VXP2500 STIRRED MILL OPTIMIZATION AT CASMYN MINING TURK MINE

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ABSTRACT

The development of stirred milling technology has proven to be an enabling technology in fine grained metallic deposits. The increased grinding efficiency allows for the economic size reduction required to produce saleable concentrates. This improvement has opened the door to retreatment projects such as reprocessing of historic gold mine tailings.

Recently a VXP2500 stirred mill was installed at Casmyn Mining Zimbabwe Turk mine to allow the reprocessing of historic mine tailings. After commissioning, an extensive joint research project between Casmyn and FLSmidth Minerals was conducted to optimize the performance of the mill.

This paper outlines the challenges encountered in the optimization program and the outcomes from the joint research project.

KEYWORDS

FLSmidth VXP, gold, Zimbabwe, stirred mill, tailings reprocessing, fine grinding

INTRODUCTION

The development of stirred mills has opened up many new opportunities to recover valuable minerals from refractory ores. Stirred mills have already been reported as an enabling technology for the processing of fine grained ores in lead/zinc applications (Pease, Young and Curry, 2005). Historically, conventional ball mills were unable to economically grind material fine enough to produce the required recovery or concentrate grade. This often resulted in the loss of valuable materials to the final plant tailings. The advent of stirred milling has now provided an opportunity which has both economic and environmental benefits, the reprocessing of historic mine tailings. Many tailings stockpiles now contain economic concentrations of gold because of the ability of stirred mills to efficiently and economically grind the tailings to liberation sizes.

The primary advantage of reprocessing historic tailings is very low cost processing. Recovering the tailings is usually as simple as pumping the material into the reprocessing circuit. The disadvantage of reprocessing tailings is the low feed grade and greater difficulty in recovery valuable minerals at the same size distribution. The material has already been previously processed so fresh surface area or an increase in metal exposure is required. These are both provided by regrinding the tailings material.

The FLSmidth VXPmill has proven to be an efficient way to provide fine grinding for retreatment projects. These vertical stirred mills were originally developed in South Africa to produce fine pigments. This early development was carried out by Deswik (Pty) Ltd. In 2011, the technology was advanced through the establishment of a joint venture between Deswik International Limited and Knelson (a corporate partnership). This joint venture, Knelson Milling Solutions, was subsequently acquired by FLSmidth in September 2011. There is currently a wide range of VXPmills which are suitable for a range of applications. These include laboratory models, pilot scale versions, and six production models (Table 1).

Table 1 – VXPmill product range.

Mill Type	Net Volume (L)	Design Speed (rpm)	Installed Power (kW)
Laboratory			
VXP2	3	1763	3.7
VXP10	10	1763	15
Pilot			
VXP25	27	1175	30
VXP50	50	1175	56
Production			
VXP100	110	764	110
VXP250	290	509	132
VXP500	480	432	224
VXP1000	910	304	337
VXP2500	2425	241	699
VXP5000	5026	180	1475
VXP10000*	10000	140	3000

* Currently under design.

Casmyn Mining Zimbabwe (Casmyn), a subsidiary of New Dawn Mining, is based in Bulawayo, Zimbabwe. They own a number of mines and tailings resources in the region. One of these, the Turk Mine, is located approximately 55 km north of their offices in Bulawayo. During an economic review of the project, the large tailings dumps were identified as being able to provide a significant supplement to gold production from their underground operations. The key to successfully recovering gold from the dump was fine grinding. A review of applicable technologies identified the VXP2500 as the most economic option for fine grinding the tailings material before gold recovery by leaching.

A VXP2500 was subsequently purchased to grind the dump material from an estimated size of 100 microns (F80) down to 20 microns (P80) prior to leaching. The VXP2500 based regrind circuit was commissioned in early 2012. Later in the year a joint research project between Casmyn and FLSmidth was launched. The objective of this research project was to optimize the VXP2500 performance by varying the mill configuration to improve the grind for the current tailings material.

PROCESS DESCRIPTION

The Turk mine is an underground gold mine that has been in intermittent operation since 1925 (Martin, 2008). The property was purchased by Casmyn in 1995 and a series of capital and process upgrades have been carried out since that time. The processing flow sheet is straightforward with run-of-mine (ROM) material crushed and milled in one of two parallel ball mills circuits. This ground material is then sent to cyanide leaching. The gold is recovered from this leach circuit by carbon adsorption. Current mine production capacity is about 20,000 tonnes per month.

To augment gold production from the mine, Casmyn decided to install a new gold recovery circuit to reprocess historic tailings. Like the ROM plant, the tailings retreatment process is straightforward. The dump material is hydraulically mined and pumped to a trash removal screen. Water is added to control slurry density before the tailings are pumped to the VXPmill feed tank. The VXP2500 is operated in open circuit with the mill discharge pumped to a leach conditioning tank. Lime and cyanide are added and the overflow from the leach tank flows through a series of carbon absorption tanks.

In addition to fine grinding dump material, the feasibility study indicated that additional grinding of the main plant CIL tails could increase gold recovery. However, operation after startup showed that the additional gold recovered from the CIL tails was not economic. Therefore the decision was made to focus on regrinding only the reclaimed dump material. This provided the greatest economic benefit.

TEST PLAN DESCRIPTION

The optimization program for the VXP2500 was designed around several mill configurations and controllable operating parameters. These configuration and process parameters are:

- Disc diameter - three different disc diameters were used in the testing program.
- Feed flow rate - this was varied to change the residence time in the grinding zone.
- Disc tip speed - motor RPM was used to change the angular velocity of the discs
- Grinding media type - two different beads were used to vary media SG
- Media fill - different media types allow for different fill levels for the same power draw

The effect of disc diameter on grinding performance was examined by selecting three different disc sizes. The standard grinding disc diameter in the VXP2500 is 950mm. This research program also used 920mm and 890mm discs to determine the effect of adjusting the gap between the wall of the mill and the tip of the grinding disc. This change in diameter varied the gap size from 115 mm with the largest discs to 145 mm with the smallest discs. Since the grinding media size was approximately 3 mm during the optimization program, this varied the gap to media size ratio from 38:1 to 48:1. The complete change out of the twelve grinding discs required more time to complete than varying any other configuration variable. Since the optimization program was being carried out while the plant was in full operation, disruptions to production were minimized by running with each disc size for four continuous weeks. The discs were examined each week to monitor wear.

Unlike disc diameter, it was easy to vary the feed flow rate to the mill. The feed pump is equipped with a variable frequency drive and the regrind mill feed tank provided a buffer between the incoming flow of dump material and slurry flow to the mill. The flow rate to the mill was limited on the low end by the minimum flow required to fluidize the media bed. The upper flow rate was dictated by pump capacity and the potential for media to "float" to the top of the mill. Both of these limits are affected by the media specific gravity. The slurry flow rate was changed as required throughout the day as the test plan required.

One of the advantages of the VXPmill is that the main motor is equipped with a variable frequency drive that allows them to operate effectively across a wide speed range. This allows the mill speed to be changed to meet process conditions. In its standard configuration, the VXP2500 is operated at a disc tip speed of 12 m/s. In this optimization program the tip speed was varied between 10 and 13 m/s to determine the effect on grinding performance.

The final two parameters changed during the optimization program were related to the grinding media. The importance of grinding media selection on stirred mill performance is well documented in the literature so both the media type (density) and volume fill were varied in the optimization program. Two media types were selected for trialing: zirconium silicate (SG 4.1) and ceria stabilized zirconium (SG 6.1). These two media types were identified as "light" and "heavy" throughout the testing program. The media type was changed once a week throughout the testing program.

The media fill level was quantified as the percent fill of the net mill volume with the grinding assembly installed. In standard practice the normal fill level for the VXPmills is between 50 and 65%. The media type has an influence on the amount of grinding media that can be added to reach the design running torque of the VXP2500 (22,000 Nm). All other things considered equal, the light grinding media will have a lower torque at the same volume fill as the heavy media. This is reflected in the ranges of media fill that were examined in the testing program. A full charge volume of 65% was used for the light grinding media. At this volume fill the running torque remained below the maximum running torque for the mill. In contrast, operating with the heavy media required the full running torque at volume fill levels between 40% and 52% depending on other operating parameters. The actual running torque for both media types depended on the other operating parameters being examined (e.g. disc diameter and slurry flow rate). The mill was shut down each day to determine the current media fill level. This was easily done through the mill observation port at the top of the mill. A tape measure was used to determine the distance to media surface below a reference level. The volume fill could then be back calculated and additional media added as required.

After determining the configuration and process parameters for the optimization program, the actual test plan needed to be designed to provide meaningful results. The statistical software "Stat-Ease" was used to develop a test matrix that would make the most of a reasonable number of test conditions. This software was also used in the subsequent data analysis. The initial design was based on the Response Surface method. Because the tests are to be done in an industrial environment and for an operating plant, maintaining flexibility was a key requirement. Details of the experimental plan and actual test data and preliminary analysis of test results have been presented previously (Shah, Hines, Reddick, & Rahal, 2013). Data collection at each trial condition was standardized. For each test, the mill parameters were set to the desired settings and the process was allowed to stabilize for thirty minutes. Once the system stabilized, the mill feed and discharge were sampled four times at fifteen minute intervals. These individual samples were analyzed with the results averaged for statistical analysis. A Malvern Mastersizer was used for the size analysis.

CHALLENGES OF FIELD TRIALS

One of the underlying assumptions when planning a research program using the DOE is that all planned tests can be completed during the allotted time period. In the operating plant setting this does not allow for issues with feed supply, upstream and downstream limitation, power outages, and shortages in process water supply. In field studies, dealing with these events is never simple. It is often necessary to adapt the test plans to the real life situations while not giving up on the requirement for high quality test design. In the case of this field study, operating in Zimbabwe added logistical challenges and power supply issues that may not have been encountered in more fully developed regions. The VXP2500 testing program was conducted over a four month period. During that time there were changes in feed supply, availability issues with upstream and downstream equipment, spares delivery issues, and sporadic power loss on site.

One of the bigger challenges in interpreting the test data was to account for the change in feed size during the testing program. As the dump reclaiming process moved to different areas, the average feed size changed with time. This change increased the experimental error associated with determining the effect of disc diameter on mill performance. This effect could have been reduced by more frequent disc changes to "block" time in the experiment. Unfortunately this was not possible due to the previously noted limitation of needing to minimize the disruptions to plant production.

Another affect on the testing program caused by reprocessing the tailings was the change in slurry density with time. The feed slurry density was measured using a coriolis meter on the feed line. However there was no control system in place to manage changes in slurry density. The feed slurry density changed with the amount of water used to hydraulically transfer the dump material to the mill feed tank. This change was managed by delaying the testing program until the slurry density came back to within an acceptable range of the target slurry density of 1.35 kg/L. Delaying sampling until the slurry density was acceptable reduced the variability in feed conditions but it lead to delays in the actual testing program.

Other delays to the testing program included undefined support equipment limitations and location induced factors such as power and spares availability. The original test plan assumed that the full range of process equipment in the regrind plant would be available throughput the optimization program. In reality this was not the case. In several cases external equipment limited the flow rate to the mill or required premature mill shutdown during the grinding tests.

The final set of challenges associated with the project was related to the remote location of the Turk Mine. Practically all of the consumables and supplies that were needed during the research program had to be imported. Importing supplies and spares was complicated. Clearing these items through customs proved to be challenging and the time required to get these items to site was unpredictable. This long and uncertain lead time, combined with frequent power outages, had a significant impact on the project schedule on many occasions. These delays required continuous review and adaptation of the original test plan.

RESULTS

Despite the challenges faced, the VXP2500 optimization program produced a large amount of data that could be used to quantify mill performance under a range of operating conditions. These results allowed a statistical analysis to quantify the effect of both mill configuration and process conditions on size reduction and throughput. The effect of changing disc diameter, disc tip speed and media type (and fill) on production is described in the remainder of this section.

Disc Diameter

The change in feed size as different areas of the dump material were recovered caused a bias in the results for different disc sizes. The discs used later in the testing program had a coarser feed than those used at the start. This made it difficult to compare the discs in terms of specific energy required to achieve a fixed product size (e.g. 20 microns) when the feed size changed through the testing program. The change in the average feed size for different disc diameters is shown below in Table 2. As can be seen, the average feed size for the 950 mm discs is coarser than that of the other two disc sizes for the light media. This trend is reversed for the heavy media. It should be noted that the degree of change is much smaller for the feeds to the heavy media tests.

Table 2 - Feed size bias for light and heavy media testing of three disc sizes

	Light Media			Heavy Media		
Disc Diameter (mm)	Minimum F80 (µm)	Maximum F80 (µm)	Average F80 (µm)	Minimum F80 (µm)	Maximum F80 (µm)	Average F80 (µm)
890	45	101	67	48	114	76
920	45	106	74	47	106	72
950	88	147	114	41	107	62

Every attempt has been made to normalize the production data to account for this change in the data analysis. However this systematic change could have influenced the final results. Figure 1 displays the specific energy plot for grinding with the light grinding media with the three different disc sizes. In the graph, the results for both the 890 mm and 920 mm are similar. The specific energy consumption with the 950 mm is measurably worse.

It is believed that the performance of the 950 mm discs was affected by the coarser feed size. This is supported by the results of the heavy media trials shown in Figure 2. It can be seen that the specific energy consumption was similar for the three disc sizes when the coarser +110 micron (F80) data was filtered out of the graph. Additional work is under way to clarify the effect of actual feed size on shifts in specific energy consumption to achieve a fixed product size.

While the plots do not appear to provide a conclusive result, statistical modeling of the data set indicated that the smaller 890 and 920 mm discs are more efficient than the 950 mm discs. It is hoped that additional field work at a site in South Africa will provide more confidence in this conclusion. The advantage in this future study is that four mills will operate in parallel on the same feed stream. This will eliminate most of the experimental error associated with changing feed size.

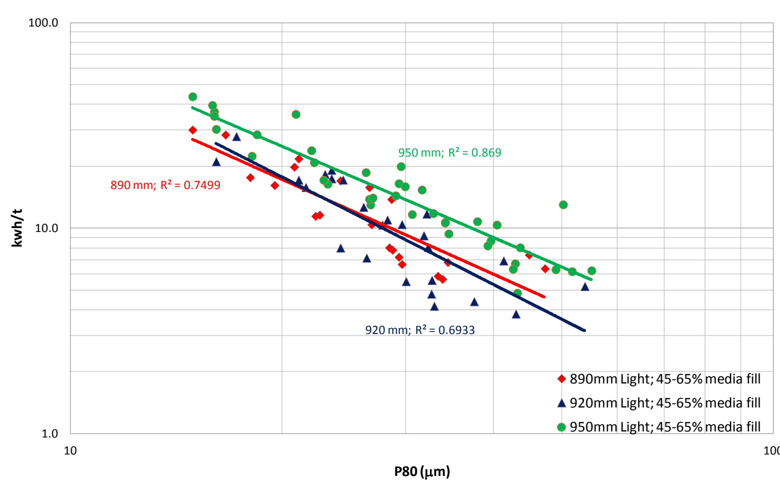

Figure 1 - kWh/t versus P80 for three disc sizes, light media.

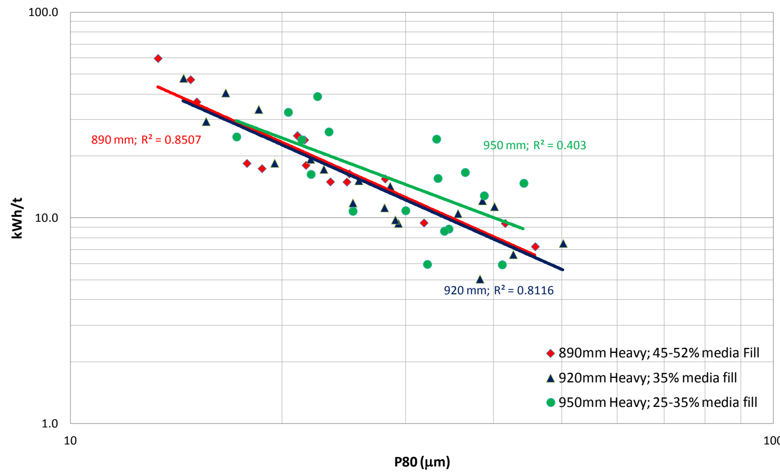

Figure 2 - kWh/t versus P80 for three disc sizes with dense media.

Grinding Disc Tip Speed

The grinding disc tip speed is related to the disc diameter when referenced as tip speed (m/s). The smaller discs require a higher motor RPM to achieve the same tip speed as a larger disc. This was dealt with in the testing program by ensuring that the RPM was adjusted such that all disc diameters operated at the reference tip speeds of 10, 12 and 13 m/s.

Figure 3 below shows the difference between the specific energy plot for the three different tip speeds (950 mm discs with a 55% light media fill). This graph was selected because it had the highest number of data points for a fixed set of conditions (disc diameter, media type, and media fill). Despite the separation between the tip speed lines shown for this test condition, there was no statistically significant difference in the three disc speeds when considering the data in its entirety (Figure 4). The heavy grinding media is not presented in this section because gaps in the field data prohibited the comparison of the three tip speeds.

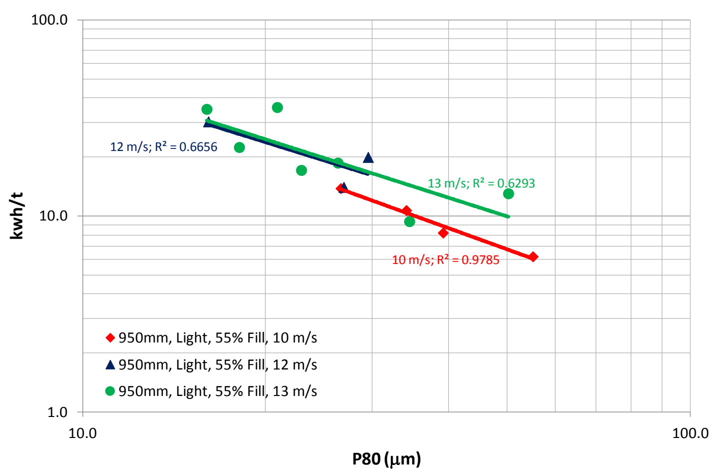

Figure 3 - kWh/t versus P80 for 950 mm discs, 55% light media fill.

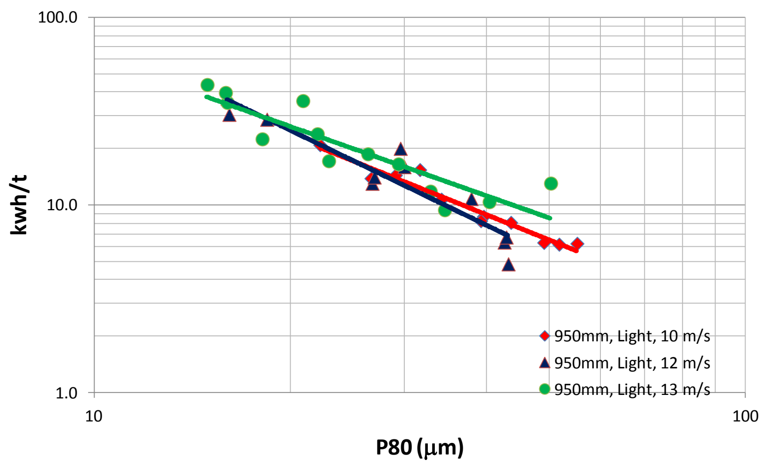

Figure 4 - kWh/t versus P80 for 950 mm discs, all light media fill.

Grinding Media

The effect of grinding media on mill efficiency was examined by comparing two media types (different densities) at several media fill levels. These tests were carried out over the full set of operating conditions (disc diameters, mill speeds, media fills and feed flow rate).

The choice of a light and a heavy media for the VXP2500 optimization was driven by the need to find the best compromise between power consumption and particle breakage rate. As an example, for equivalent mass fills of light and heavy media, the light media occupies more volume. This translates to a higher volume fill and more grinding media (potential breakage sites) within the mill. In some cases a higher power draw also occurs due to greater contact between the media and grinding assembly (Rahal, Roberts and Rivett, 2011). In contrast, the heavy media at the same mass fill will have fewer potential breakage sites. This is potentially offset by its providing a higher stress intensity for particle breakage (Jankovic, 2001). The goal was to determine if the greater number of potential breakage sites for the light media offset any advantage provided by the larger stress intensity of the heavy media. An important point to note here is that the maximum fill of heavy media was limited by the design running torque of the VXP2500. The results comparing the light and heavy grinding media (SG 4.1 and 6.1 respectively) can be seen below in Figure 5.

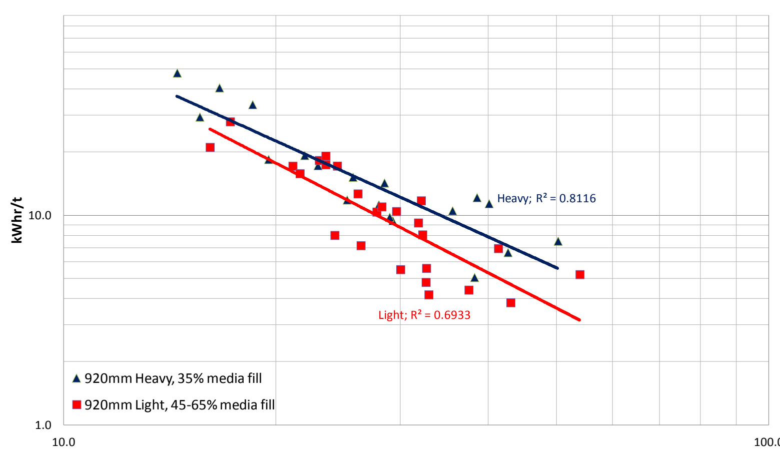

Figure 5 – kWh/t vs. P80 for two media types with 920 mm discs.

The graph above shows that the lighter grinding media used less specific energy (kWh/t) to achieve a target product size compared to the heavy media. For example, to achieve a product size of 20 microns (P80) the light media required 17.7 kWh/t while the heavy media consumed 22.6 kWh/t. This was an increase of 22% for the same product size. In this trial it appears that the greater stress intensity and power draw for the heavy grinding media did not translate to higher breakage rates.

While the light media appeared to be more power efficient, both media types have drawbacks. Neither provides a perfect solution for the Turk regrind. The strengths and weaknesses of each are:

- Light media (SG 4.1)
  - Unable to draw full power with a media load of 65%. This leaves some of the potential mill capacity "on the table".
  - Media float was observed at higher feed flow rates (65-80 m3/h depending on disc diameter). Unfortunately no sizing data was obtained when this occurred to determine whether or not there was a decrease in particle breakage.
  - The lighter media costs significantly less than the heavy media.
- Heavy media (SG 6.1)
  - Reaches the design running torque for the VXP2500 at a lower media fill. This reduces the total number of potential breakage size sites in the mill.
  - Greater media stress intensity did not appear to translate to more particle breakage.
  - Is able to draw the full design power.
  - Resists media float to a higher relative density to the slurry.

The effect of media type on power draw for both grinding media is closely associated with the media fill levels that can be achieved with each. During the optimization program the media fill varied from 45 % to 65% for light media and 25% - 52% for heavy media. For the light media, the range of media fill value was based on the experimental design. There was no limit imposed by running torque. The running torque was lower than the motor design torque so additional media could have been added to the mill. In contrast, the heavy media was added to the mill until the running torque was achieved. The variation in media fill in this case was influenced by the slurry feed flow rate. More heavy media could be added for the same running torque at higher flow rates.

The results of grinding with light media at two different fill levels are shown in Figures 6 and 7. The first graph shows that there is no significant difference in the specific energy consumption based on the media fill. The benefit of using more media in the mill with the 890 mm discs is that the increased number of breakage sites allows for a higher total throughput (Figure 7).

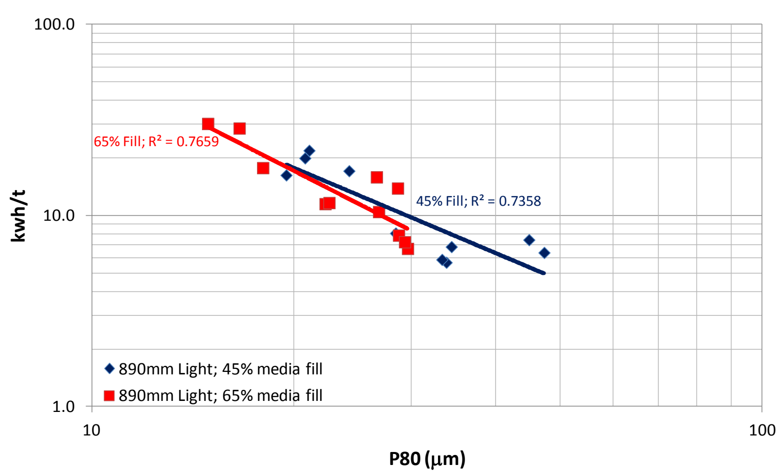

Figure 6 – kWh/t vs. P80 for two media fill levels (890 mm disc).

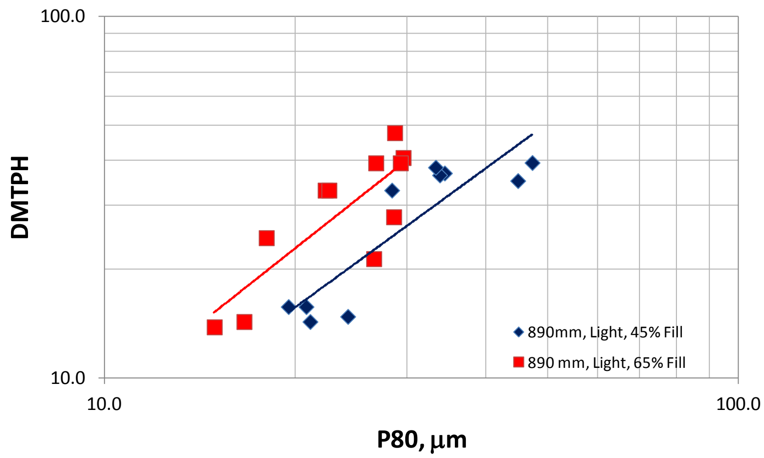

Figure 7 – Production vs. P80 for two media fill levels (890 mm disc).

CONCLUSION

The VXP2500 optimization program at Turk Mine produced a large amount of performance data. The challenges faced during the program prohibited the use of a full statistical analysis. This meant that the results were predominantly focused on the more complete data set, the light grinding media.

Statistical modeling showed that changing the disc diameter had an effect on grinding performance. The smaller discs (890 and 920 mm) provided a slight improvement in the kWh/t required to achieve a given product size compared to the 950 mm discs. This trend warrants additional field research because changing feed size may have influenced the results. In addition to disc diameter, the research program investigated the effect of tip speed on grinding performance. There was no significant difference in the tested range of 10 m/s to 13 m/s.

The amount and type of media used in a stirred mill had a significant effect on grinding performance. The optimization program compared the performance of a light and heavy grinding media (SG 4.1 and 6.1 respectively). It was found that the light media was more efficient in terms of kWh/t required for a given product size. However, the full mill power was not utilized even with a full media load. In contrast, the heavy media provided the full running torque (power) at a lower volume fill. The net outcome in this case was that the greater power utilization was offset by few potential breakage sites in the mill. The shortcomings of the light and heavy media indicate that an intermediate bead density (SG 5-5.3) may provide a better solution for this application. It may allow a larger volume fill and full power utilization.

The results obtained during the research program provided a new set of operating parameters for the Turk VXP2500. The recommendations for changes to the standard operating procedure for regrinding the dump material are:

- Disc Diameter – decrease the standard disc diameter from 950 to 920 mm
- Disc Tip Speed – decrease the operating tip speed from 12 to 10 m/s
- Grinding Media – use light grinding media at the maximum media load

These recommendations have resulted in lower operating costs and a higher throughput.

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