BEST ENGINEERING PRACTICES IN THE DESIGN OF HYDRAULIC WORKS FOR HANDLING MASSIVE SLURRY SPILLS IN COPPER PROCESSING PLANTS

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ABSTRACT

Usually copper processing plants can be analyzed as a hydraulic system driven by gravity, although there are many pumped recirculation lines within the plants due to process requirements. The hydraulic system goes from the grinding area - where the coarse ore is mixed with water in mills to reduce the average solid particle size - down to the delivering areas of the final product (copper concentrate slurry) and waste (thickened tailings slurry). During normal operation, many pipes and tanks are full of slurry containing solid particles which can easily settle down if there is insufficient turbulence. Solids in slurries typically remain suspended due the turbulence produced by the impingement of slurry jets feeding a tank or the presence of mechanical agitators into it. When a general power failure occurs, some pipes, tanks and equipment tend to get steady, dramatically reducing the usual turbulent environment, and therefore rapidly increasing the risk of massive settling of solids. The latter is unacceptable since it could lead to significant losses due the inability to run the processing plant for several hours, or even days. The way to avoid this issue is having operational protocols in place to rapidly empty the critical tanks and pipes (those unable to drain by gravity) when power fails, together with an adequate set of hydraulic works especially designed to handle these massive spills. This paper summarizes the best engineering practices successfully applied to the design of the hydraulic works for handling massive slurry spills, including feedback from actual operations.

Keywords: Slurry; Spills; Copper Plant; Energy Failure; Hydraulic Works.

1 INTRODUCTION

The traditional way of designing hydraulic works for handling massive slurry spills at the grinding building of a copper processing plant, consists of a central collection trench, 3.5-5.0 m wide, plus lateral floors (with slopes in the range of 2-10%) receiving major spills and feeding the trench. Spills collected in the trench are intended to flow towards a low point where vertical sump pumps are installed on a fixed structural support. The system is designed to allow a front-end loader to remove the coarse ore that has settled on the floor. The system also has an overflow weir connected to a slurry conveyance system discharging into an emergency pond, which is located outside the grinding building. This correspond to the design paradigm used in the 80’s and 90’s.

Site technical visits in the 2000’s demonstrated that systems following the abovementioned design approach were not working as expected. In fact, sump pumps were rapidly disabled after beginning operation because they were irreparably covered by accumulated spilled slurry. Coarse ore settled as expected, but most of the fine ore and water was not drained away as fast as expected and significant amount of fine solid particles remained on the floor in the form of mud. This made the front-end loader operation practically impossible (see Figure 1).
Figure 1. Design approach in the 80’s and 90’s. Trench permanently flooded due to low maintainability.

Massive slurry spills from the grinding process normally contains large and heavy solids, such as pebbles (2 inch diameter), steel ball chips (1-2 inch diameter) and even entire steel balls (3-6 inch diameter), all of which comes with the ore feeding Semi-Autogenous Grinding (SAG) mills and Ball mills. Massive spills are capable of transporting these large solids, dragging them to low points or sinks, blocking the suction of the sump pumps, blocking grids horizontally arranged, and even affecting the capacity of the liquid conveyance system for major spills. Also, due a lack of maintenance, minor spills could generate a large and extensive zone of solids accumulation, forming an important layer of mud in the trench (see Figure 1). This could also produce significant embankments at the entry of the discharge pipe that belongs to the liquid conveyance system, and therefore helping to reduce even more its projected capacity.

2 NEW DESIGN APPROACH

Based on useful feedback from operations and recognizing the root cause that made the old design not being successful in achieving its purpose, the main improvement of the new design approach consists in adding new stages to the system, while other several minor improvements were also developed and implemented in projects executed within the last 15 years:

- The spill design flowrate is determined based on equipment and pipe capacities. The design basis is defined together with the owner and engaging representatives from operations.
- Floor slopes have been increased to improve slurry transport towards the trench (up to 12%, avoiding going further because of the risk of slippery floor to the operators).
- The system’s lowest point has been located at one end of the trench, where a primary detention volume is provided within the trench.
- The detention volume is sized to capture very coarse solids, while the rest of the slurry (finer fraction and liquid) overflows to a secondary settling chamber.
- The secondary settling chamber allows additional storage for solids. It also has an overflow weir feeding the third and last chamber, where vertical sump pumps are installed.
- Also, the upstream end of a liquid conveyance system (typically a drainage pipe running partially full in line with energy dissipators) is connected to the last chamber. This conveyance system discharges into an emergency pond located outside the grinding building.
- Both the primary and secondary detention volumes have adequate access space for a front-end loader to maneuver and remove settled solids.
- Both the primary and secondary detention volumes consider screens arranged vertically, to allow liquid and fine solid particles to access the following chamber, while the coarse solid particles are retained in the detention volume, with reduced chances of clogging the grid or screen due to its vertical arrangement.
- Process data related to slurry characteristics (solids density and particle size distribution) is used to estimate the total solids’ amount retained in the total detention volume (primary plus secondary).
- Although the liquid conveyance system connected to the last chamber is intended to transport mainly liquid with fine solid particles, the design considers the possibility of transporting slurry. This can happen if the detention volumes are not available whenever a major spill event occurs.

The current conceptual design accounts for four different stages, which are complementary. The first two rely on settling and screening solid particles, the third one corresponds to pumping back the slurry to the process (mainly taking care of “minor spills”) and the last one is the liquid conveyance system.

3 TOTAL VOLUME AND FLOW RATE ESTIMATION

As mentioned above, the total volume and spill design flowrate are determined based on the equipment and pipe capacities of each specific copper processing plant. This typically consist of different equipment such as Semi-Autogenous Grinding (SAG) mills, Ball mills and hydrocyclone clusters (HCs), together with transfer boxes, pumps and pipes to transport the mineral slurry. Normally, massive slurry spills systems are required in the grinding building of the process plant, although other process areas can make smaller contributions (e.g. sometimes flotation and regrind areas).

When a total power failure happens, the process of emptying transfer boxes, the whole length of the pipes and some of the slurry contained into different equipment, is crucial to avoid massive settling of solid particles, so those are the main volumes that must be considered in the design. On top of this calculated volume, a 20% allowance should be considered to account for wash water and other complementary operational tasks.

Knowing the total volume to be handled, an estimated peak flow rate can be calculated assuming certain time for the discharge or certain hydrograph shape, being the former the most used approach for its simplicity. The time for the discharge usually depends on specific operation protocols when facing these scenarios, but it is a usual practice to consider between 15 to 30 minutes. An example of total volume and peak flow rate estimation for a massive slurry spill event is shown in Table 1.
Table 1. Total volume and peak flow rate estimation for massive spills in grinding area.

<table>
<thead>
<tr>
<th>Element</th>
<th>Dimensions</th>
<th>Quantity</th>
<th>Volume (m³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Primary HCs feed box</td>
<td>W = 8.0 x L = 9.0 m H = 9.6 m</td>
<td>1</td>
<td>691</td>
</tr>
<tr>
<td>HCs feed pipes</td>
<td>D = 36 in</td>
<td>2</td>
<td>105</td>
</tr>
<tr>
<td></td>
<td>L = 50 m each</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Grinding HCs</td>
<td>D = 7 m</td>
<td>2</td>
<td>277</td>
</tr>
<tr>
<td></td>
<td>H = 6 m each</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>60% of total capacity assumed</td>
<td></td>
<td></td>
</tr>
<tr>
<td>HCs overflow discharge pipe</td>
<td>D = 40 in</td>
<td>2</td>
<td>83</td>
</tr>
<tr>
<td></td>
<td>L = 30 m each</td>
<td></td>
<td></td>
</tr>
<tr>
<td>HCs oversize collection box</td>
<td>W = 3.05 x L = 8.5 m H = 5 m</td>
<td>1</td>
<td>130</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Volume of Slurry</td>
<td></td>
<td></td>
<td>1 286</td>
</tr>
<tr>
<td>Wash water and other tasks</td>
<td>20% allowance</td>
<td>1</td>
<td>257</td>
</tr>
<tr>
<td>Total volume</td>
<td></td>
<td></td>
<td>1 543</td>
</tr>
</tbody>
</table>

Estimated peak flow rate

<table>
<thead>
<tr>
<th>Time of discharge</th>
<th>Volume (m³/h)</th>
</tr>
</thead>
<tbody>
<tr>
<td>15 minutes</td>
<td>6 172</td>
</tr>
<tr>
<td>30 minutes</td>
<td>3 086</td>
</tr>
</tbody>
</table>

With:
W = width of element; L = length of element; H = height of element; and D = diameter of element.

4 DESIGN OF MAIN HYDRAULIC WORKS

Once the total volume and peak flow rate are computed, it is possible to design the different chambers that would contain the coarse solid particles and the liquid of the massive spill. First, some information about the slurry properties is needed, such as the solids concentration by volume (Eq.[1]), which can be determined knowing the specific gravity of solids and the solids concentration by weight (Wilson et al., 2006).

\[ C_v = \frac{S_w \cdot C_p}{S_s - C_p (S_s - S_w)} \]  

[1]

Where:

- \( C_v \): Solids concentration by volume [non-dimensional].
- \( C_s \): Solids concentration by weight [non-dimensional].
- \( S_s \): Specific gravity of solids [non-dimensional].
- \( S_w \): Specific gravity of water [non-dimensional].

With this information it is possible to determine a range of volume of solids that will have to be handled in the firsts stages of the system. Using the values of the example shown in Table 1, assuming a solids concentration by weight between 30% and 60%, and using a specific gravity of solids of 2.7, the total volume of solids is determined in Table 2.

Table 2. Volume of solids estimation.

<table>
<thead>
<tr>
<th>Slurry properties</th>
<th>Min</th>
<th>Max</th>
</tr>
</thead>
<tbody>
<tr>
<td>Specific gravity of water</td>
<td>1.0</td>
<td>1.0</td>
</tr>
<tr>
<td>Specific gravity of solids</td>
<td>2.7</td>
<td>2.7</td>
</tr>
<tr>
<td>Solids concentration by weight</td>
<td>30%</td>
<td>60%</td>
</tr>
<tr>
<td>Solids concentration by volume</td>
<td>14%</td>
<td>36%</td>
</tr>
<tr>
<td>Final Quantities</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Volume of slurry (m³)</td>
<td>1286</td>
<td>1286</td>
</tr>
<tr>
<td>Volume of solids (m³)</td>
<td>176</td>
<td>459</td>
</tr>
</tbody>
</table>

The total volume of solids to be handled is required to size the main trench of the grinding building - which typically is the access of the front load equipment to the building and the first detention stage of the system - and the rest of the chambers of the system. An example of a layout arrangement (plan view) of a grinding
building in a copper processing plant, which has been designed with the new design approach for handling massive slurry spills, is shown in Figure 2.

The equipment that would potentially spill after a total power failure event (also called “blackout”) is shown in yellow and the solids settling chambers are shown in light blue. Four different stages can be observed, with its different flow directions. The main trench is the first element to collect and convey the massive spill and it has to be designed with a detention volume sized to capture very coarse solids, while the rest of the slurry (finer fraction of solids and liquid) overflows to a secondary settling chamber.

![Figure 2. Layout arrangement (plan view) of the grinding building in a copper processing plant considering the new design approach.](image)

The secondary settling chamber allows additional storage for solids and the access to the sump pumps. It also has an overflow weir feeding the third and last chamber, where vertical sump pumps are installed. These vertical pumps are mainly needed to return minor and frequent spills back to the process, but also, they can help draining out part of the remaining liquid that could be stored in case of a massive spill event.

The flow passage from the main trench to the access ramp and from the access ramp to the chamber where sump pumps are located, should consider vertical grids disposed to retain the largest solid particles, so only smaller solid particles would pass to the pumps chamber. A recommended size of the openings in the grid is 0.5 inch width by 2 inch height. Based on feedback from operations, it is very important that these grids are arranged vertically. Older designs that considered grids horizontally arranged, got clogged easily and cleaning them was very difficult and impractical.

Finally, one last weir is needed to separate the sump pumps chamber from the final chamber, where the liquid conveyance system starts with the discharge pipe. This weir is intended to provide the necessary submergence required by the pumps to evacuate operational and smaller spills.

For each weir / grid and for the inlet control produced by the upstream end of the discharge pipe, it is necessary to calculate the hydraulic head generated by the design flow rates, ensuring that the dimensions defined (width / height) in the design are suitable for handling the estimated flow rates without flooding other surrounding areas and affect, for instance, electrical equipment. Also, it should be verified whether the discharge pipe inlet will operate full or not. In the case the inlet operates with a liquid level higher than 70% of the discharge pipe diameter, a vent pipe should be located between 2 to 5 diameters downstream from the inlet.
The three detention areas shown in Figures 2 and 3 (the main trench, the access ramp and the sump pumps chamber) have a total volume of approximately 300 m$^3$ in this particular case. On the other hand, the more conservative approach of the solids volume estimation (Table 2) shows that a massive spill could produce a maximum volume of solids of 459 m$^3$. Therefore, for this case there is a volume of 159 m$^3$ of fine solids remaining to be handled by the liquid conveyance system.

Figure 3. Detailed 3D view for chambers configuration and flow direction.

5 LIQUID CONVEYANCE SYSTEM DESIGN

Usually, copper processing plants don’t have enough space for constructing large settling chambers inside the buildings or next to them, so the resources for freely designing are limited. Continuing with the case described in previous sections of this paper, and assuming that the total volume for retaining solid particles is limited, the next step is to verify the capacity of the liquid conveyance system.

The liquid conveyance system is composed by a discharge pipe, which should be able to transport the liquid phase of the massive spill plus the solids that could not be retained in the settling chambers, to an emergency pond. It is right to consider that the 300 m$^3$ volume of solids contained by the first 3 chambers would be made up of the coarsest individual particles, so the remaining 159 m$^3$ volume of solids would correspond to the 35% finest particles of the total volume of solids. With this information, a solid particle size distribution is required to determine the largest solid particle that would be transported through the liquid conveyance system. Figure 4 shows a solid particle size distribution for characterizing the slurry corresponding to the massive spill.

Figure 4. Referential slurry particle size distribution.
According to the information provided in Figure 4, the hydraulic characteristics of the flow inside the discharge pipe need to be consistent with the need of transporting all the solid particles below 0.36 mm (360 microns). Being conservative and assuming a maximum solid particle size of 1.0 mm, it is possible to estimate the minimum flow in the discharge pipe for having a flow velocity at least 10% higher than the limit settling velocity. The limit settling velocity can be calculated based on the method proposed by Green et al. (1978), which combines the Darcy-Weisbach and Shields equations:

\[ V_s = \sqrt{\frac{8 \cdot \theta \cdot g \cdot d (S_p - 1)}{f}} \]  

[2]

Where:
- \( V_s \): Limit settling velocity [m/s].
- \( \theta \): Particle motion constant [non-dimensional]. \( \theta = 0.8 \) to prevent solids settling.
- \( g \): Gravity acceleration [m/s²].
- \( d \): \( d_{50} \) particle size [m].
- \( S_p \): Specific gravity of solids [non-dimensional].
- \( f \): Darcy-Weisbach friction factor [non-dimensional].

Also, it is very important to verify the total capacity of the discharge pipe and its correct operation for the estimated peak flow rates. Flow velocity in open channels can be calculated by using the Darcy-Weisbach and the Coolebrook-White equations (or equivalent), with the diameter conventionally used in these equations replaced by four times the hydraulic radius, as shown below:

Darcy-Weisbach equation:

\[ V = \sqrt{\frac{8 \cdot R \cdot g \cdot i}{f}} \]  

[3]

Where:
- \( V \): Average velocity in the pipe [m/s].
- \( R \): Hydraulic radius [m].
- \( g \): Gravity acceleration [m/s²].
- \( i \): Pipe slope [m/m].
- \( f \): Darcy-Weisbach friction factor [non-dimensional].

Coolebrook-White equation:

\[ \frac{1}{\sqrt{f}} = -2 \cdot \log \left( \frac{k_s}{3.7 \cdot (4R)} + \frac{2.51}{Re \cdot \sqrt{f}} \right) \]  

[4]

\[ Re = \frac{4RV}{\nu} \]  

[5]

Where:
- \( k_s \): Equivalent roughness [m].
- \( Re \): Reynolds Number [non-dimensional].
- \( \nu \): Slurry kinematic viscosity [m²/s].

The discharge pipe of the abovementioned case corresponds to a 1 200 mm HDPE pipe, with a slope of 1.5%. In Table 3 it is shown the hydraulic calculations (Green et al.,1978) for the 3 most important flows that the discharge pipe would have to handle. Item 1 shows the minimum flow rate at which the pipe is able to transport 1.0 mm size particles without presenting the risk of settling; item 2 shows how the maximum flow rate estimated in Table 1 behaves in the discharge pipe; and item 3 represent the maximum flow rate that the pipe is able to transport with a maximum flow depth / diameter ratio close to 70%.

<table>
<thead>
<tr>
<th>Item</th>
<th>Flow Rate (m³/hr)</th>
<th>Pipe Diameter (mm)</th>
<th>Slope</th>
<th>Design Velocity (m/s)</th>
<th>Transport Velocity (m/s)</th>
<th>Flow depth /diameter ratio</th>
<th>Depth of Flow (mm)</th>
<th>Friction Factor (-)</th>
<th>V/V_L</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1 000</td>
<td>1059</td>
<td>1.50</td>
<td>2.80</td>
<td>2.54</td>
<td>0.17</td>
<td>180</td>
<td>0.017</td>
<td>1.10</td>
</tr>
<tr>
<td>2</td>
<td>6 172</td>
<td>1059</td>
<td>1.50</td>
<td>4.57</td>
<td>2.79</td>
<td>0.44</td>
<td>467</td>
<td>0.014</td>
<td>1.64</td>
</tr>
<tr>
<td>3</td>
<td>12 500</td>
<td>1059</td>
<td>1.50</td>
<td>5.32</td>
<td>2.87</td>
<td>0.69</td>
<td>735</td>
<td>0.013</td>
<td>1.86</td>
</tr>
</tbody>
</table>

The correct functioning of the discharge pipe occurs for flow rates between 1 000 m³/h and 12 500 m³/h, so it works properly for the peak flow rates estimated and shown in Table 1. The resulting slurry velocity is
between 4.5 and 5.5 m/s for the design and maximum flow rates, correspondingly. This is accepted given the occasional nature of these spill events, meaning that wear produced by slurry flowing at high velocity is not an issue in these cases. Moreover, decreasing the velocity by the slope would mean a decrease in the capacity to evacuate solid particles of greater size. For example, if during a blackout event the total volume of the settling chambers are not fully available due to lack of maintenance, the pipe would still have the capacity to transport more concentrated slurry and with larger solids in it.

Also, it is usual that copper mine sites are located in steep terrain, where the elevation difference to be handled by the liquid conveyance systems is important. So, if the emergency pond is located far away from the building where the massive spill is been managed, there are high chances of needing energy dissipators (called “drop boxes”) to address this difference in elevation along the liquid conveyance system.

A new design approach has been also developed for the liquid conveyance system, including drop boxes as needed and taking in account that the whole system only works occasionally. Drop boxes has been proved to be required due to serious failures reported by operations when using very steep drainage pipes, designed and built without drop boxes and reaching slopes of about 100% in some portions. What happened in a particular case, was that after 10 years of operation the high velocities of the slurry – even considering the the flow occurred occasionally – eventually produced full wear in a vertical bend in the discharge pipe, spilling a large volume of liquid and slurry very close to sensitive earthen structures, leading to significant scour and therefore putting at serious risk the operation of the processing plant.

The design concepts and procedures discussed both in Mery (2013) and Chanson (2015), are useful in the design of hydraulic energy dissipators and related hydraulic works. The main goal is to reduce the drop boxes dimensions but always keeping an adequate energy dissipating capacity. For doing so, the drop box design is divided in two chambers: the feeding chamber, that receives the slurry in a first smaller drop, and the discharge chamber that loses the main elevation in a second and higher drop. The simplest hydraulic calculations for sizing the drop boxes should include at least:

- The liquid level at the discharge chamber (h_d)
- The liquid level at the feeding chamber (h_f)
- The liquid jet trajectory at the entrance of the box (L_p1) and at the discharge chamber (L_p2).

![Figure 5. Drop box design.](image)

The liquid level at the discharge chamber (h_d) can be obtained using a culvert inlet control equation (U.S. FHWA, 2005), so with this parameter it is possible to stablish the minimum height loss of the drop box to generate hydraulic independence from upstream. As it was said before, the elevation difference to be handled by the liquid conveyance system could be very high, so normally, a larger drop could be required and the depth of the discharge chamber would vary depending on each case. Between the feeding chamber and the discharge chamber, a free overfall weir is recommended. This weir would provide a stilling basin for accumulating solid particles and receiving the concentrated liquid jet entering to the box, helping to avoid wear issues and working as an energy dissipator. The liquid level at the feeding chamber (h_f) is controlled by the weir, so this level could be obtained using simple free overfall weir equations (Mery, 2013).

The length dimensions for the drop box are controlled by the jet trajectories entering to each chamber. There are many different equations to estimate liquid jet trajectories in the literature (Ervine and Falvey, 1987; Ervine et al., 1997; Franzetti and Tanda, 1987; etc.), but they can be also estimated using simple free falling
trajectory equations, once the liquid levels \( (h_1 \text{ and } h_2) \) are computed in each chamber. The principal free falling trajectory equations are:

\[
V = \sqrt{V^2_x + V^2_y} \quad [6]
\]

\[
V_x = V_o \cdot \cos(\theta) \quad [7]
\]

\[
V_y(x) = V_o \cdot \sin(\theta) - \frac{g \cdot x}{V_o \cdot \cos(\theta)} \quad [8]
\]

\[
\alpha(x) = \tan^{-1}\left(\frac{V_y}{V_x}\right) \quad [9]
\]

\[
y(x) = x \cdot \tan(\theta) - \frac{g \cdot x^2}{2 \cdot V_o \cdot \cos(\theta)} \quad [10]
\]

Where:
- \( V \): Average velocity of the jet [m/s].
- \( V_x \): Horizontal component of jet velocity [m/s].
- \( V_y \): Vertical component of jet velocity [m/s].
- \( V_o \): Flow velocity at the pipe or launder end [m/s].
- \( \theta \): Slope at the pipe or launder end [Rad].
- \( \alpha \): Jet angle with respect to the horizontal [Rad].
- \( x \): Horizontal distance from the pipe or launder end [m].
- \( y(x) \): Vertical distance from the pipe or launder end [m].

For the feeding chamber is desirable that its length fully contains the liquid jet when it is empty, i.e. without considering the liquid depth generated by the weir. This recommendation applies mostly for the feeding chamber due to the significant liquid momentum concentrated in the feeding jet coming from the pipe or launder. On the other hand, the discharge chamber length can consider the liquid level established by the discharge pipe inlet control, so keeping in mind that the jet trajectory should never reach the opposite wall, it is possible to reduce the dimensions of the structure to make it as compact as possible.

Finally, it should be verified whether the drop box outlet will operate fully submerged or not. In the case the outlet operates with a level higher than 70% of the pipe diameter, a vent pipe should be located between 2 to 5 diameters from the box outlet.

6 CONCLUSIONS

Site technical visits in the 2000’s demonstrated that systems for handling massive slurry spills designed following the ‘traditional’ approach were not working as expected. Based on useful feedback from operations, and how it has impacted subsequent engineering designs, a new design approach has been developed, which...
mainly consists in adding new stages to the system. Throughout this paper the best engineering practices successfully applied to the design of hydraulic works for massive slurry spills handling were reviewed, including detailed design recommendations for each stage.

Total volume and maximum flowrates estimation for massive slurry spills methodology was reviewed, along with the volume required for the retention of solids due a massive spill event. The new conceptual design accounts for four different stages, which are complementary. The first two rely on settling and screening solid particles, the third one corresponds to pumping back the slurry to the process (mainly taking care of “minor spills”) and the last one is a liquid conveyance system, which should be able to transport the liquid phase of the massive spill plus the solids that couldn’t be retained in the settling chambers to an emergency pond. Vertical grids disposed to retain the largest size solids in between the different settling chambers are required. Based on feedback from operations, it is very important that these grids are arranged vertically. Older designs that considered grids horizontally arranged, got clogged easily and cleaning them was very difficult and impractical.

A new design approach has been also developed for the liquid conveyance system, including energy dissipators (“drop boxes”) as needed and taking in account that the whole system only works occasionally. Drop boxes has been proved to be required due to serious failures reported by operations when using very steep discharge pipes operating as hydraulic chutes. Still, the slurry velocity in the pipe is recommended to be sufficiently high, in order to increase its capacity to evacuate solid particles of large size.

REFERENCES