d_m = 22.5$ mm
$L_m = 1800$ mm  $d_p = 10.0$ mm
$L_0 = 82.3$ mm  $n_b = 1.416$ kg/min

SYMBOL   $m_{aux}$, kg/min

- ○ $0.0000$
- ▼ $0.2580$
- □ $0.2928$
- X $0.3860$

140 x 10^2
120
100
80
60
40
20
0

0  25  47  102  147  192  258  300  368

LENGTH, mm

055.0  052.5  028.0

028.0  052.5  055.0