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Investigation of Hydrocyclone Modernization in Küre Copper Ore Regrinding Circuit and Its Effect on Grinding Performance

M. Temucin Uysal, M.Sc.[1], Fatih Enisoglu[2], Yasar Kara[3]
Eti Bakir A.Ş.
Küre, Kastamonu, Türkiye
[1]Chief Process Engineer
mustafatemucin.uysal@etibakir.com.tr
[2]Plant Manager
fatih.enisoglu@etibakir.com.tr
[3]Operations Manager
yasar.kara@cengiz.com.tr

Abstract **-** After the capacity increase and modernization of the Küre mineral processing plant, the reduction of the particle size led to uncontrollable change in system parameters (pressure, cut size) depending on the grade changes in large diameter hydrocyclones in the re-grinding circuit. Therewithal, the advantages of new generation equipment, which are modernized with developing technologies instead of equipment used in old plants, are important in preventing metallurgical losses. Modern hydrocyclones, can separate more successfully in finer grain sizes. In addition, the need for finer grain size liberalization arises as the grade of the processed ores tends to decrease and the copper minerals in the processed ores have a more complex structure. In this study, samples were taken from ball mill and hydrocyclone unit to determine particle size distribution, hydrocyclone performance, mill performance and mass balance. According to the results obtained from the study, it was decided to modernize the hydrocyclone unit. After the hydrocyclone modernization, simulation studies conducted for different operating conditions to obtain maximum recovery. In the simulation scenarios, apex, hydrocyclone feed percent solids, mill percent solids, hydrocyclone feed pressure parameters were changed to determine optimum conditions and maximize recovery. In conclusion, circuit parameters can be controlled efficiently with lower diameter hydrocyclones. However, higher efficiency has been achieved with the increase in the grinding rate of the closed-circuit ball mill which results in sharper separation of the modernized hydrocyclone unit.

Keywords**:** Copper, Regrinding, Hydrocyclone, Plant Modernization

1. Introduction

The purpose of the grinding process is to provide sufficient liberation and prepare the processed ore for the next enrichment process [1]. Although newly established plants often use the latest grinding technologies, traditional grinding combinations such as rod-ball mill combination or ball-ball mill grinding are more common in plants that have been operating for a long time. Grains that do not reach the desired particle size in traditional grinding are required to be classified with right equipment and subjected to re-grinding in order to gain desired enrichment. Essentially, it is wanted to be sure that once a particle has been ground to desired liberation size, it is effectively removed from the milling process as soon as possible by a classification method [2].

The equipment to be used in this classification process varies depending on the particle size, the type of ore and enrichment process. The main equipments used in classification are screens, spiral classifiers, hydraulic classifiers (jigs), cyclones and hydrocyclones. In coarse particle sizes, screens are found to be improved separation efficiency and throughput by some researchers [3]. In traditional wet grinding circuits, closed circuit grinding and hydrocyclones are generally used for the classification process [4]. Following are the main parameters to be followed in operation of these hydrocyclones:

a) Cyclone feeding diameter
b) Apex and vortex diameters
c) Cyclone pressure
d) Cyclone feeding density

The variability of plant copper feed grade makes it difficult to control the above-mentioned parameters in the regrind circuit. When ore grade is below 2% copper, which is the annual average plant feed copper grade and tends to decrease [5], the equipment operating in 250 mm hydrocyclones in the circuit is reduced to one operating hydrocyclone. This causes uncontrollable variable conditions to remain far from the desired level in hydrocyclone separation performance. Based on the sampling studies, it was concluded that the 250 mm diameter hydrocyclones in the circuit could not adapt to suitable operating conditions due to variable parameters and an efficient grinding-classification process could not be achieved.

Within the scope of this study, the results of simulation and sampling studies are presented which carried out at Eti Bakir AŞ Küre Plant, which has been operating since 1987 in Turkey. In the plant, chalcopyrite, and pyrite minerals are ground and classified and the concentrate taken from the coarse flotation circuit is subjected to re-grinding-classification in order to increase liberation, are presented. It should be emphasized that the data obtained within the scope of this study is facility-wide and the findings are based on real data. Firstly, while the existing 250 mm diameter regrinding circuit within the facility was operating, samples of ore structure and grade values were carried out at different times. The properties of these samples were investigated by particle size distribution, density and chemical analysis in the Küre ore preparation laboratory. Following these analyses, material balance calculations were made to determine hydrocyclone performance, mill performance and hydrocyclone adequacy. The solution scenario produced after the calculations and the findings; The current hydrocyclones that can't tolerate the changing feed grade were switched to small diameter hydrocyclones and the parameters (working pressure, density, etc.) will be kept under control. It is thought that discussing and presenting the results obtained in this plant-based study will show a possible solution to facilities experiencing the same problem and will also contribute to the academy.

2. Materials And Methods

2.1 Küre Regrinding Circuit

The ore processed at Eti Bakir AŞ Küre Enterprise Ore Processing Plant contains high amounts of sulfur minerals. The ore contains chalcopyrite, pyrite and sphalerite as main minerals, and quartz, chlorite, siderite, and muscovite as gangue minerals.

The ore extracted from the underground mine is passed through the first crusher in underground and transported to the stock area. The ore is passing through secondary and tertiary crushers in the fine crushing unit is ground with a rod-ball mill combination, particle size separation is made with a hydrocyclone and sent to the copper flotation circuit. In the copper flotation circuit, 3 stages of rougher flotation are performed. The first concentrate taken in the rougher copper flotation circuit is sent directly to the final concentrate thickener with 18% copper content, mostly consisting of liberated grains, and the concentrates of the second and third rougher flotation circuits are sent to the regrinding circuit to ensure liberation. The regrinding circuit consists of 1 rubber-lined ball mill and hydrocyclone unit operating in a closed circuit. Technical information of the mill is given in Table 1, and technical information of the hydrocyclone unit is given in Table 2.

Table 1. Mill technical information

Feature	Ball Mill
Diameter (m)	2.7
Length (m)	4.5
Ins. Power (kW)	450
Critical Speed (d/dk)	21 (81%)
Ball Diameter (mm)	15
Liner Type	Rubber

Table 2. Hydrocyclone unit technical information

Feature	Hydrocyclone unit
Diameter (mm)	250
Amount	8
Apex	40
Vortex	65
Feed Pressure (bar)	0.5-1.5

In the closed-circuit regrinding system, grains that reach the desired particle size (-20 µm) are sent to the copper cleaning circuit via the hydrocyclone overflow. The ore, which is subjected to 4 stages of cleaning and sent to the final concentrate thickener with 17.5-18% copper content. The regrinding flow chart is given in Figure 1.

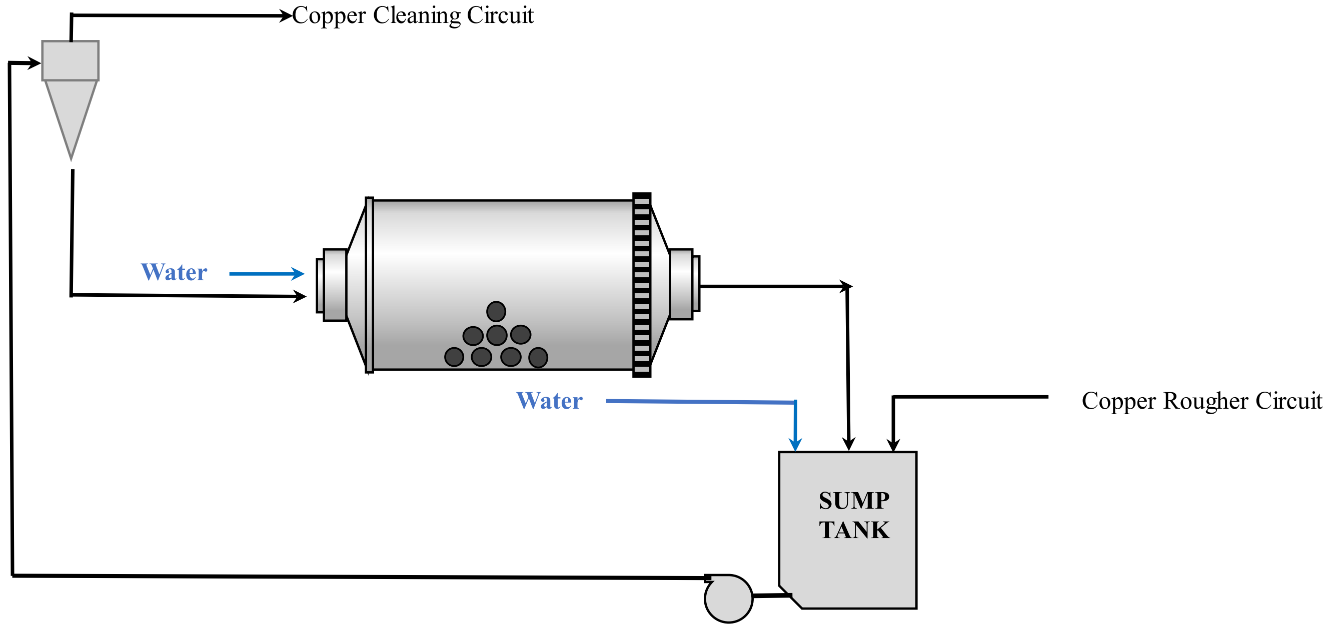

Figure 1. Regrind circuit flow diagram

2.2 Experimental Studies

In order to examine the operating conditions of the current system under normal conditions, samples were taken from the required points on the circuit. Experimental studies carried out to determine particle size distribution, percent solids and density analyses for each sample. The samples were dried and separated by quartile method until sufficient material was obtained, and grain size analysis was performed using the Retsch brand sieve analysis device. Since the sieving efficiency in the Retsch brand shaking sieve analysis device decreases below 20 micron size, the lowest analysis was performed up to the mentioned grain size. All tests were carried out in the Eti Bakir Küre Mine ore preparation laboratory.

3. Results And Discussion

3.1 250 mm Hydrocyclone Sampling and Performance

Sampling studies were carried out to analyse the circuit performance in the regrind circuit. The substance equivalence obtained in the study conducted on 250 mm hydrocyclones is given in Figure 2, and the average values of the hydrocyclone parameters are given in Table 3.

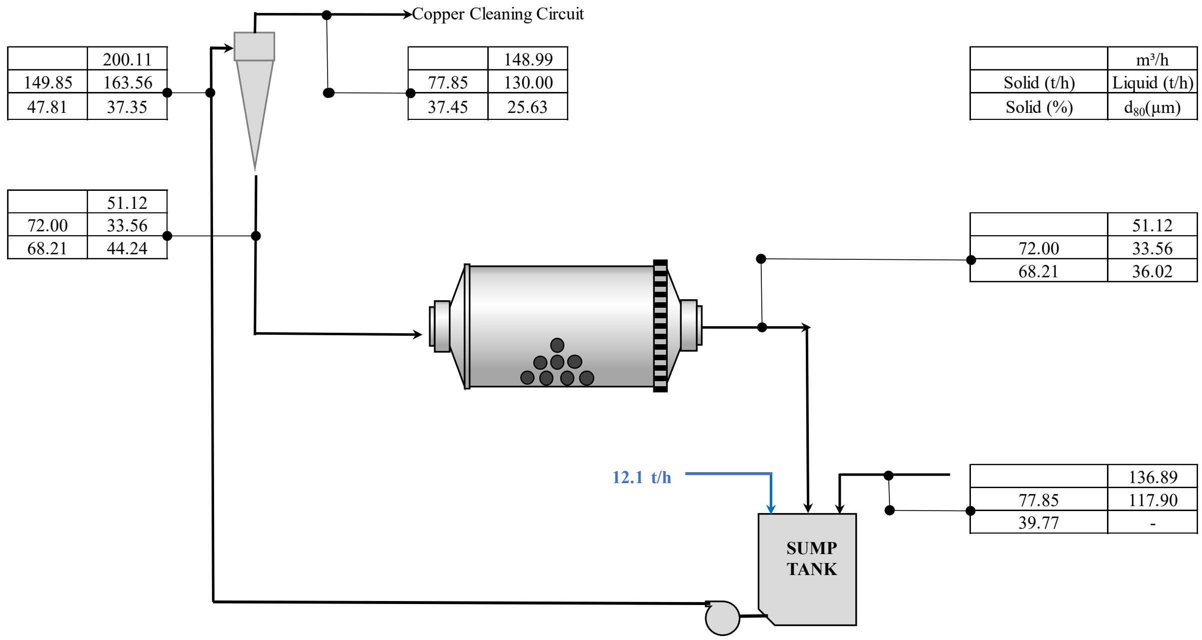

Figure 2. 250 mm hydrocyclone circuit sampling

It is understood from the l_n and l_d values that hydrocyclones cannot make a sharp separation in the averages of sampling studies. At the same time, the high bypass value causes the ore to be over-grinded and escape into the slime during separation. It has been observed that slime coatings have negative effects on flotation [6].

In 250 mm hydrocyclones, the upper stream solid density is high, and the lower stream solid density is lower than expected, causing the solid concentration of the mill not to increased. This prevents efforts to improve grinding performance.

The average number of working hydrocyclones was 3 in the sampling. When a cyclone is closed due to the pulp volume, the cyclone pressure reaches 1.5 bars. This causes the faster wear of the equipment, and the desired separation cannot be achieved. When the copper grade processed in the facility drops below 2%, the number of operating hydrocyclones decreases to 1. According to the simulation made after this problem was identified, it was simulated that the hydrocyclones to be used in the current circuit would provide better separation with a diameter of 150 mm.

Table 3. 250 mm cyclone sampling averages

Hydrocyclone Dia. (mm)	**250**
Feed (p80)	31,36
Underflow (p80)	39,46
Mill Discharge (p80)	35,21
Upperflow (%-20 µm)	81,02
Feed (% Solid)	47,28
Upperflow (% Solid)	40,12
Underflow (% Solid)	64,18
Hydrocyclone Pressure (Bar)	1,04
Grinding Ratio	1,12
Circulating Load (%)	91,99
Bypass (%)	32,46
Imperfection$_{normal}$	0,58
Imperfection$_{Corrected}$	0,43
d25	20,62
d50	27,10
d75	43,78
Working Hydrocyclone	3

3.2 150 mm Hydrocyclone Selection and Performance Analysis

Following plant-based sampling, it has been seen in the sampling simulations that when the cyclone diameter is reduced in the mass balance circuit, the circuit parameters can be controlled more easily, the cutting size can be reduced, the regrinding mill can be operated more efficiently and grinding in finer grain sizes can be achieved. The simulated version of the samples is given in Figure 3.

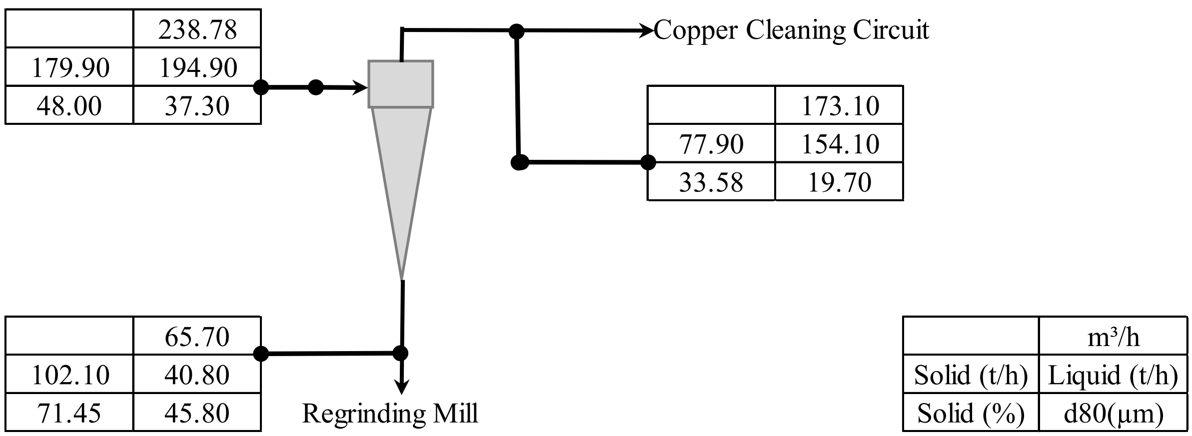

Figure 3. 150 mm hydrocyclone simulation

Table 4. Sampling averages at 17-20-25 mm apex diameters

Hydrocyclone Dia. (mm)	150			250
Apex Dia. (mm)	**17**	**20**	**25**	**40**
Feed (p80)	32,35	31,60	33,68	31,36
Underflow (p80)	52,90	45,69	42,41	39,46
Mill Discharge (p80)	32,03	30,47	34,78	35,21
Upperflow (%-20µm)	80,53	87,75	83,69	81,02
Feed (% Solid)	45,34	46,22	51,31	47,28
Upperflow (% Solid)	38,87	36,91	37,05	40,12
Underflow (% Solid)	78,35	75,71	70,78	64,18
Hydrocyclone Pressure (Bar)	1,20	1,20	1,26	1,04
Grinding Ratio	1,66	1,52	1,22	1,12
Circulating Ratio (%)	44,97	65,50	150,66	91,99
Bypass (%)	12,00	19,08	37,45	32,46
$Imperfection_{normal}$	0,38	0,33	0,43	0,58
$Imperfection_{Corrected}$	0,33	0,29	0,26	0,43
d25	22,45	19,60	18,89	20,62
d50	31,12	25,14	23,64	27,10
d75	43,10	34,45	31,36	43,78

Hydrocyclone simulation has shown that 150 mm hydrocyclones can work more efficiently. At the same time, the number of hydrocyclones increased from 8 to 16 will ensure operation under constant operating conditions by keeping the pressure constant during grade changes. Lower apex and vortex sizes will play a role in reducing the cutting size. The lowest vortex size that the hydrocyclone manufacturer can provide is 35 mm. For this reason, in this study, the vortex diameter was kept constant considering the cutting length and apexes of 3 different sizes (17-20-25 mm) were tested. Trial samplings were carried out with on-off work at different times, and it was aimed to minimize the effect of the variability of the ore mineralogical structure with a total of 22 samples. Table 4 shows the averages of samples made at different apex sizes.

Each size has advantages and disadvantages in sampling at different apex diameters, made by keeping the vortex diameter constant. For example, Although the mill comminution rate is highest at the apex size of 17 mm, the mill circulating load is the lowest. The mill operates inefficiently because not enough ore can be fed to the mill. Bypass represents the amount of material leaving the hydrocyclone bottom stream without being subjected to classification [7]. Thus, with the low bypass ratio, it has been observed that both solid-liquid separation and grain separation are more efficient than previous hydrocyclones. When we look at the hydrocyclone upper flow values, it remained at 81% level of -20 µm, which is almost the same value as the 40 mm apex size. For this reason, the 17 mm apex size was not preferred.

Looking at the 25 mm apex measurement values, it was seen that the circulating load increased to 150%, but the grinding rate remained at 1.22. It was observed that the bypass rate was around 37% and the cutting size decreased. Although it can be seen from the in value that the sharpest separation is made in this size in the corrected curve of the separation, 25 mm apex diameter was not preferred when the low mill grinding rate was evaluated in terms of performance efficiency.

20 mm apex size gave the best results in simulations. Parallel results were observed in the samples, with the highest upper flow measured at -20 µm 88%. This shows that the best liberation is achieved for flotation. In terms of separation-grinding performance efficiency, these experiments and operations were continued with 20 mm apex size and analysis of other parameters was started. First, working pressure was discussed, sampling results are given in Table 5.

Table 5. 150 mm hydrocyclone pressure sampling

Apex Diameter (mm)	**20**			
Hydrocyclone Pressure (bar)	1,10	1,20	1,30	1,40
Feed (p80)	32,89	37,80	29,39	32,57
Underflow (p80)	46,10	45,72	46,59	45,82
Mill Discharge (p80)	30,21	34,24	30,32	35,07
Upperflow (%-20µm)	87,66	87,40	92,88	81,04
Feed (% Solid)	45,28	42,74	46,57	50,45
Upperflow (% Solid)	35,19	32,47	38,40	39,40
Underflow (% Solid)	73,91	77,54	74,32	77,55
Mill Grinding Rate	1,53	1,34	1,54	1,31
Circulating Load (%)	77,23	84,08	64,07	64,05
Bypass (%)	21,15	21,33	20,39	19,66
$\text{Imperfection}_{\text{normal}}$	0,33	0,29	0,28	0,43
$\text{Imperfection}_{\text{Corrected}}$	0,30	0,27	0,24	0,34
d25	19,21	19,04	18,80	20,80
d50	24,28	23,94	23,45	27,45
d75	33,75	31,86	29,94	39,67

Pressure analysis studies were carried out between 1.10-1.40 bar. Values obtained in studies other than these values were not included in the evaluation because they were far from the desired results. During the sampling process, since experiments were not carried out in ideal environments such as laboratory conditions, sampling was tried to be carried out in as stable conditions as possible. However, since plant conditions were variable, all other values could not be kept constant while measuring one parameter. The sharpest distinction in the hydrocyclone pressure sampling results was between 1.20-1.30 bar, as can be seen from the I_n and I_d values. Subsequent experiments and operation were continued in this pressure range. Another important parameter, cyclone feed solid density, has an important place in separation performance. (ref). Feed density evaluation is given in Table 6.

Table 6. 150 mm hydrocyclone feed percent solid sampling

Feed (% Solid)	40,00	45,00	50,00
Feed (p80)	35,88	30,49	30,13
Underflow (p80)	47,38	45,91	43,46
Mill Discharge (p80)	31,92	30,26	29,56
Upperflow (%-20 µm)	87,55	88,36	86,44
Upperflow (% Solid)	32,78	37,74	38,96
Underflow (% Solid)	78,18	75,45	73,89
Grinding Ratio	1,48	1,52	1,47
Circulating (%)	74,67	61,43	66,50
Bypass (%)	18,16	18,35	21,82
$Imperfection_{normal}$	0,30	0,33	0,37
$Imperfection_{Corrected}$	0,28	0,29	0,31
d25	19,12	19,68	19,89
d50	24,10	25,37	25,62
d75	32,78	34,59	35,75

Sampling was done at operationally possible 40-45-50% solids values. It has been observed that as the feed solid ratio increases, the bypass increases, the cut size increases, and the separation performance decreases. While evaluating the feed solid density, it was decided to work at 40%, which is the sharper discrimination value. All operating parameters of the hydrocyclone were reviewed and optimum conditions were selected. Following the hydrocyclone performance, density tests were carried out at 3 different solid ratios to improve the grinding performance. During these experiments, the ball charge filling ratio was kept constant at 37% in the mill.

Table 7. Mill percent solids sampling

Mill Feed (% Solid)	70,00	75,00	80,00
Feed (p80)	29,75	28,60	33,55
Underflow (p80)	42,13	44,44	47,62
Mill Discharge (p80)	27,43	27,24	32,98
Upperflow (%-20µm)	89,73	91,16	85,60
Upperflow (% Solid)	47,35	46,17	45,79
Feed (% Solid)	37,91	37,86	36,13
Grinding Ratio	1,55	1,65	1,45
Circulating Load (%)	79,08	56,77	63,56
Bypass (%)	25,65	18,34	16,74
Imperfection$_{normal}$	0,32	0,32	0,35
Imperfection$_{Corrected}$	0,29	0,28	0,30
d25	19,10	19,22	19,96
d50	24,05	24,30	25,92
d75	32,82	32,80	35,76

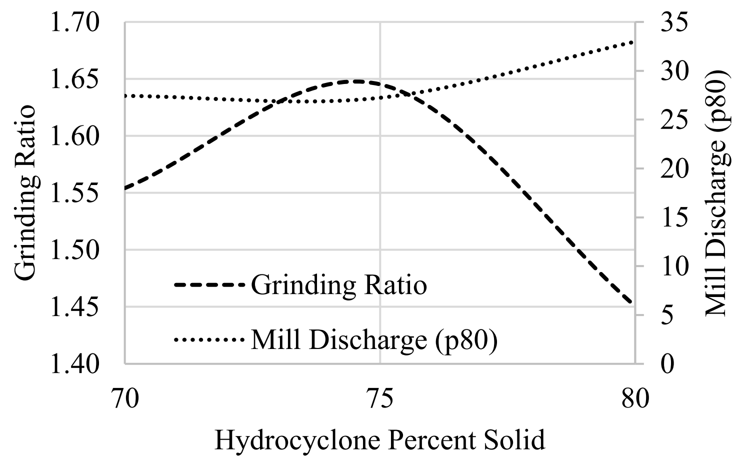

Figure 4. Mill percent solids chart

As can be seen in Table 7 and Figure 4, in the samples made with 3 different percent solids, 75% gave the best grinding performance and the highest upper flow value, which is 91,16% (-20µm). 60% and 65% mill feed solids ratios were also studied, but at these values, the mill comminution ratio could not exceed 1.3.

4. Conclusion

Hydrocyclones are essential equipment used in closed circuit grinding circuits. Selection of the correct hydrocyclone diameter and operating parameters directly affects circuit performance and grinding size. It is also one of the first points to be addressed for plants that want to increase capacity [8].

Reducing the diameter of the hydrocyclone used in this study reduced the cut size, resulted a better solid-liquid separation by reducing the bypass ratio, enabled ore to be fed to the mill at a higher solid rate, increased the mill comminution

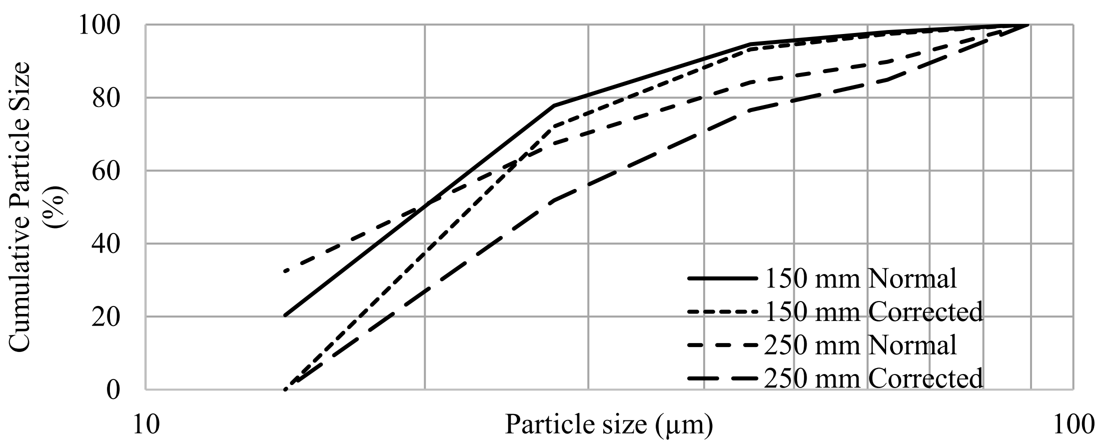

Figure 5. Hydrocyclone partition curves

rate, contributed to the liberalization by reducing the upper stream grain size and resulted in plant grade changes. It has paved the way for stable operation at the desired pressure.

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