CHAPTER 5.
CONCLUSIONS AND RECOMMENDATIONS
5.1. Conclusions

(a) Characterization of Overloading at the Sinks

- This study has established clearly that the onset of rope discharge at the sinks represents the point at which the maximum spigot capacity of the dense medium cyclone is reached.

- A critical sinks ore concentration at which spigot overloading occurs has been observed. The quantity of the sinks ore concentration during roping observed in this study was generally between 43 and 54% (v/v), depending on the spigot diameter and particle size distribution of the medium particles. This equates to sinks medium-to-ore ratios ranging from 0.9 to 1.3 (v/v) (Fig. 5.1). These values are in good agreement with those reported in the literature of 40% (v/v) and higher. Further, $\%V_{MSU}$ values for classification cyclones, ranging from 39% to 68% (v/v), reported in the literature are also in good agreement with those obtained in the current study. It is thought that $\%V_{MSU}$ values of around 60% and higher were probably a consequence of increased short-circuiting of fines to the underflow.

![Figure 5.1. $C_{mvu}$ expressed in terms of volumetric medium-to-ore ratio at the sinks.](image)

- The sinks ore concentration during roping remained constant with further addition of ore into the cyclone with all the other variables unchanged. This is consistent with literature on both classification and dense medium cyclones. It has been established that the onset of spigot overloading can be predicted or anticipated by monitoring the volumetric underflow ore concentration.
• An argument that often arises with regard to anticipating the onset of roping is whether the feed ore concentration (or medium-to-ore ratio in the feed) could be used to predict the onset of roping. It is the author’s opinion that the best (and simplest) indicator of the onset of roping is the volumetric sinks ore concentration. This can best be illustrated by considering an example of two hypothetical cyclones of the same dimensions, operating under the same conditions except that cyclone A is fed with silica only, and cyclone B with coal and silica. Assume that both cyclones are operating at a medium density above that of the coal and below that of the silica. If the two cyclones are allowed to reach the roping state the following is expected:
  - during roping the volumetric sinks ore concentration for both cyclones should be of similar quantities, however,
  - the feed concentration for cyclone A at the onset of roping would be less than that of cyclone B because of the coal present in the feed. Ideally all the coal should exit at the floats stream.

• During the onset of roping some of the sinks particles were indiscriminately misplaced to the floats stream. The same behaviour has previously been reported in the literature for both classification and dense medium cyclones. Moreover, there was no evidence of significant sinks particles misplacement to the float stream when a semi-rope discharge was prevalent at the spigot of both the 165mm and 350mm cyclones. Before roping commenced at the sinks, the cyclone still operated as a separation device, rather than a mass splitter, even close to the transition point from semi-rope to rope discharge. Further, the particle size distribution of the silica particles misplaced to the floats stream was exactly the same as that in the sinks stream. This behaviour was observed with both 165mm laboratory-scale and 350mm industrial-scale cyclones.

• Medium flow behaviour within the cyclone has been observed to govern the behaviour of various parameters of importance during the transition to roping, namely: the sinks ore concentration, slurry flow through the outlets, and the density differential. This was especially true at the onset of spigot overloading.
• $R_m$ was consistently higher than $R_f$ at $R_f$ and $R_m$ values below 0.6 during spray and semi-rope discharges. However, during roping $R_f$ and $R_m$ values were consistently almost always equal.

• The density differential was diminished during the transition to roping; the density differential was close or equal to zero when the cyclone was operated in roping conditions. The exception, obviously, being when the cyclone was operated with coarse magnetite particles. The density differential could possibly be useful in detecting and/or avoiding overloading of the spigot. Furthermore, the floats and sinks medium densities were observed to equal the feed medium density during roping.

(b) Effect of Cyclone Geometry on Spigot Capacity

• $D_u$ was found to be the variable that influenced $Q_{USM}$ and $Q_{UM}$ the most. The nature of the relationship between $Q_{UM}$ and $Q_{USM}$, and $D_u$, especially for the data obtained with the 165mm cyclone operating with the cone A, was in good agreement with the literature. This applies to both classification and dense medium cyclones. $Q_{UM}$ was, however, less sensitive to changes in $D_u$ for the relationship that included data from both the 165mm and 350mm cyclones. The change in the sensitivity of $Q_{UM}$ to $D_u$ at larger cyclone diameters was also reported by Jull (1972), and Mular and Jull (1978). $C_{mvu}$ was found to increase slightly with increasing $D_u$, although the correlation was poor.

• There are strong indications that the cyclone diameter has a significant and independent influence on $Q_{UM}$. Thus, for a scenario in which two cyclones have the same $D_u$ but different $D$, the one with a larger $D$ should have a larger $Q_{UM}$ given that the operating conditions are the same. This has serious implications for the case in which a choice must be made between one large cyclone or two smaller ones. Due to the independent effect of $D_u$ and $D$, the two parameters that influence $Q_{UM}$ the most (eq. 4.5), larger cyclones are expected to have disproportionally higher spigot capacities as compared to a combination of smaller cyclones. This is illustrated in Table 5.1. $N$ is the number of cyclones required to reach the spigot ore capacity of a 350mm cyclone when using a combination of smaller cyclones or those with same $D$ and a smaller $D_u$. 
Table 5.1. Number of cyclones required to reach the spigot ore capacity of a 350mm cyclone when using a combination of smaller cyclones or those with smaller $D_u$.

<table>
<thead>
<tr>
<th>$D$ (mm)</th>
<th>$D_u$ (mm)</th>
<th>$Q_{UM}$ (l/hr ore)</th>
<th>$\frac{Q_{UM(350mm)}}{Q_{UM(D)}}$</th>
<th>$N$</th>
</tr>
</thead>
<tbody>
<tr>
<td>165</td>
<td>45</td>
<td>3016*</td>
<td>5.46</td>
<td>6</td>
</tr>
<tr>
<td>200</td>
<td>60</td>
<td>5290*</td>
<td>3.11</td>
<td>4</td>
</tr>
<tr>
<td>250</td>
<td>75</td>
<td>8570*</td>
<td>1.92</td>
<td>2</td>
</tr>
<tr>
<td>350</td>
<td>60</td>
<td>7298</td>
<td>2.26</td>
<td>3</td>
</tr>
<tr>
<td>350</td>
<td>75</td>
<td>11884</td>
<td>1.39</td>
<td>2</td>
</tr>
<tr>
<td>350</td>
<td>100</td>
<td>16461*</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>

*Calculated through equation 4.5, with $H = 10D$ and $\rho_{med} = 1.5$kg/l.

- Spigot design was observed to have a significant effect on the spigot capacity. $Q_{USM}$ and $Q_{UM}$ values obtained with cone B were higher than those obtained with cone A by about 20% and 16%, respectively. Both cones have an angle of 20°, the main difference between cone A and B is that cone A is 115mm longer (which results in increased resistance to flow). DSM design provides the least resistance to flow, and therefore should give higher spigot capacities.

- $Q_{USM}$ and $Q_{UM}$ increased significantly with increasing $D_i$. The effect of $D_i$ on $Q_{USM}$ and $Q_{UM}$ was due to the increase in $Q$ with increasing $D_i$. $S_R$, $C_{mvu}$ and $R_m$ were observed to be independent of changes in $D_i$ in this study.

- $Q_{USM}$ and $Q_{UM}$ decreased slightly with increasing $D_o$. This effect is thought to be a consequence of the influence of $D_o$ on $Q$ and $S_R$. No correlation was found between $D_o$ and $C_{mvu}$ in the current study. On the contrary, Fahlstrom (1963) and Heiskanen (2000) observed $\%V_{MSU}$ to increase slightly with increasing $D_o/D_o$ ratio. The results obtained in the current study seem to suggest that the increase in $\%V_{MSU}$ with increasing $D_o/D_o$ reported by Fahlstrom (1963) and Heiskanen (2000) was probably due to the effect of the spigot diameter only.

- Differences in the spigot design of the cones employed obscured the effect, if any, of the cone angle on the spigot capacity. The results obtained to determine the effect of cone angle on spigot capacity were inconclusive.
No correlation was found between Bl, and $Q_{USM}$ and $Q_{UM}$. Further $Q$, $S_R$, $C_{mvu}$, and $R_m$ were also found to be independent of changes in the barrel length.

(c) Effect of Operational Variables on Spigot Capacity

- $Q_{USM}$ and $Q_{UM}$ increased with increasing $H$, and the effect was relatively small. It is thought that the effect of $H$ on $Q_{USM}$ and $Q_{UM}$ is a consequence of its influence on $Q$ and $S_R$. No correlation was observed between $H$, and $C_{mvu}$.

- $Q_{USM}$ and $Q_{UM}$ decreased with increasing feed medium densities, and their sensitivity to $\rho_{med}$ increased significantly at around $\rho_{med} \approx 1.5RD$. This behaviour was observed with data obtained with the 165mm cyclone (cone A only). Data obtained with the 350mm cyclone indicate that $Q_{UM}$ to reach a maximum at around $\rho_{med} \approx 1.5RD$, beyond this medium density $Q_{UM}$ decreased with increasing $\rho_{med}$. The density differential was also observed to reach a maximum and then decrease as $\rho_{med}$ was increased. It is thought that the effect of $\rho_{med}$ on $Q_{USM}$ and $Q_{UM}$ is related to changes in the medium rheology with increasing $\rho_{med}$.

- No correlation was found between medium grade and any of the following parameters: $Q_{USM}$, $Q_{UM}$, $Q$, $S_R$ and $R_m$. Medium grade was, however, found to have a statistically significant effect on $C_{mvu}$ at the 0.05 significance level, although the correlation was poor.

- There are indications that particle size has an influence on the spigot capacity and none on $C_{mvu}$, whilst the width of the particle size distribution has no influence on the spigot capacity but has an effect on $C_{mvu}$.

(d) Comparison with DSM

- $Q_{UM}$ values obtained in this study were generally more than double those specified by DSM. A safety factor, defined as the difference between $Q_{UM}$ values between the two investigations divided by the relevant $Q_{UM}$ value from the current study, of about 60% was established. This factor was determined making use of data obtained from cyclones that were not geometrically similar, whilst DSM data was determined on geometrically
similar cyclones. It can, therefore, be concluded that there is large potential to increase the ‘spigot capacities’ specified by DSM. Especially considering that the cyclone still behaves as a separation device even close to the transition point from semi-rope to rope discharge. It is, however, not advisable to operate too close to this transition point because variations in the feed can easily lead to overloading.

- There are indications that DSM possibly defined their ‘spigot capacities’ as the maximum spigot loading that can be achieved before semi-roping commences. This notion is supported by the sinks ore concentrations (at the DSM specified ‘spigot capacities’), which were inferred from the DSM data and are consistent with semi-roping conditions. Further, the spigot loading (in l/hr ore) at the transition point from a spray to semi-roped discharge was about 40% of the maximum spigot capacity; this gave a safety factor of about 60%, which is consistent with that given above.

- Correction for the independent influence of cyclone diameter on $Q_{UM}$ yielded a safety factor of about 50%, which is applicable to geometrically similar cyclone. Assuming that this safety factor of about 50% holds for all conditions, then the spigot ore capacities for the larger cyclones could be estimated as illustrated in Fig. 4.55 (repeated here for convenience). The extrapolated spigot ore capacities in Fig. 4.55 are at best estimates; experimental work is required to valid them.

![Figure 4.55](image-url)  

Figure 4.55. Comparison of $Q_{UM}$ predicted from eq. 4.5 (to correct for effect of D) and those specified by DSM. Dashed line is extrapolation of eq. 4.11.
(e) Model

- The following empirical equations, based on a 165mm cyclone (cone A only), to predict spigot capacity ($Q_{USM}$ and $Q_{UM}$) were developed in this investigation:

\[
Q_{USM} = 0.394D_u^{2.09}D_o^{-0.14}D_i^{0.43}H^{0.36} \exp\left[-5.67(\rho_{med} - 1.45)^3\right] \quad (4.3)
\]

\[
Q_{UM} = 0.226D_u^{2.16}D_o^{-0.11}D_i^{0.38}H^{0.20} \exp\left[-7.59(\rho_{med} - 1.45)^3\right] \quad (4.4)
\]

Only variables that were significant at the 95 percent confidence level were added to the regression equations. Inclusion of the data obtained with the 350mm dense medium cyclone into the regression analysis yielded the following expression:

\[
Q_{UM} = 0.235D_u^{0.63}D_i^{1.51}H^{0.18} \exp\left[-1.58(\rho_{med} - 1.45)^2\right] \quad (4.5)
\]

The quality of the fit was very good for these three expressions (Table 5.2).

<table>
<thead>
<tr>
<th>Equation No.</th>
<th>$R^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>4.3</td>
<td>0.9805</td>
</tr>
<tr>
<td>4.4</td>
<td>0.9821</td>
</tr>
<tr>
<td>4.5</td>
<td>0.991</td>
</tr>
<tr>
<td>4.6</td>
<td>0.9446</td>
</tr>
<tr>
<td>4.7</td>
<td>0.9637</td>
</tr>
<tr>
<td>4.10</td>
<td>0.96</td>
</tr>
</tbody>
</table>

Furthermore, expressions to predict $Q$, $S_R$ and $R_m$ during roping were also developed:

\[
Q = 64.72\left(D_u^2 + D_o^2\right)^{0.74}D_i^{0.90}H^{0.62}\rho_{med}^{0.18} \quad (4.6)
\]

\[
S_R = \frac{Q_{USM}}{Q_{OS}} = 10^{-4.52}D_u^{2.76}D_o^{-0.25}H^{-0.70}C_{vf}^{0.83} \quad (4.7)
\]

\[
R_m = 10^{-3.78}D_u^{1.96}D_o^{-0.25}H^{-0.17}C_{vf}^{0.52} \quad (4.10)
\]
5.2. Recommendations

- Spigot overloading of a dense medium cyclone can be detected visually by observing the discharge type at the sinks and monitoring particle misplacement to the floats stream. The simplest and best indicator of possible spigot overloading is the sinks ore concentration, measurement of this parameter could, however, prove challenging on most industrial cyclones.

- It is important to consider the composition of the ore to be treated in the process of sizing and selection of dense medium cyclones. When the cyclone feed constitutes a high proportion of sinks particles there is a danger of overloading the spigot. It is the sinks ore concentration rather than feed concentration that is of importance in anticipating overloading at the sinks. The higher the proportion of sinks particles in cyclone feed the lower the feed ore concentration must be in order to avoid spigot overloading.

- There are essentially 5 ways in which the spigot capacity can be increased, and that is through \( D_u \), \( D \), \( D_i \), \( H \), and \( D_o \).
  - \( D_u \) and \( D \) have the strongest influence on the spigot capacity. There is, however, a limitation on how much \( D_u \) can be increased; when \( D_u/D_o \) ratio is more than 85% the separation efficiency suffers according to DSM (1985).
  - \( D_i \) also presents a viable option to increase the capacity of a cyclone that is spigot constraint.
  - Spigot capacity can also be increased through \( H \), although its influence is relatively weak.
  - Increasing the spigot capacity through \( D_o \) does not seem to be a reasonable option because this would be at the expense of the floats capacity and \( D_o \)’s influence on the spigot capacity is small. In cases where only a small portion of the ore in the feed exits through the floats stream, the use of \( D_o \) to increase the spigot capacity becomes an option because overloading at the floats would not be a concern any longer.

- There is strong case for the usage of large diameter cyclones because of the relatively strong, independent influence of \( D_u \) and \( D \) on the spigot capacity. The disproportionately
higher spigot capacities of large diameter cyclones allows for the operation of cyclones at relatively high medium-to-ore ratios while simultaneous achieving high capacities.

- Manufacturing of dense medium cyclones with an adjustable geometry seems to be worth considering given that the spigot capacity is determined mainly by the cyclone geometry. The necessary changes to the cyclone geometry can therefore be made to accommodate the character of the ore being treated.
CHAPTER 6. REFERENCES


DSM. 1985. Guide to the calculation of h.m. cyclone and w.o cyclone plants. Stamicarbon bv, Netherlands.


