ABSTRACT

Reeves and Platt\(^1\) stated that dense medium separation is one of the most complex unit processes in mineral processing today particularly if cyclones are used. It is also the most efficient gravity concentrating process available to process engineers. The complexity of the process and large number of design and operating variables means that the process has largely remained more an art than a science. Dense medium separation is well established in the diamond, coal and iron ore industries but is gaining popularity as a pre-concentration step in other industries. The maintenance issues are addressed that will affect the efficiency of the operation.

KEYWORDS

Dense medium, cyclone, ferrosilicon
INTRODUCTION

The purpose of the dense medium separation (DMS) process is to separate the valuable material from the waste based on gravity differences. However, the specific gravity difference between the two fractions must be large enough to achieve high efficiencies. Heavy particles sink through the dense liquid and light particles float.

DMS is also used for the pre-concentration of minerals before further downstream processes like comminution, in order to minimise the treatment costs. Examples are the pre-concentration of diamond ores or metalliferous ores like nickel, copper and cobalt.

Dense medium separation is also used to upgrade the material to meet different market specifications, for example in coal and iron ore applications.

A typical dense medium separation process for a diamond application is shown in Figure 1.

Figure 1 – Dense medium separation flow sheet (diamonds)

FEED PREPARATION

Vibrating screens

Slimes is defined as clay material and is normally referred to as the fraction smaller than 45 micron that is not magnetic. Viscosity problems arise when slimes or clay contaminant is present. Viscosity influences the dense medium separation of especially the finer particles.
Wash water

Effective de-sludging is therefore necessary before the dense medium separation of industrial minerals, ores and coal. Wash water is used for de-sludging on the feed preparation vibrating screen. The amount of water necessary for effective de-sludging must give a maximum solids concentration of 7% by volume in the underflow of the screen.

The formula to calculate the amount of water required is as follows:

\[ A \text{ (m}^3/\text{hr}) = 0.133 \times \left( \frac{a \times S}{\gamma_{pr}} \right) \]  

Where \( a \) is the percentage of the feed solids to the screen smaller than the screen cut size, \( S \) is tonne per hour of solids in the feed to the screen and \( \gamma_{pr} \) is the specific gravity of the solids. The +0.5mm material in the feed has no effect on the total amount of de-sludging water required. It is recommended to use 45 m\(^3\)/hr water per meter width of screen or 2-3 m\(^3\)/tonne for coal. Multistage washing is also recommended for a higher efficiency.

Bed depth

The allowable load \( C \) in t/h per m-screen width for the drain and rinse screen is:

\[ C = 8 \sqrt{d_a^2 \times \gamma_{pr}^2} \text{ t/h/m} \]  

Where \( d_a \) is the average particle size of the product in mm
\( \gamma_{pr} \) is the average specific gravity of the product

Depending on the top size of the material, the ideal bed depth should be less than 20 mm.

CYCLONE

The cyclone consists of various components as shown in Figure 2.

![Figure 2 – The dense medium cyclone](image-url)
A cyclone is a constant volume device and it is critical that the cyclone receives a constant feed.

Factors influencing DMS operation are:

- Cyclone design parameters.
- Operational parameters.

**Cyclone diameter**

The centrifugal force as a function of cyclone diameter is shown in Figure 3 at an operating head of 9D. The reduction in centrifugal force increases the particle size where the drag forces are larger than the centrifugal forces and there is insufficient time to separate the particles effectively.

![Centrifugal Acceleration vs Cyclone Diameter](image)

Figure 3 – The centrifugal force as a function of cyclone diameter

The minimum diameter of cyclone that must be used is determined by the top size of particle in the feed to the cyclone. The size or number of cyclones installed is also a function of the feed or spigot capacity to be handled as shown in Table 1.
Table 1 - Dimensions and capacities of Multotec cyclones

<table>
<thead>
<tr>
<th>Cyclone Diameter (mm)</th>
<th>Max Particle Size (mm)</th>
<th>Coal Feed (t/h)</th>
<th>Cyclone Diameter (mm)</th>
<th>Max Particle Size (mm)</th>
<th>Coal Feed (t/h)</th>
</tr>
</thead>
<tbody>
<tr>
<td>510</td>
<td>34</td>
<td>54</td>
<td>510</td>
<td>51</td>
<td>99</td>
</tr>
<tr>
<td>610</td>
<td>41</td>
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</tr>
<tr>
<td>660</td>
<td>44</td>
<td>97</td>
<td>660</td>
<td>66</td>
<td>175</td>
</tr>
<tr>
<td>710</td>
<td>47</td>
<td>114</td>
<td>710</td>
<td>71</td>
<td>207</td>
</tr>
<tr>
<td>800</td>
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<td>149</td>
<td>800</td>
<td>80</td>
<td>270</td>
</tr>
<tr>
<td>900</td>
<td>60</td>
<td>196</td>
<td>900</td>
<td>94</td>
<td>355</td>
</tr>
<tr>
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<td>249</td>
<td>1000</td>
<td>100</td>
<td>454</td>
</tr>
<tr>
<td>1150</td>
<td>77</td>
<td>351</td>
<td>1150</td>
<td>115</td>
<td>638</td>
</tr>
<tr>
<td>1300</td>
<td>87</td>
<td>468</td>
<td>1300</td>
<td>130</td>
<td>854</td>
</tr>
<tr>
<td>1450</td>
<td>97</td>
<td>608</td>
<td>1450</td>
<td>145</td>
<td>1108</td>
</tr>
</tbody>
</table>

Vortex finder to spigot ratio

The spigot size determines the mass recovery to the underflow. The spigot diameter also affects the differentials – the higher the spigot to vortex finder ratio, the lower the differentials. The spigot diameter must not exceed 85% of the vortex finder diameter. The smaller the spigot, the higher the cut density and the lower the spigot capacity. Larger spigots reduce the hang up of coarse particles and the excessive wear that takes place when hang up occurs. Figure 4 shows the EPM and spigot to vortex finder ratio relationship.
Feed size distribution

The smaller the particle, the less centrifugal force exerted, resulting in an increase in the fine “sinks” reporting to the “floats”.

The separation efficiency (Ep value) is normally measured per size range – at a specific bottom size the separation efficiency will decrease. Smaller diameter cyclones are employed for finer feed materials in order to reduce the breakaway size. The breakaway size for a specific cyclone diameter is calculated by:

$$d_b = (6 \times \Theta^{1.64}) \times 10^{-5}$$  \hspace{2cm} (3)

Figure 5 shows the breakaway size for different cyclone sizes.
Density shift

The density separation of ore particles is time dependent – larger particles separate faster than small particles. The separation of large particles will take place at a higher level within the cyclone and hence lower density. As the solids get smaller in size, so the \( d_{50} \) cut point for that particular size of solids increases. This is referred to as the density shift.

OPERATING PARAMETERS

Medium to ore ratio

The medium to ore ratio is important to prevent “over-crowding” of the ore. Typical ratios are:

- easy to wash coals                           3 : 1.
- other minerals                                 5 : 1.

Figure 6 shows the effect of the M:O ratio on the EPM.

![Figure 6 – The EPM and M:O relationship](image)

Higher ratios appear to have very little effect in terms of improved efficiency and result in increased equipment size, higher operating cost and increased medium losses.

Head/pressure

At a high feed inlet pressure, the slurry flow rate to the cyclone increases. The tangential velocity of the particles increases which increases the centrifugal force which in turn improve the separation process especially of fine particles despite the shorter residence time. Unfortunately a high feed inlet pressure increases the classification of the media, the density differential of the media increases which is measurable by determining the underflow and overflow densities respectively and calculating the density differential. A fluctuating head affects the medium to ore ratio, especially when the solids feed rate is left unchanged.
Recommended feed heads are:

- coal 9 x D.
- diamonds 12 – 15 x D.
- other minerals 12 – 20 x D.

It is generally accepted that below 7D the cyclone air core becomes unstable and the cyclone performance is likely to deteriorate.

Table 2 shows the relationship between pressure fluctuation and inlet velocity/spigot density changes.

<table>
<thead>
<tr>
<th>Total Head</th>
<th>Δ Pressure</th>
<th>Δ Inlet Velocity</th>
<th>Δ Spigot Density</th>
</tr>
</thead>
<tbody>
<tr>
<td>182 kPa</td>
<td>-10%</td>
<td>15.5%</td>
<td>1.1%</td>
</tr>
<tr>
<td>182 kPa</td>
<td>-5%</td>
<td>8.0%</td>
<td>0.6%</td>
</tr>
<tr>
<td>182 kPa</td>
<td>0%</td>
<td>0.0%</td>
<td>0.0%</td>
</tr>
<tr>
<td>182 kPa</td>
<td>+5%</td>
<td>-8.7%</td>
<td>-0.9%</td>
</tr>
<tr>
<td>182 kPa</td>
<td>+10%</td>
<td>-18.4%</td>
<td>-2.1%</td>
</tr>
</tbody>
</table>

Figure 7 shows the relationship between relative pressure and the relative wear rate.

Figure 7 – Effect of pressure on wear rate

Differentials

A dense medium cyclone performs a separation within a separation. Classification of the medium solids (separation via size) occurs; therefore the medium solids will separate to a certain degree. The feed, overflow and underflow will have different medium densities. Factors affecting differentials are:

- medium viscosity/stability.
- feed head (pressure).
- cyclone diameter.
• inlet design.
• barrel section.
• spigot size.
• medium density.

The differential is calculated as:

\[
\frac{RD_{\text{feed}} - RD_{\text{overflow}}}{RD_{\text{feed}}} = 3 - 12\% \tag{4}
\]

If the differentials are too big, hang-up of particles in the cyclone can occur. The “near dense” material in the cyclone is causing the hang-up. Coarse sinks particle hang-up is a concern in the diamond industry. Figure 8 shows the acceptable medium properties.

Figure 8 – Medium properties

**DENSE MEDIUM CYCLONE CHECK AND PROBLEM SOLVING**

Table 3 lists a number of observations and identifies a possible problem for the observations as well as the recommended action.
<table>
<thead>
<tr>
<th>Observation</th>
<th>Possible problem</th>
<th>Action</th>
</tr>
</thead>
<tbody>
<tr>
<td>Feed to the preparation screen is fluctuating.</td>
<td>Inconsistent feed rate from ore preparation section.</td>
<td>Investigate problem and rectify.</td>
</tr>
<tr>
<td>Not enough water on screens.</td>
<td>Water pressure too low, water not open, spray nozzles blocked.</td>
<td>Verify water pressure, ensure water valves are open, unblock spray nozzles, add sufficient water to remove clay. Minimize clay balls and cyclone blockages by ensuring the spray nozzles on the spray bars are open, rather have too much water than too little.</td>
</tr>
<tr>
<td>Screen blockage, no proper draining.</td>
<td>Type of material treated, contamination with vegetation, require different type of screen panel, screen motion. Prevent contamination of medium.</td>
<td>De-blind screen where required, maintain aperture size, verify correct panels for the application, ensure screen stroke is sufficient. Have a weir bar between the drain and rinse to prevent medium carryover to the rinse section, use enough water on the rinse section to minimize adhering medium losses.</td>
</tr>
<tr>
<td>Coarse material in effluent and medium.</td>
<td>Holes in screen panels.</td>
<td>Check condition of screen panels and rectify.</td>
</tr>
<tr>
<td>Fluctuating cyclone pressure.</td>
<td>Mixing box level not constant, insufficient medium in circuit. Medium to mixing box is fluctuating. Poor cyclone efficiency. Accelerated wear.</td>
<td>Ensure header tank level. Check correct medium sump level, add medium if required. Maintain level in mixing box, open medium flow to mixing box. Check for obstructions in medium flow to mixing box. Low pumping efficiency, check condition of correct medium pump, make sure ore feed rate is constant. Operate as constant as possible. Cyclone pressure to be in the specified operating range.</td>
</tr>
<tr>
<td>Pressure decreases.</td>
<td>Decrease in medium density.</td>
<td>Check density and rectify, may require FeSi.</td>
</tr>
</tbody>
</table>
**CONCLUSION**

Dense medium separation is used to separate the valuable material from the waste.

Slimes, defined as the -45 micron clay particles, cause viscosity problems in the medium which influence the separation of near density particles. It is recommended to add 2-3 m³ water/tonne coal to the preparation screen for de-sliming. The bed depth should be less than 20 mm depending on the top size of the feed material.
A fluctuation of 10% in the cyclone pressure will result in a fluctuation of 15% in the inlet velocity to the cyclone. The aim should always be to keep the cyclone pressure as constant as possible. Cyclone operation should not be at a too high pressure (>20D), as the pressure to wear rate ratio is an exponential function. The differential over the cyclone can be calculated to determine whether the operation is in the acceptable range.

REFERENCES

