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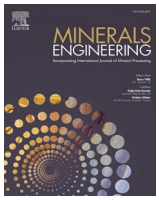

Investigation of Seasonal Variations in Glencore's Kidd Creek Cu-Zn ore flotation

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ABSTRACT

Water management in mining and mineral processing operations is becoming increasingly important in the 21st century due to water scarcity concerns and as part of a greater push for sustainability. The aim of this study is to investigate the impacts of seasonal water quality in the Glencore's Kidd Creek copper-zinc concentrator in Timmins, Ontario, Canada.

Mineralogy results indicate that the Kidd ore consists primarily of pyrite (22%) and quartz (22%), followed by pyrrhotite (9%), sphalerite (8%) and chalcopyrite (7%).

Investigating the flotation of Kidd Creek ore at bench scale between March 2022 and February 2023 identified seasonal trends in both copper and zinc flotation. However, post hoc analysis could not identify which months were significant. Oxidation of the ore samples or the use of process water could have contributed to an increase in sphalerite floated to the copper concentrate by 20 to 30% in summer months. Sphalerite surfaces in July have higher intensities of copper and collector species resulting in higher zinc recovery in the copper concentrate. Species in the process water and on the mineral surfaces may partially explain the differences in performance between the spring and the summer months.

1. Introduction

Seasonal variations in mineral processing are described as a variation in metallurgical results throughout a year in a concentrator brought on by either weather and/or water quality changes (Pashkevich et al., 2022). Despite being recognized as an issue for many decades, relatively few records exist in the scientific literature about seasonal variations. In a recent comprehensive review article, Pashkevich et al. (2022) summarized known seasonal variations and temperature effects in froth flotation based on ore type. In this article, climatic events are identified as the main initiator for water quality and temperature changes, which trigger grade, recovery, or selectivity issues in concentrators globally. Sulphide flotation is more resistant to changes in temperature, but water quality is a critical parameter in these operations. Seasonal variations not only affect flotation, but also settling, grinding, and size separation (Ji et al., 2013; Lin, 1989; Pashkevich et al., 2022). Rao & Finch (1989) summarized the negative effects on selectivity and recovery when using recycle water in sulphide flotation as residual xanthate and decomposition products which adsorb unselectively on sulphide minerals, residual sulphides which depress sulphide mineral flotation, metal ions which cause inadvertent activation, and alkaline earth metal ions that can either activate or depress gangue minerals. Complex sulphide ores are particularly sensitive to process water quality changes (Broman, 1980).

The flotation of copper-nickel-platinum group metal (Cu-Ni-PGM) sulphide ore at the Boliden Kevitsa concentrator in Finland has been previously documented (Muzinda & Schreithofer, 2018). In particular, the dilution of process water in spring causes a decrease in conductivity in process water. As a result, nickel reporting to the copper concentrate increases from 4% in the summer to almost 9% in the spring (Le et al., 2020).

At the Matagami concentrator in Quebec, Canada there is a 2.5% decrease in the zinc concentrate grade caused by smaller bubble sizes and increased surface area flux in the winter (Nesset et al., 2005). Similarly, operators at the Brunswick Mine complex sulphide ore concentrator noticed a 0.1% decrease in the zinc concentrate recovery when the temperature dropped below 35 °C (Roberts et al., 2008). In Portugal, there is a reported trend in terms of sphalerite recovery in the

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summer at the Neves-Corvo plant (Fernandes, 2016). It was found that sphalerite recovery decreased from 70% to 30% when the temperature of the pulp increased from 30 °C to 60 °C. Historically, at the Prieska Copper Mines concentrator in South Africa, temperature linked flotation kinetic changes resulted in an increase in sphalerite kinetics as compared to chalcopyrite in the summer months, leading to zinc losses in the copper concentrate.

Selectivity issues are encountered at the Clarabelle mill in Sudbury, Canada (Xu & Wilson, 2000). Pentlandite selectivity decreases and nickel recovery drops by 2%, potentially from dissolved nickel ions in the process. An earlier study by Kelebek et al. (1996), reported that the copper-nickel separation in the column flotation circuits was adversely affected in the winter months as compared to the summer months. Significantly less nickel impurity was recovered in the final copper concentrate in the summer months, where the slurry temperatures during a typical summer month and a winter month may differ by as much as 25 °C. The kinetics of surface reactions involving reagents and sulphide mineral particles were accelerated and the decomposition rate of residual collectors was faster in the summer.

Gold losses in the copper concentrate in winter have been reported at the Hudson Bay Mining and Smelting mill (Levanaho et al., 2005). The gold recovery in the copper concentrate decreases in summer by up to 30%, in contrast to a baseline recovery of 60%.

Kidd Creek is a copper-zinc mine in Timmins, Ontario, Canada. The main valuable minerals are chalcopyrite and sphalerite with a minor amount of galena and a substantial amount of silver (45 g/t). The average composition of Kidd Creek ore is 1.75% copper, 12% iron, 3.7% zinc, and 0.1% lead. There are considerable amounts of pyrite as a sulphide gangue in the ore, and the main non-sulphide gangue mineral is quartz. The ore is shipped approximately 40 km from the mine to the concentrator (Kidd Operations), where it is processed without blending. Process water, which is recycled from the tailings thickener overflow, and raw river water are used in the concentrator. Process water is the main water resource, whereas the purpose of river water is as a secondary resource in the case of equipment malfunctions or other unexpected events. Batch flotation of Kidd Creek ore using real process water has been studied previously (Liu et al., 1993). Process water was beneficial to copper flotation performance due to elevated concentrations of $S_2O_3^{2-}$ and Ca^{2+} ions. Copper rougher grade and recovery both increased by 2% and pyrite-chalcopyrite selectivity was reduced by 10%, respectively when process water was used for flotation compared to distilled water. Figure 1 shows the B Division grinding and copper and zinc flotation circuits from Canadian Milling Practices (Taylor et al., 2020).

The ore is ground in two stages comprising a rod mill and ball mill combination producing a cyclone overflow with an 80% passing particle size (P_{80}) of 100 μm, which is further ground in a secondary ball mill circuit to a P_{80} of 44 μm (Taylor et al., 2020). The reagents used in the copper circuit are lime which is added to the rod mill to obtain a pH of 10.5 in the copper circuit, 3418A and R208 as collectors, and methyl isobutyl carbinol (MIBC) as a frother. The sphalerite is first activated by $CuSO_4$ addition in the zinc circuit, followed by the xanthate collector and the F160-10 frother. The pH is adjusted using lime to 11.5 in the zinc flotation circuit.

Operators and engineers at Kidd Operations have noticed poor metallurgical results impacting both the copper and the zinc circuits in the spring months of operation. The monthly copper recovery between 2017 and 2020 at Kidd Creek is shown in Figure 2.

Evidently, there is a seasonal trend in the metallurgical results, leading to a loss of valuable minerals recovered in the process starting in the spring months of March or April. The cause for the seasonal performance issue at Kidd may be the formation of an ice cap on the tailings pond, which is the location of the process water recycle. When this ice cap melts, the process water characteristics are affected by dilution, which causes processing problems. It could also be that the rate of

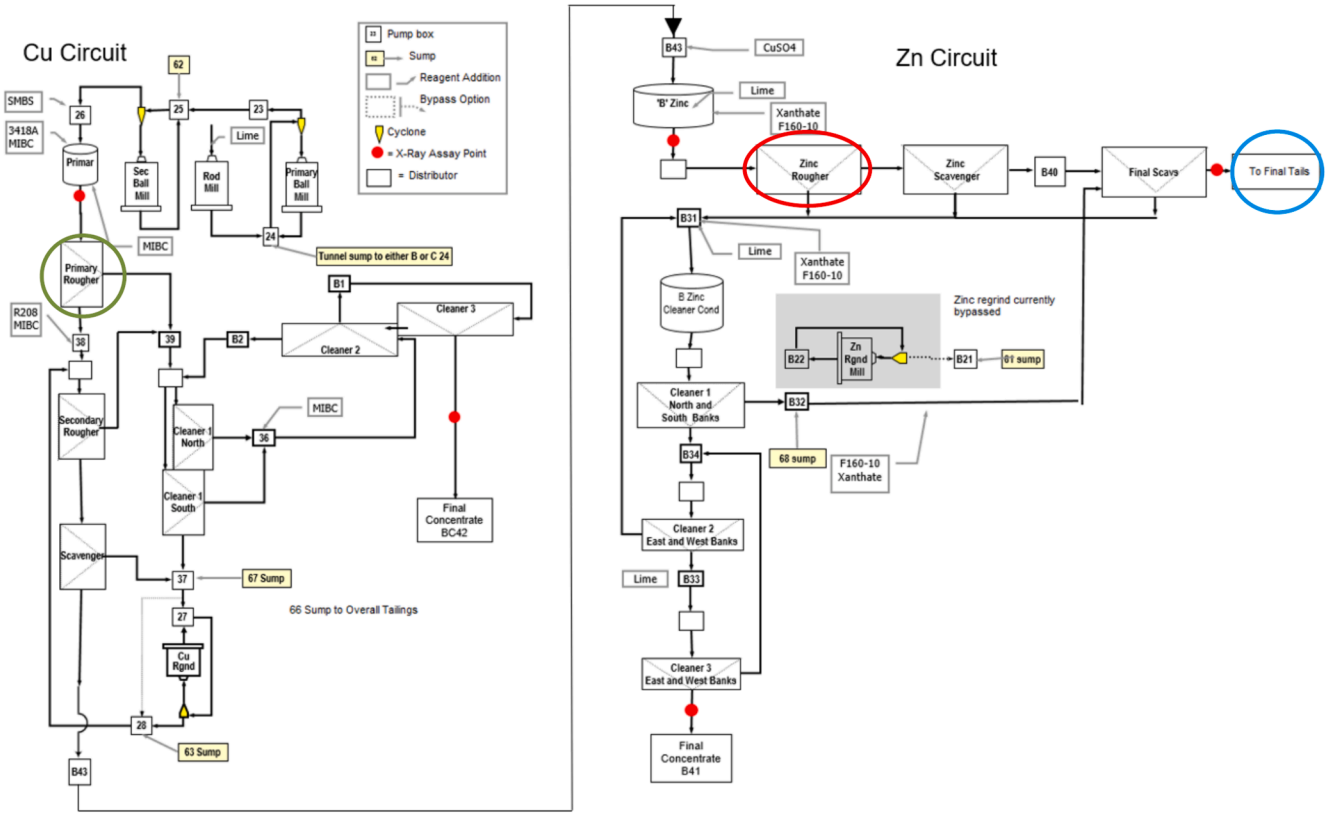

Figure 1. Kidd Creek B Division grinding, copper and zinc flotation circuits. Green indicates the copper rougher, red indicates the zinc rougher, and blue indicates the approximate location of the process water recycle). Reprinted with permission of the Canadian Institute of Mining, Metallurgy and Petroleum.
source. Figure from "Glencore - The Kidd Concentrator" in Canadian Milling Practice 2020 (Taylor et al. 2020)

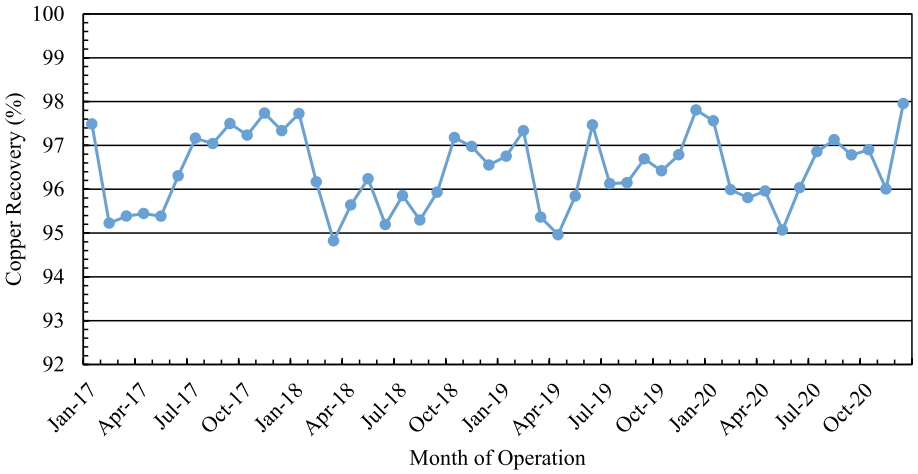

Figure 2. Copper concentrate recovery in the Kidd concentrator from 2017 to 2020. Average monthly copper recovery in the copper concentrate is calculated based on daily metallurgical balances and plotted from January 2017 to December 2020.

decomposition of the residual reagents in the tailings pond is lower in the winter months due to the relatively colder outside temperatures and a decrease in ultraviolet (UV) exposure, resulting in a concentration of organic and inorganic flotation chemicals the process. This phenomenon is experienced at the Boliden Kevita copper-nickel concentrator, where freshwater is trapped in an ice cap in the tailings water, which concentrates the process water. As the ice cap melts, the process water is diluted, which leads to a decrease in conductivity and dissolved species concentrations and an increase in nickel reporting to the copper concentrate (Le et al., 2020).

Given the aforementioned phenomena, this study aims to use real process water for the flotation of Kidd Creek ore in simulated copper and zinc roughers (locations shown in blue, green, and red in Figure 1, respectively). The flotation of a complex copper-zinc sulphide ore has been investigated at bench scale over a year of operation using real process water and ore from Kidd Creek Operations. The temperature of the slurry directly before entering the flotation circuit at Kidd Creek Operations was used (sump number 62 from Figure 1). Statistical analyses as per Di Feo et al. (2021), along with mineralogical and surface analyses tools were applied in this study to better understand the complex sulphide flotation system of the Kidd Creek ore.

2. Materials and Methods

Process water was sampled starting in March 2022 and ending in February 2023 at Kidd Operations, in Timmins, Ontario, Canada. In the plant, process water is recycled from a settling pond which is fed by the tailings thickener overflow. Every month, approximately 100 liters of process water were sampled from a wash water station in the circuit. The pH and the temperature of the water were recorded, and the samples were frozen and shipped to CanmetMINING in Ottawa, Ontario, Canada. Once the water samples arrived in Ottawa, the water was immediately stored in a walk-in fridge at 5 °C for the entire testing campaign.

Reagent grade (99%) calcium oxide (CaO) was supplied by Sigma-Aldrich (Saint-Louis, United States). Sodium metabisulphite (SMBS; $Na_2S_2O_5$) at 98.6–99.8 % was purchased from DeFalco's (Ottawa, Canada). A dithiophosphinate mixture with a purity of greater than 95% trademarked under the name Aerophine® 3481A promotor was supplied by Cytec Canada Inc. (Niagara Falls, Canada). The frother, 99.0% MIBC, was purchased from Celanese Ltd (Irving, United States). Univar Canada Ltd. (Richmond, Canada) supplied 90–100% copper sulphate pentahydrate ($CuSO_4 \bullet 5H_2O$). The zinc collector potassium isobutyl xanthate (PIBX; $C_5H_9KOS_2$) of 80% xanthate was supplied by Prospec Chemicals (Fort Saskatchewan, Canada). The silica sand of 87-99.9% purity that was used to clean the grinding media and mill was purchased from Unimin Canada Ltd (Havelock, Canada). Road salt (Sifto Canada, Mississauga, Canada) at a purity of 97% NaCl was used for the saturated salt cooling of pulp in flotation experiments. Grade 4.8 (99.998% N_2) nitrogen gas and liquid nitrogen were supplied by Messer Canada Inc (Mississauga, Canada) and were used for purging samples for surface analysis. Fischer Scientific (Ottawa, Canada) supplied 99.8% methanol, technical grade (~100%) sodium metasilicate pentahydrate for dispersion, and reagent grade nitric acid (68-70%) for sample acidification prior to water analysis.

2.1. Sample Preparation

Approximately 250 kg of Kidd Creek ore was received in August 2021 and stored at -15 °C. Sample processing was started in August and ended in September 2021. However, it is believed that some surface activation (galvanic interactions) may have occurred during sample processing due to the hot and humid conditions of late summer and the difficulty in separating copper and zinc during flotation.

The ore sample had a considerable mass of fines, which were first screened off using number 10 mesh (2 mm). The oversized fraction was then screened using a 12 mm screen. The +12 mm material was crushed in a jaw crusher and screened using 10 mesh. The -12+2 mm fraction was crushed in a smaller jaw crusher. After crushing, the sample was blended for 16 hours. Approximately 50 kg of the sample had to be air-dried due to moisture adsorption. The sample was then re-blended to ensure homogeneity. Charges weighing approximately 1 kg were prepared using a spin riffler.

Feed samples for analysis were prepared by blending and splitting to produce representative samples for mineralogical and head assay analysis. To produce representative samples for mineralogical and head assay analyses, a 1 kg feed charge was blended for 2 hours and then split into 125 g aliquots. Eight aliquots were analyzed at the analytical lab at Kidd Operations for copper, iron, lead, and zinc using inductively coupled plasma (ICP) and sulphur using ELTRA. A separate charge was used to prepare two aliquot samples for mineralogical analysis. The same procedure was followed as with the head assay samples. However, one 125 g split charge was further split into 16 g charges.

2.2. Grind Curve and Head Assay

To match the grinding curve used in the mine-site laboratory, 1 kg charges were ground in a laboratory ball mill. Charges were ground at various times (between 2 and 30 minutes) to achieve a P_{80} of 44 µm. High chrome cast iron were used in the mill at 60% solids by volume. After grinding, the pulp was filtered using 42 grade filter paper, washed

with methanol, and dried at 50 °C in an oven. Samples were rolled out using a rolling pin and then passed through a 300 μm sieve. Blending was done for 60 minutes and were split into 125 g charges. One 125 g aliquot was sonicated for 30 minutes in a 1000 g/t technical grade sodium silicate solution diluted with tap water. The sonicated pulp was then wet sieved using a 150 μm sieve followed by a 53 μm sieve. The -53 μm fraction was filtered in a pressure filter and dried at 50 °C. The dried +150 μm and -150+53 μm fractions were further sieved to separate the -53 μm fraction which was passes through a cyclosizer. The grind curve determination was an iterative process.

2.3. Mineralogy

The cone and quartering technique was used to produce two 10 g samples for mineralogy. Data on mineral associations, liberation, grain size, and modal mineralogy of the feed was obtained using an automated scanning electron microscope, TESCAN Integrated Mineralogical Analyzer, or TIMA (TESCAN USA Inc., Warrendale, United States). A feed sample was run using TIMA at an acceleration voltage of 25 kV, adsorption current of 4 nA, and a mapping mode step of 3 μm.

2.4. Flotation

Tests were conducted every month in triplicate, with a fourth test performed specifically to collect samples for surface analysis testing. The circuit temperature at the start of the flotation circuit was provided from Kidd Operations, as shown in Figure 3. To cool the pulp after grinding (prior to the start of the flotation test), a saturated salt solution at -15 °C was circulated through a one-quarter inch stainless steel tube placed in the flotation cell containing the pulp using a peristaltic pump and plastic tubing. If the pulp needed to be heated, tap water was heated in a beaker using an immersion heater. The flotation procedure for the seasonal tests is shown in Table 1. In Table 1 the conditioning of reagents was done first followed by flotation. For example, in copper (Cu) flotation after MIBC was added to the pulp, it was conditioned for 1 minute followed by flotation for 1 minute. Also in Table 1, the blank spaces mean that no reagents were added. The flotation froth removal rate was one stroke for every 5 seconds (1/5 seconds) at a froth depth of 2 inches.

2.5. Liquid Sample Analysis

Approximately 10 mL of process water was acidified, using concentrated nitric acid, to prevent precipitation during the analysis of 33 elements by inductively coupled plasma atomic emission spectroscopy (ICP-AES). The list of elements analyzed is available in Appendix B. A Varian Vista RL ICP-AES and Varian SPS-5 Autosampler (Varian Inc., Palo Alto, United States) were used for the analysis of these elements.

About 100 mL of process water was used for the analysis of sulphate (SO_4), total carbon (TC), total inorganic carbon (TIC), total organic carbon (TOC), and total dissolved solids (TDS). Sulphate ions were analyzed via ion chromatography using a Dionex conductivity detector CDM–1 (Dionex Corporation, Sunnyvale, United States). TC, TIC, and TOC were analyzed using an Apollo 9000 carbon analyzer (Teledyne Tekmar Co., Mason, United States). Process water TDS was analyzed using a Traceable TDS meter and probe from Fischer Scientific (Ottawa, Canada).

Tetrathionate ($S_4O_6^{-2}$) and trithionate ($S_3O_6^{-2}$) were measured by reverse-phase chromatography and indirect UV. A Dionex ICS-5000 ion chromatography apparatus (Dionex Corporation, Sunnyvale, United States) was used along with a Nova-Pak C-18 column (Waters Limited, Mississauga, Canada). Thiosulphate ions were measured at Kidd Operations using titration.

2.6. Statistical Analysis

Multivariate statistics were performed using SAS v9.4. Due to the multivariate nature of this flotation system, MANOVA was chosen to identify problem months. MANOVA has three main assumptions (Johnson & Wichern, 2019): normality of residuals, constant variance, independent sampling groups.

In this study, the residuals were not normally distributed (Q-Q plots), which are shown in Appendix A. Therefore, the Kruskal-Wallis (KW) extended MANOVA test can be used. This method has been described previously (Aljobaily, 2018; He, 2013). For normality, quantile-quantile (Q-Q) plots are used, which compares the Mahalanobis distance for each observation with the ranked Chi-squared quantile. More information can be found elsewhere (Johnson & Wichern, 2019). The sample Mahalanobis distance (d_j^2) is a measurement of the distance of an observation from the centroid of the data:

$$d_j^2 = (x_j - \bar{x})^T \Sigma^{-1} (x_j - \bar{x}) \quad (1)$$

where x_j is the observations, $\bar{x}$ is the sample mean of variable p, and Σ^{-1} is the inverted covariance matrix, calculated using the following equation for j observations, where σ_p^2 is the variance of variable p.

$$\Sigma = \begin{bmatrix} \sigma_1^2 & 0 & \cdots & 0 \\ 0 & \sigma_2^2 & \cdots & 0 \\ \vdots & \vdots & \ddots & \vdots \\ 0 & 0 & \cdots & \sigma_p^2 \end{bmatrix} \quad (2)$$

The general form of the hypothesis test for the Kidd Creek flotation system is shown below.

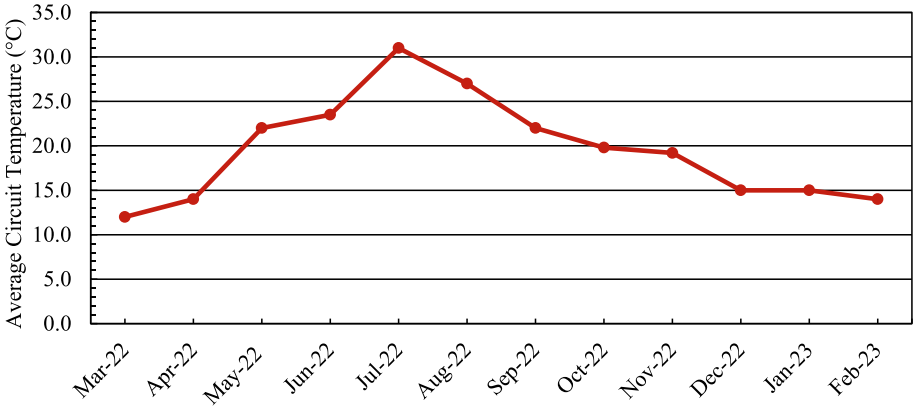

Figure 3. Average circuit temperature at the start of flotation at Kidd Operations. Data points represent the temperature of the pulp at the start of the flotation circuit at Kidd Operations. The x-axis values refer to months in 2022 (-22) or 2023 (-23) during which flotation experiments were conducted.

Table 1
Flotation conditions for seasonal flotation.

Stage	Time (min)		pH	Air	SMBS	3418A	MIBC	$CuSO_4$	PIBX
	Cond.	Flot.		(L/min)	(g/t)	(g/t)	(drops)	(g/t)	(g/t)
Cu conditioning	3		11	2	0	0			
	3		11	0	400	0			
	2		11	0	0	9			
Cu flotation	1	1	11	1.5			1		
	1	2	11	1.5			1		
	1	4	11	1.5			1		
	1	8	11	1.5			1		
Zn conditioning	5		11.5	0				90	0
	3		11.5	0				0	5
Zn flotation	1	1	11.5	4			1		
	1	2	11.5	4			1		
	1	6	11.5	4			1		

SMBS: sodium metabisulphite; MIBC: methyl isobutyl carbinol; PIBX: potassium isobutyl xanthate. Cond. = conditioning time; flot. = flotation time.

$$H_0: \begin{pmatrix} \mu_{Cu} \\ \mu_{Fe} \\ \mu_{Zn} \\ \mu_S \end{pmatrix}_{Jan} = \begin{pmatrix} \mu_{Cu} \\ \mu_{Fe} \\ \mu_{Zn} \\ \mu_S \end{pmatrix}_{Feb} = \cdots = \begin{pmatrix} \mu_{Cu} \\ \mu_{Fe} \\ \mu_{Zn} \\ \mu_S \end{pmatrix}_{Dec} \quad (3)$$

The null hypothesis (H_0; Eq. (3) in this case is that the means (μ_j) for observation j (either Cu, Fe, Zn, or S)) are equal. The alternate hypothesis (H_a) is that at least one mean (μ_j) between months is statistically significant at the 95% level.

To evaluate which months were significant, a post hoc analysis was conducted. The Dwass, Steel, Critchlow-Fligner multiple comparison analysis was used to test the significance of both the copper, iron, zinc, and sulphur grades and recoveries in the copper and zinc concentrates. This method is based on the pairwise two-sample Wilcoxon comparisons and has been described previously (Dwass 1960; Steel, 1960; Critchlow & Fligner 1991).

2.7. Surface Species Analysis

Samples for surface analysis were taken in a separate test after the triplicate flotation tests from each month. Briefly, samples of approximately 25 mL were collected from the pulp during SMBS or $CuSO_4$ (modifier) conditioning, 3418A or xanthate (collector) conditioning, and after flotation during both the copper and zinc flotation stages. Samples of bulk copper and zinc concentrates were taken after the total flotation times of 8 and 6 minutes, respectively. The samples were purged with nitrogen gas (99.998%) and then frozen by immersion in liquid nitrogen. The samples from months with good (March) and poor (July) flotation results were stored at -15 °C and sent to Surface Science Western (SSW) for analysis.

The surface analysis of sphalerite was performed by SSW at the University of Western Ontario using an ION-TOF, TOF SIMS IV^{TM} secondary ion mass spectrometer. This technique allows for the analysis of the outermost one to three atomic layers of a surface by mass spectrometry.

Table 2
Feed grade for the Kidd Creek ore.

Element	Cu	Fe	Pb	Zn	S
Average (%)	1.78	14.0	0.21	3.99	12.2
Standard deviation (%)	0.029	0.19	0.0064	0.057	0.12
RSD (%)	1.7	1.3	3.1	1.4	1.0

Note. RSD refers to the relative standard deviation, which is calculated by dividing the sample standard deviation by the sample average. Cu, Fe, Pb, Zn, and S denote copper, iron, lead, zinc, and sulphur, respectively.

3. Results and Discussion

The feed grade for the ore used in this study is shown in Table 2. The relative standard deviation (RSD) is calculated by dividing the sample standard deviation by the average. Typically, an RSD value of less than 5% is desirable and is representative of good sample preparation (Di Feo & Lastra, 2019).

3.1. Mineralogy

Modal mineralogy results for the Kidd ore are presented in Figure 4. Iron sulphide minerals contribute to a high head iron assay. Other silicate, carbonate, and sulphide minerals are also present in the Kidd Creek ore. As expected, pyrite and quartz are the dominant minerals. Chalcopyrite and sphalerite are present at 7% and 8%, respectively, the pyrrhotite content of this ore is 9%.

Chalcopyrite and sphalerite have different particle liberation characteristics. The surface liberation of the chalcopyrite decreases with decreasing particle size. On the other hand, sphalerite liberation increases as particle size decreases.

3.2. Water Quality

Water samples were collected at Kidd Operations starting in May 2022 and ending in February 2023. The water and pH of each sample were recorded directly after sampling. Characteristics of the process water samples are summarized in Table 3. The water quality of the process water varied throughout the year and the main parameters are

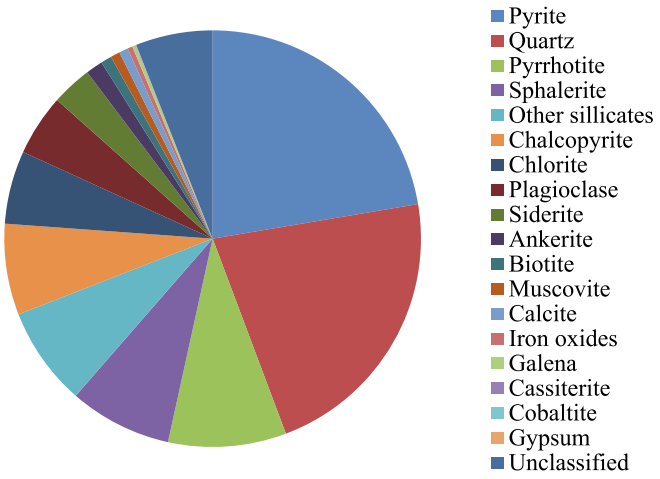

Figure 4. Kidd Creek ore composition. Other silicates refer to silicate minerals that could not be differentiated using the TESCAN database.

Table 3
Water sample information.

Date	Temperature	pH	Ionic Strength
dd/mm/yy	°C	-	M
28/03/22	2	9.6	0.032
25/04/22	4	10.2	0.030
27/05/22	14	9.1	0.031
20/06/22	15	9.3	0.037
19/07/22	23	9.9	0.047
09/08/22	20	10.3	0.044
27/09/22	13	9.6	0.046
24/10/22	9	9.6	0.038
07/11/22	9	10.6	0.038
15/12/22	5	9.5	0.036
17/01/23	3	9.9	0.040
02/02/23	2	9.6	0.048

shown in Table 4. ICP-AES analyses from each month are available in Appendix B. Ionic strength (I) was calculated using Eq. (4) and the water quality data is provided in Appendix B:

$$I = \frac{1}{2}\sum_{i=1}^{i=n} c_i z_i^2 \quad (4)$$

where ci is the concentration of ionic species i, and zi is the charge of ion i. The ionic strength is a summation of all ions (n) in a solution and is an indicator of the strength of the solution.

Le et al. (2020) published a procedure for a closed-loop ore dissolution test for estimating plant process water. Comparing the dissolution water sample to that of the Kidd process water, the concentration of calcium ions is approximately five times higher in this study, whereas the sulphate concentration in this study is double compared to the dissolution test water. However, the concentration of potassium, magnesium, and sodium are all approximately 5 times greater in the study by Le et al. (2020) compared to this study. The concentrations of Cu, Fe, Pb, and Zn ions were almost always below detection in this study.

Certain minerals have an outsized role in affecting flotation performance, especially those able to potentially contribute polyvalent cations to the pulp (Pugh et al., 1997; Weissenborn & Pugh, 1995). Using synthetic water with ion spiking, Dzingai et al. (2020, 2021) estimated threshold concentrations for several common ions in the flotation of a Cu-Ni-Pt ore. The estimated thresholds were approximately 400 mg/L for calcium, over 800 mg/L for magnesium, 720-1200 mg/L for sulphate, and greater than 78 mg/L $S_2O_3^{2-}$. It can be seen in Table 4 that the calcium and sulphate concentrations in the Kidd Creek water are at the threshold limit defined by Dzingai et al. (2020, 2021). The calcium levels in this study are comparable to the concentration used in Liu et al. (1993), however the thiosulphate concentration in this study is much lower. The concentration of thiosulphate was found to increase the copper grade when the pulp temperature increased (Corin et al., 2024).

3.2.1. Seasonal Flotation

Grade and recovery curves for copper and zinc flotation are shown in Figure 5 and Figure 6, respectively. Figure 5 illustrates the copper grade-recovery for the copper concentrate (copper flotation) and Figure 6 shows the zinc grade-recovery for the zinc concentrate (zinc flotation). The copper results in Figure 5 appear to be grouped closely. It appears that July and August have the worst copper grade-recovery curves. Interestingly, the January grade-recovery curve is grouped close to these two summer months. In terms of zinc in Figure 6, there are two groupings of grade-recovery curves. Hot summer months from June to September experienced relatively poorer zinc flotation. Interestingly, November flotation results are grouped with the summer months. All other months appear to have relatively better zinc flotation results as compared to the summer months.

The cumulative concentrate grades and copper recoveries are plotted monthly in Figure 7. The copper recovery decreases by approximately 4% in the copper concentrate during the summer months.

In Figure 8, cumulative selectivity data for specified variables with respect to copper recovery is shown. Several important trends are found. Firstly, the zinc recovery to the copper concentrate increases in the summer months by 20% to 30%. Secondly, the water recovery increases in the winter, which agrees with the ionic strength trends. As measures of froth stability, the water recovery and the solids recovery are expected to increase with ionic strength (Corin et al., 2011, 2022; Moimane et al., 2016; Manono et al., 2012, 2013). However, the solids recovery did not increase during this period as expected. Alternatively, this phenomenon could be due to the higher viscosity of the water in

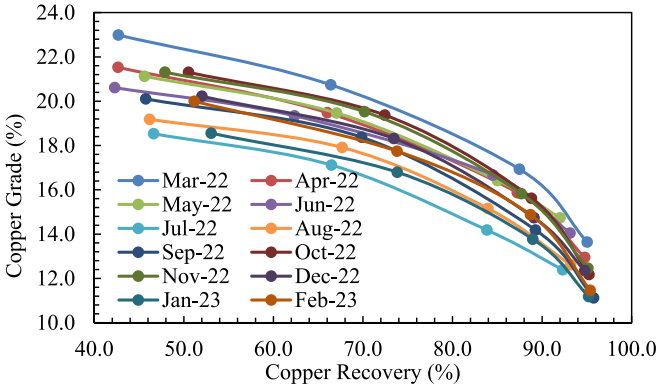

Figure 5. Copper concentrate grade-recovery curves from seasonal testing. The legend refers to months in 2022 (-22) or 2023 (-23) during which flotation experiments were conducted. Triplicate test results are averaged.

Table 4
Water quality of Kidd Creek process water.

Date	Ca^{2+}	K^{+}	Mg^{2+}	Na^{+}	SO_4^{-2}	$S_2O_3^{-2}$	$S_3O_6^{-2}$	$S_4O_6^{-2}$	TDS	TC	TIC	TOC
dd/mm/yy	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
28/03/22	276	10.1	14.7	47.6	761	21	3.2	1.8	843	7.4	0.31	7.0
25/04/22	252	5.58	7.77	23.9	663	10	2.1	<1	765	2.7	0.23	2.5
27/05/22	253	9.67	14.1	46.2	758	24	<1	<1	701	5.1	3.4	1.7
20/06/22	335	9.69	8.42	42.2	885	0	<1	<1	970	4.8	0.17	4.6
19/07/22	436	11.3	4.19	49.9	1127	0	<1	<1	1144	5.0	2.9	2.1
09/08/22	422	10.7	4.73	48.5	1003	0	<1	<1	1070	5.5	2.7	2.8
27/09/22	440	8.98	5.2	40.2	1106	5	<1	<1	964	6.1	4.4	1.7
24/10/22	359	9.98	5.23	33.3	881	6	<1	<1	818	5.3	2.8	2.6
07/11/22	368	9.52	2.68	36.4	877	15	<1	<1	826	3.8	1.1	2.7
15/12/22	288	8.26	22.1	38.3	898	44	0.7	0.5	751	6.9	2.5	4.4
17/01/23	322	17.5	17.1	61.3	1003	6	13	9.0	854	7.8	2.4	5.4
02/02/23	377	17.3	19.2	70.9	1219	28	13	8.7	967	6.3	0.90	5.4

Note. Date is given in the day/month/year format. TDS, TC, TIC, and TOC refer to total dissolved solids, total carbon, total inorganic carbon, and total organic carbon, respectively.

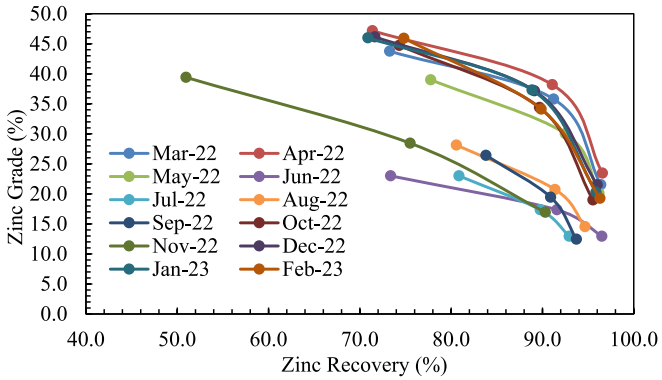

Figure 6. Zinc concentrate grade-recovery curves from seasonal study. The legend refers to months in 2022 (-22) or 2023 (-23) during which flotation experiments were conducted. Triplicate test results are averaged.

winter months due to lower temperature which results in increased water recovery (O'Connor & Mills, 1990). Finally, it appears there is a decrease of about 1% in cumulative copper grade which starts in September 2022 and ends in May 2022. The decreased copper concentrate grade could be due to a corresponding increase in the gangue recovered during copper flotation. Interestingly, the decrease in copper grade matches a trend of decreased iron recovery in the copper concentrate of 18% in the summer months compared to greater than 20% during the rest of the year. The flotation of iron sulphide minerals is more efficient at higher temperatures (O'Connor et al., 1984). However, the recovery of iron (Figure 8) decreased in the hotter summer months from May 2022 to August 2022, indicating depression of pyrite during this period. Tang & Wen (2019) found a 6% increase in iron recovery when using tailings water which was influenced by polyvalent cations, for example with an aluminum (Al) concentration of higher than 800 mg/L. The flotation recovery of pyrite can be depressed when the concentration of sulphate ions is elevated close to the level (1000 mg/L) encountered in this study (Bıçak et al., 2012). In a recent study, Bıçak et al. (2023) found that pyrite recovery decreased when the temperature was raised from 20 °C to 60 °C, respectively and that temperature was more impactful than water quality in the flotation of a copper-lead-zinc ore at high temperatures.

The increase in zinc reporting to the copper concentrate in the hot summer months could be due to the activation of sphalerite by copper ions (Deng et al., 2015), or by activation during sample processing, grinding, and/or flotation (Özçelik & Ekmekçi, 2022). Bulut & Yenial (2016) found that zinc grade and recovery increased when recycle water was used. There may also have been significant oxidation of the ore during dry sample processing prior to the bench-scale testing due to hot and humid conditions in the laboratory. In industrial practice, this

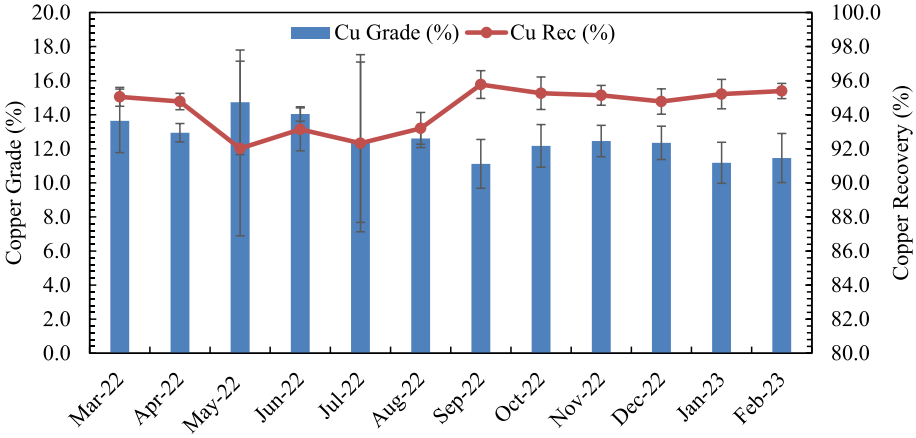

Figure 7. Cumulative copper flotation seasonal results. The x-axis values refer to months in 2022 (-22) or 2023 (-23) during which flotation experiments were conducted. Triplicate test results are averaged, and the error bars are shown based on the 95% confidence level.

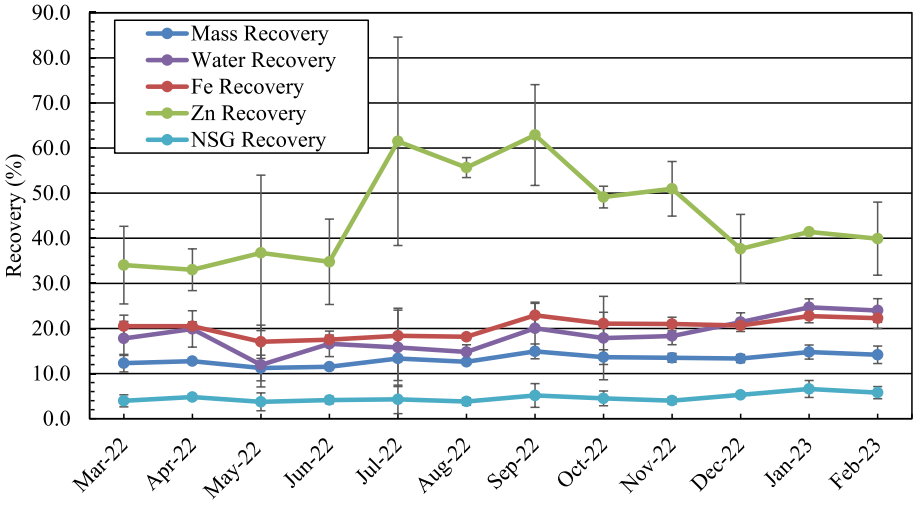

Figure 8. Cumulative copper flotation seasonal selectivity. The x-axis values refer to months in 2022 (-22) or 2023 (-23) during which flotation experiments were conducted. Triplicate test results are averaged, and the error bars are shown based on the 95% confidence level. NSG: non-sulphide gangue.

means that the residence time the ore spends in the ore stockpiles or the storage bins should be considered at all stages after ore fragmentation as an integral part of any large-scale investigations.

Cumulative zinc recovery and grade during the zinc flotation stage are shown in Figure 9. The zinc flotation performance in the summer months of July 2022 to August 2022 is relatively poor as compared with the rest of the year. From Figure 9, there was a decrease of approximately 1 to 4% in the cumulative zinc recovery which coincided with a 10% decrease in concentrate grade. Selectivity data is available in Figure 10.

There is no trend in terms of the variables in the zinc concentrate linked to the selectivity data in Figure 10, and therefore the zinc flotation results depend strongly on the available zinc after copper flotation. If more zinc is floated during the copper stage, there is less available for zinc flotation. There is an accompanying decrease in the zinc concentrate grade and the zinc recovery during the summer (June, July, August) months, which agrees with the trend of zinc reporting to the copper concentrate in these same months.To gain a better idea of which months in particular are affected, the KW method was used on both the grade and the recovery data for the copper concentrate and the zinc concentrate, for a total of four KW analyses. The KW test results for the copper and the zinc concentrates are shown in Table 5. The tests statistics of Wilks' Lambda, Pillai's Trace, Hotelling-Lawley Trace, and Roy's Greatest Root describe the multivariate system, and a p-value of less than 0.05 (at a confidence level of 95%) indicates a statistically significant variable in one of the classes (months), as shown in Eq. (3).

As can been seen in the KW table, at least one of the copper, iron, zinc, or sulphur recovery means are most likely statistically significant in at least one month for each data set for both the copper and the zinc concentrates. To infer which variables are significant at a particular time of year, the distribution graphs for each dependent variable must be investigated for recovery and grade in both the copper and the zinc concentrates. These plots are shown in Appendix A and are summarized in Table 6. Notable trends that are most likely statistically significant as compared to the rest of the year are shown in Table 6. Trends are identified as months that have lower or higher mean distributions for dependant variables as compared to the distributions from the rest of the year. If there is no overlap between the distributions of dependant variables, then there is most likely a statistically significant difference in that period of the year. As mentioned previously, the data is not normal, so the KW method was used. Q-Q plots are shown in Appendix A for each data set.

From Table 6, the copper concentrate recovery is most likely significant for all variables except for sulphur. The copper and the iron recoveries are relatively low in summer months (May, June, July, August) as compared to the rest of the year. The zinc recovery to the copper concentrate is most likely significantly higher in the months of July, August, September, October, and November. The copper concentrate recovery KW results agree with the trends from copper flotation (Figure 7 and Figure 8). The copper concentrate grade data is most likely significant in terms of all variables but is most likely statistically different during different time periods for each variable.

Interestingly, the iron recovery and the grade in the zinc concentrate are not statistically significant. The copper grade and the recovery in the zinc concentrate are most likely significantly higher in the summer months (May, June, July, August), whereas the zinc grade and the recovery are most likely significantly lower in the late summer for the same dataset (July August, September).

The Kruskal-Wallis (KW) tests for the copper concentrate recovery, zinc concentrate recovery, copper grade and zinc grade were significant. That means that at least one elemental recovery or grade between the months is different. Thus, post-hoc tests were done on the Cu, Fe, Zn and S recovery and grade results from the copper and zinc concentrates using the Dwass, Steel, Critchlow-Fligner multiple comparison method.

The results of the post hoc analysis are shown in Appendix A and illustrate that the Cu, Fe, Zn and S recovery and grade results from the copper and zinc concentrates between the months are not significant. The power to detect changes is low due to the small sample size of three replicates. This does not mean that there are no significant differences between any of the months. It simply implies that there was a lack of statistical power due to the sample sizes. Another explanation may be due to the high number of factor levels. The more pairwise comparisons there are, the more p-values will get penalized to decrease the risk of rejecting null hypothesis while they are true ((XLSTAT Help Center, 2023). In the future more replicates would have to be done.

3.3. Surface Analysis

The surface analysis performed by the scientists at SSW focused on sphalerite from copper flotation. The samples were chosen based on the sphalerite recovery in the copper concentrate, which was 34% in March 2022 and 61% in July 2022. Samples were taken during modifier (SMBS) conditioning, collector (3418A) conditioning, as well as during and after copper flotation. For the comparative analysis, the intensity of selected species detected on the grain surfaces are presented in vertical box plots. All ToF-SIMS data presented are normalized by the total ion intensity for the region of interest (ROI), which allows for the comparison of different sized grains. As the data reflects analysis of the surface from greater than 25 grains, the data is typically highly variable. Therefore, for the comparative analysis between test samples, the normalized intensity data, plotted as vertical box plots, illustrates the relative changes in the abundance of surface species for the mineral

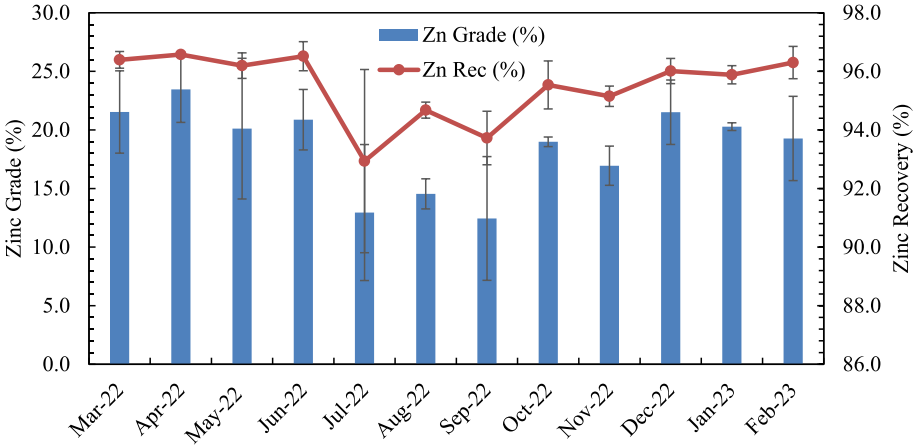

Figure 9. Cumulative zinc flotation seasonal results. The x-axis values refer to months in 2022 (-22) or 2023 (-23) during which flotation experiments were conducted. Triplicate test results are averaged, and the error bars are shown based on the 95% confidence level.

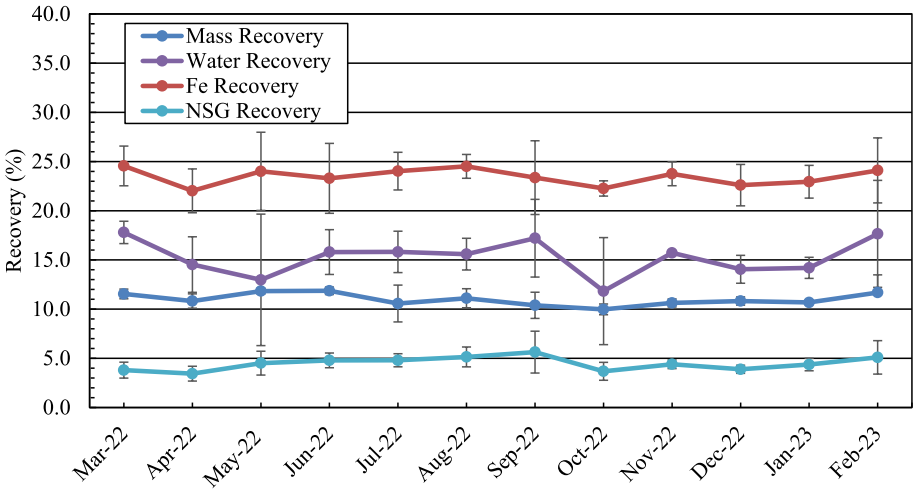

Figure 10. Cumulative zinc flotation seasonal selectivity. The x-axis values refer to months in 2022 (-22) or 2023 (-23) during which flotation experiments were conducted. Triplicate test results are averaged, and the error bars are shown based on the 95% confidence level. NSG non-sulphide gangue.

Table 5
MANOVA statistics for cumulative seasonal copper and zinc flotation.

Statistic	Cu concentrate recovery		Cu concentrate grade		Zn concentrate recovery		Zn concentrate grade	
	F-value	p-value	F value	p-value	F-value	p-value	F-value	p-value
Wilks' Lambda	4.39	<0.0001	10.3	<0.0001	4.37	<0.0001	4.68	<0.0001
Pillai's Trace	2.62	<0.0001	4.93	<0.0001	2.48	0.0001	2.89	<0.0001
Hotelling-Lawley Trace	7.88	<0.0001	18.8	<0.0001	7.72	<0.0001	7.91	<0.0001
Roy's Greatest Root	30.8	<0.0001	58.0	<0.0001	30.0	<0.0001	30.1	<0.0001

Table 6
Summary of statistically significant variables from Kidd Creek seasonal flotation.

Responses	Dependent Variable				Comments
	Cu	Fe	Zn	S	
Cu concentrate recovery	☒	☒	☒	☒	**Cu**: Relatively lower in May, June, July, August**Fe**: Relatively lower in May, June, July, August**Zn**: Relatively higher in July, August, September, October, November
Cu concentrate grade	☒	☒	☒	☒	**Cu**: Relatively higher in March, April, May, June**Fe**: Relatively lower in July, August, September**Zn**: Relatively higher in July, August, September, October, November**S**: January relatively lower
Zn concentrate recovery	☒	☒	☒	☒	**Cu**: Relatively higher in May, June, July, August**Zn**: Relatively lower in July, August, September
Zn concentrate grade	☒	☒	☒	☒	**Cu**: Relatively higher in May, June, July, August**Zn**: Relatively lower in July, August, September**S**: Relatively higher in March and April

Note. An x marks a statistically significant trend in seasonal metallurgy in which a dependent variable is significant compared to the rest of the year.

grains examined. For the ensuing discussion, differences in relative intensity on grain surfaces will be based on the mean values given in each box for the samples discussed. Shown in Figure 11 are the normalized intensities for the species representative of 3418A (parent molecule marker at 209 amu and PO_4) on the surface of sphalerite grains from the various samples in the Cu flotation.

The normalized intensities for copper collector species are either higher or the same for the July samples compared to the March samples, with the exception of the July modifier sample. The collector 3418A shows a higher intensity on the sphalerite grains from the July concentrate samples, signifying that this reagent has some part to play in the increase in sphalerite recovery to the copper float seen for this month. Additionally, the feed and the tails samples from July had higher intensities of 3418A species (sodium diisobutyl dithiophosphonate for copper flotation) on the sphalerite surfaces compared to the March samples, which indicates that perhaps more collector was recycled in July at the Kidd Creek concentrator. In the summer months there was less TOC (Table 4) in the water compared to the winter months. This most likely indicates that more 3418A was adsorbed by the minerals in the summer months. Another possible reason that the TOC is less in the summer is that the collectors decompose at higher temperature resulting in lower concentrations in the water in the summer. Also, the TDS concentration in the summer months (Table 4) was higher compared to the winter months. Most likely there may have been more copper precipitates on the sphalerite surface causing more 3418A to be adsorbed. Manenzhe et al. (2023) found a link between xanthate adsorption and water quality as the copper recovery decreased by 10% in the flotation of a Cu-Ni-PGM ore. The authors noted that this could be due to competitive adsorption between the sodium isopropyl xanthate and the Aerophine collectors. The relative intensities for the sphalerite matrix species are shown in Figure 12.

With the exception of the July tails, the intensity of the sphalerite matrix species Zn tends to be present in higher proportions on the surface of sphalerite grains from the July samples compared to March samples. To verify any surface activation, the relative intensities of copper (Cu) and lead (Pb) species on the surface of sphalerite grains are shown in Figure 13.

Evidently, for both Cu and Pb species, the relative intensities are higher for the July samples as compared to their March counterparts. Collector adsorption to the sphalerite surface typically requires some degree of surface activation. In this case, the surface of the sphalerite grains showing higher relative intensity of collector species (July concentrate compared to March concentrate) also shows higher relative intensity of Cu and Pb, hence collector adsorption and flotation

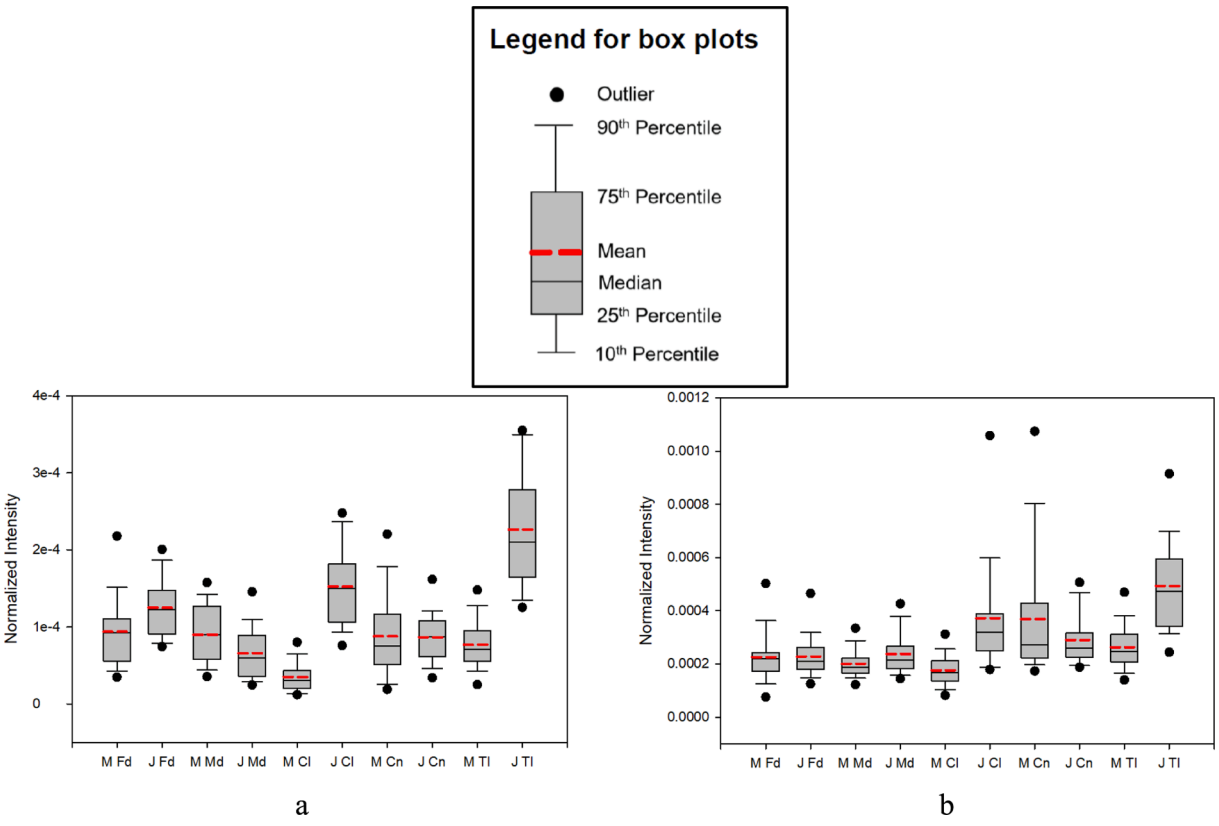

Figure 11. Relative intensities for collector species on sphalerite surfaces from copper flotation. Normalized intensities for the 3418A representative peak at 209 amu (a) and PO_4 (b) are shown for March (M) and July (J) samples. Fd, Md, Cl, Cn, and Tl represent feed, modifier, collector, concentrate, and tailings samples, respectively. The box plot legend is shown at the top.

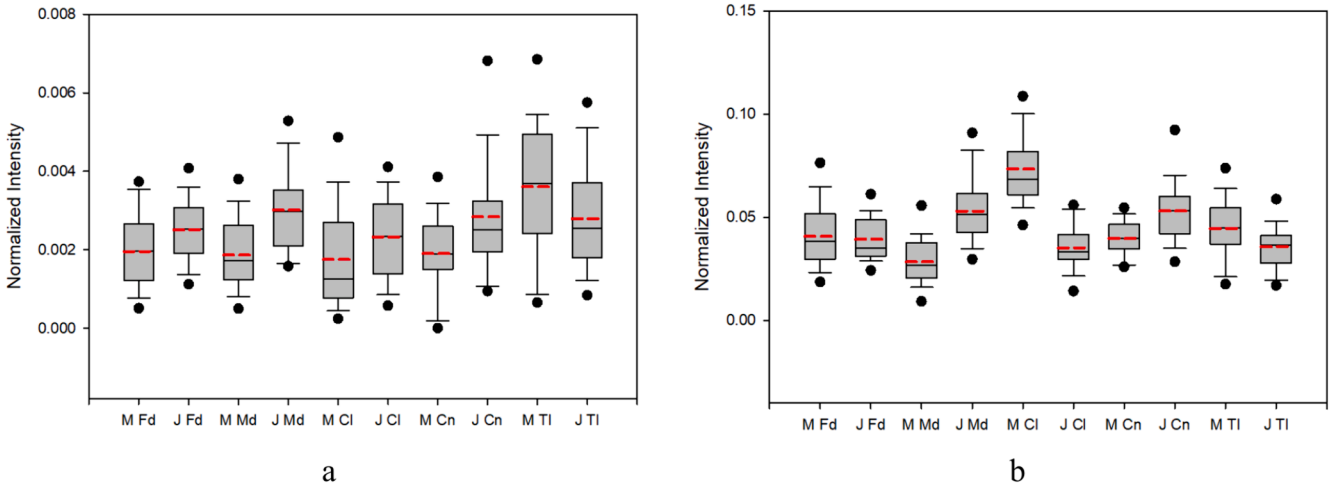

Figure 12. Intensity of sphalerite matrix species on sphalerite surfaces from copper flotation. Relative intensities for Zn (a) and S (b) are shown for March (M) and July (J) samples. Fd, Md, Cl, Cn, and Tl represent feed, modifier, collector, concentrate, and tailings samples, respectively.

facilitation. The Pb distribution on the surface of sphalerite is particularly striking as there is a significantly higher content on the grains from the July feed potentially implying greater Pb availability in the warmer months. The higher Cu species on the sphalerite surface might be due to the higher TDS in the summer months. Cu will precipitate at alkaline pH, and thus it will be difficult to determine whether there is more Cu in the summer or winter months. However, looking at TDS it can be inferred that there would most likely more copper precipitates formed in the summer resulting in higher sphalerite activation. Lead can activate sphalerite (Basilio et al., 1996), and could be another reason why sphalerite was floated in the copper concentrate. Lead will precipitate at alkaline pH, thus even though it could not be measured in solution, there may have been more lead precipitates in the summer due to higher TDS (Table 4).

The iron species and the hydroxide species are shown in Figure 14. The intensities for the hydrophilic gangue species are presented in Figure 15.

Species typically indicative of sphalerite surface oxidation (FeOH and FeO) show a very similar surface intensity distribution, higher on grains from the July feed and modifier samples and lower on the grains

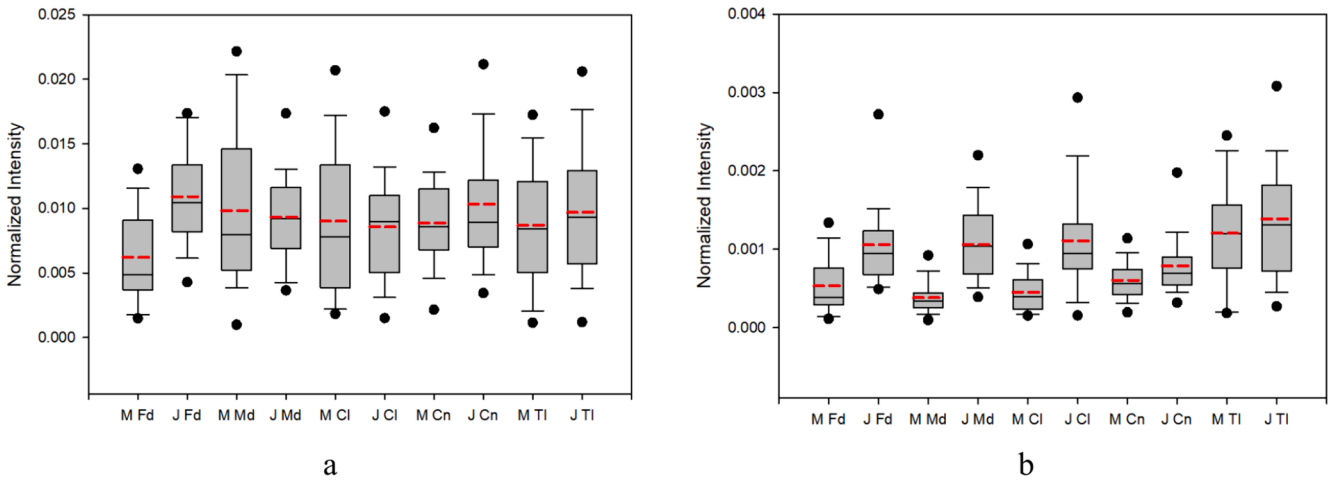

Figure 13. Intensity of copper and lead species on sphalerite surfaces from copper flotation. Relative intensities for Cu (a) and Pb (b) are shown for March (M) and July (J) samples. Fd, Md, Cl, Cn, and Tl represent feed, modifier, collector, concentrate, and tailings samples, respectively.

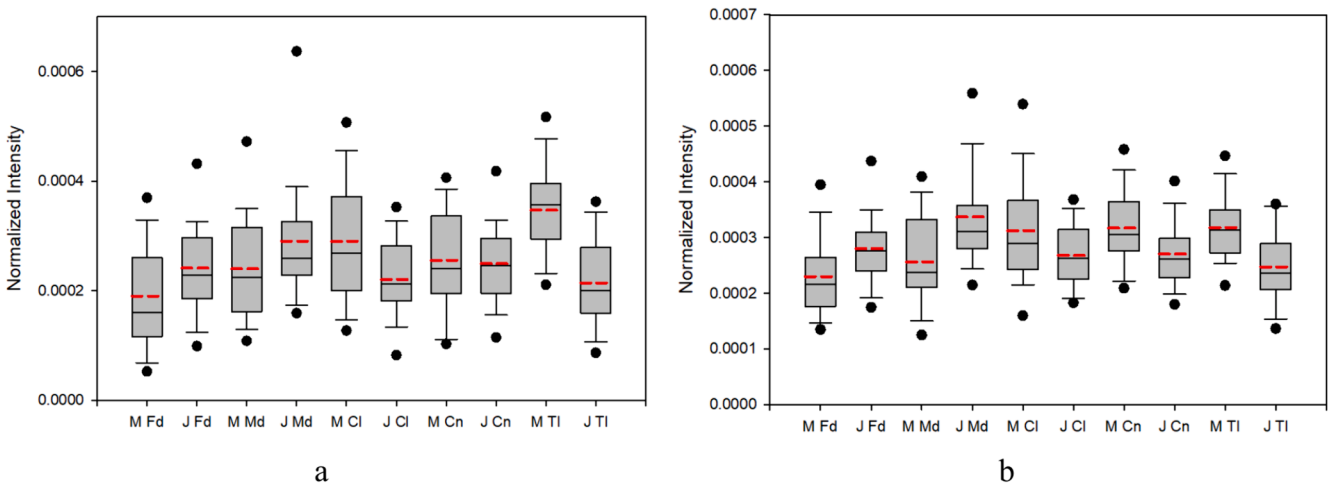

Figure 14. Intensity of iron species on sphalerite surfaces from copper flotation. Relative intensities for FeOH (a) and FeO (b) are shown for March (M) and July (J) samples. Fd, Md, Cl, Cn, and Tl represent feed, modifier, collector, concentrate, and tailings samples, respectively.

from the July collector, concentrate and tails samples. Typically, surface oxidation hinders collector attachment, and the distribution of these species appears to be linked to the relative intensity distribution of the 3418A on sphalerite surfaces (Figure 11).

Intensity of hydrophilic gangue species (Al, K, Mg and Si) on sphalerite surfaces from copper flotation is shown in Figure 15. Comparison of the intensity on the sphalerite surfaces between the listed gangue species is variable. However, for the grains from the concentrate and tails, with the exception of Si in the concentrate sample, the intensity appears to be very similar; higher on the grains reporting to the March concentrate relative to the July concentrate. In general, the sphalerite grains reporting to the July concentrate appear to be cleaner than the sphalerite grains reporting to the March concentrate. This is indicated by the higher normalized intensity of the matrix species (Zn, and S, and ZnS, Figure 12) and the lower normalized intensity of the gangue species (Al, K and Mg,) on the surface of the sphalerite grains from the July Cu circuit. However, Si is present in higher concentrations on the surface of the sphalerite grains in the July concentrate.

4. Summary and Conclusions

Several methodologies were used to investigate the Kidd Creek ore flotation system including the multivariate analysis for complex sulphide flotation (Di Feo et al., 2021) and the integrated methods for investigating flotation systems (Gerson & Napier-Munn, 2013). There is a growing trend of the use of statistical methods in mining and mineral processing and this manuscript should contribute significantly to the field. Additionally, a novel method for pulp temperature control was used. Although this does not provide comprehensive control of temperature as would a temperature control jacket, this is a relatively simple method using materials available in most mineral processing laboratories.

Water quality and temperature are linked to performance issues in Kidd Creek. However, bench-scale tests based on differences in seasonal water composition alone do not tell the full story as compared to typical observations in plant practice. The summer months were detrimental to copper flotation in terms of sphalerite selectivity. It was found using KW analyses that copper, iron and zinc recoveries in copper concentrate, copper, iron, zinc and sulphur grades in copper concentrate, copper and zinc recoveries in zinc concentrate and copper, zinc and sulphur grades in zinc concentrate data sets are most likely significant. However, post hoc analysis could not identify which months were significant. The power to detect changes is low due to the small sample size (3 replicates). This does not imply that there are no significant differences between any of the months. It simply implies that there was a lack of statistical power due to the sample sizes, and more replicates are

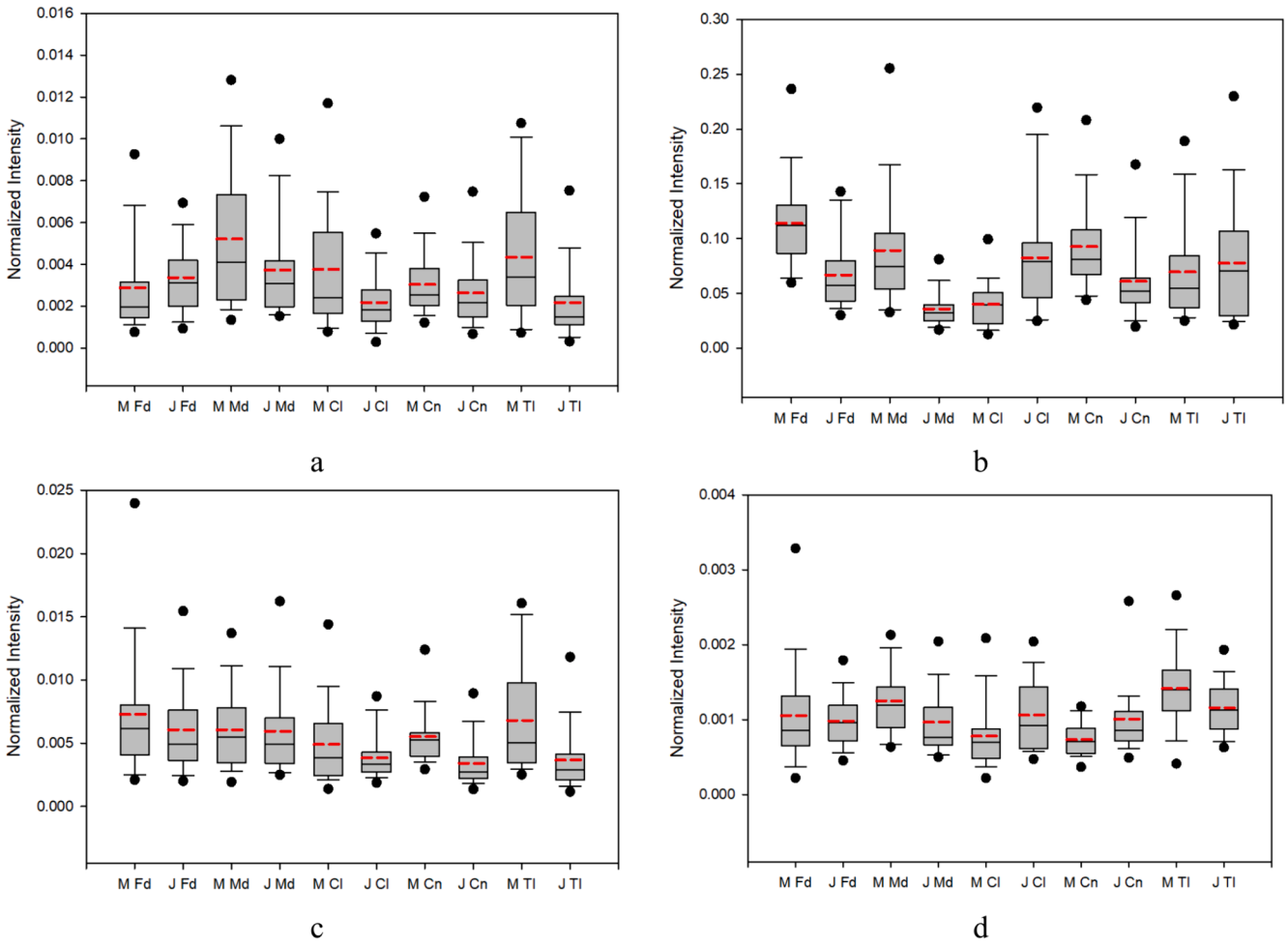

Figure 15. Intensity of hydrophilic gangue species on sphalerite surfaces from copper flotation. Relative intensities for Al (a), K (b), Mg (c), and Si (d) are shown for March (M) and July (J) samples. Fd, Md, Cl, Cn, and Tl represent feed, modifier, collector, concentrate, and tailings samples, respectively.

necessary. The selectivity issues in copper flotation in the summer months may be caused by residual reagent species or a greater degree of oxidation phenomena occurring during the production and the stockpiling of the ore or a combination of both factors. Additionally, an increased amount of copper and lead activation may have occurred in summer months. Sphalerite surfaces in July have higher intensities of copper, lead and collector species resulting in higher zinc recovery in the copper concentrate. Species in the process water and on the mineral surfaces may partially explain the differences in performance between the spring and the summer months. The oxidation of the fines during the ore stockpiling may be necessary to investigate the inadvertent activation leading to poor selectivity in the copper flotation stage. As such, a comprehensive study of the seasonal effects on complex sulphides should not only look at the changing ionic characteristics in the process water but also the oxidation-sensitive ore characteristics. Further work is needed to complete seasonal testing including the surface analysis of chalcopyrite surfaces, a higher-order design of experiments (DOE) to minimize sphalerite recovery in the copper concentrate, the treatment of process water, and a plant study. Reverse osmosis (RO) and other water treatment technologies could be applied for the treatment of process water and the higher-order DOE experiment would be completed as a priority.

CRediT authorship contribution statement

Patrick Rankin: Writing – original draft, Methodology, Investigation, Formal analysis, Data curation. **Antonio Di Feo:** Writing – review & editing, Supervision, Project administration, Methodology, Conceptualization, Software, Formal analysis. **Sadan Kelebek:** Writing – review & editing. **Baian Almusned:** Methodology, Writing – review & editing, Formal analysis. **Brian Hart:** Formal analysis, Methodology, Writing – review & editing.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: [Patrick Rankin reports financial support was provided by Natural Resources Canada. If there are other authors, they declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper].

Data availability

The authors do not have permission to share data.

Appendix A

Multivariate statistics for Kidd seasonal data

Table A1
Cumulative recoveries in the copper concentrate.

TestNumber	Month	Cu Recovery (%)	Fe Recovery (%)	Zn Recovery (%)	S Recovery (%)
1	Mar-22	95.2	20.9	31.4	28.6
2	Mar-22	95.3	21.7	39.9	31.2
3	Mar-22	94.7	18.9	30.8	26.9
1	Apr-22	94.8	20.8	35.4	29.2
2	Apr-22	95.0	20.9	30.0	27.6
3	Apr-22	94.5	19.8	33.6	28.1
1	May-22	88.5	14.6	26.4	22.2
2	May-22	93.7	17.8	46.8	27.9
3	May-22	93.9	18.7	37.1	26.6
1	Jun-22	93.2	18.0	29.5	24.9
2	Jun-22	93.8	17.7	40.7	27.2
3	Jun-22	92.4	16.9	34.2	24.9
1	Jul-22	94.0	20.1	66.6	32.3
2	Jul-22	94.2	20.5	71.9	55.5
3	Jul-22	88.8	14.5	46.0	24.2
1	Aug-22	92.7	17.7	57.1	30.6
2	Aug-22	93.1	18.3	54.5	29.5
3	Aug-22	93.8	18.4	55.4	30.1
1	Sep-22	95.7	21.3	60.3	33.6
2	Sep-22	96.3	24.5	70.4	34.2
3	Sep-22	95.4	22.9	57.9	32.7
1	Oct-22	95.7	22.0	48.0	34.0
2	Oct-22	95.4	21.9	48.7	33.9
3	Oct-22	94.6	19.4	50.7	33.0
1	Nov-22	95.4	21.5	49.5	33.9
2	Nov-22	95.3	21.5	55.1	34.7
3	Nov-22	94.8	19.9	48.3	32.5
1	Dec-22	94.6	20.8	40.1	29.6
2	Dec-22	95.3	21.0	40.4	29.9
3	Dec-22	94.5	20.1	32.4	27.4
1	Jan-23	94.8	23.3	41.5	30.9
2	Jan-23	95.1	21.7	41.4	30.2
3	Jan-23	95.8	23.2	41.3	31.4
1	Feb-23	95.1	21.1	36.2	28.4
2	Feb-23	95.5	23.7	45.4	32.4
3	Feb-23	95.6	22.0	38.2	29.8

Table A2
Cumulative grades in the copper concentrate.

Test Number	Month	Cu Grade (%)	Fe Grade (%)	Zn Grade (%)	S Grade (%)
1	Mar-22	13.44	25.75	9.80	27.53
2	Mar-22	12.65	25.23	11.73	28.28
3	Mar-22	14.83	26.40	10.82	29.55
1	Apr-22	12.61	24.90	10.65	26.51
2	Apr-22	12.98	25.56	9.19	26.06
3	Apr-22	13.25	25.37	10.60	27.13
1	May-22	16.76	24.66	11.07	27.71
2	May-22	14.17	23.43	15.42	27.76
3	May-22	13.26	23.28	11.53	24.97
1	Jun-22	13.87	24.28	10.00	25.02
2	Jun-22	13.93	23.78	13.54	26.87
3	Jun-22	14.33	23.87	12.11	26.32
1	Jul-22	10.91	20.66	17.52	25.55
2	Jul-22	10.64	20.63	18.41	26.09
3	Jul-22	15.61	22.22	17.57	30.47
1	Aug-22	12.84	21.75	17.80	28.53
2	Aug-22	12.24	21.50	16.25	27.24
3	Aug-22	12.74	22.12	16.92	28.87
1	Sep-22	11.90	22.92	16.16	29.37
2	Sep-22	11.23	22.26	17.15	28.98
3	Sep-22	10.22	21.42	13.21	25.86
1	Oct-22	11.62	23.53	13.03	26.56

(*continued on next page*)

Table A2 (*continued*)

Test Number	Month	Cu Grade (%)	Fe Grade (%)	Zn Grade (%)	S Grade (%)
2	Oct-22	11.88	23.99	13.70	27.82
3	Oct-22	13.02	23.50	15.53	29.24
1	Nov-22	12.25	24.14	13.95	28.53
2	Nov-22	12.05	23.78	15.27	28.62
3	Nov-22	13.08	24.13	14.53	29.91
1	Dec-22	12.26	23.49	11.54	26.47
2	Dec-22	11.82	23.23	11.41	26.80
3	Dec-22	12.97	24.10	9.91	26.57
1	Jan-23	10.40	22.94	10.26	22.98
2	Jan-23	11.81	23.95	11.53	25.30
3	Jan-23	11.32	24.14	10.72	24.90
1	Feb-23	11.90	23.80	10.36	25.72
2	Feb-23	10.47	23.80	11.29	26.08
3	Feb-23	12.00	25.05	11.05	27.11

Table A3
Cumulative recoveries in the zinc concentrate.

Test Number	Month	Cu Recovery (%)	Fe Recovery (%)	Zn Recovery (%)	S Recovery (%)
1	Mar-22	58.6	23.6	96.5	40.7
2	Mar-22	58.3	25.9	96.2	43.2
3	Mar-22	61.3	24.2	96.4	40.5
1	Apr-22	59.7	23.5	96.6	40.6
2	Apr-22	56.3	21.0	96.5	37.3
3	Apr-22	61.1	21.6	96.6	37.5
1	May-22	78.2	21.7	96.1	37.8
2	May-22	68.7	26.4	96.0	39.1
3	May-22	67.0	23.9	96.5	37.9
1	Jun-22	68.9	23.6	96.8	37.7
2	Jun-22	67.2	25.2	96.4	37.7
3	Jun-22	69.6	21.1	96.3	35.2
1	Jul-22	62.7	22.8	92.2	32.1
2	Jul-22	66.2	24.3	91.6	83.9
3	Jul-22	81.2	25.0	95.0	37.3
1	Aug-22	69.4	24.7	94.5	36.4
2	Aug-22	68.1	25.1	94.8	38.1
3	Aug-22	64.4	23.7	94.7	35.9
1	Sep-22	53.9	25.3	94.1	35.2
2	Sep-22	52.3	23.9	93.1	36.7
3	Sep-22	52.8	20.9	94.0	30.9
1	Oct-22	54.8	22.7	96.0	39.5
2	Oct-22	55.2	21.8	95.6	39.0
3	Oct-22	60.2	22.3	95.0	40.1
1	Nov-22	57.7	23.4	95.3	39.1
2	Nov-22	61.5	24.6	94.9	41.0
3	Nov-22	61.1	23.3	95.2	38.1
1	Dec-22	59.9	22.7	95.7	37.3
2	Dec-22	55.6	23.8	96.1	38.0
3	Dec-22	60.8	21.3	96.2	36.7
1	Jan-23	57.9	24.0	96.1	38.3
2	Jan-23	54.2	22.8	95.8	36.7
3	Jan-23	49.6	22.0	95.7	36.1
1	Feb-23	56.0	22.5	96.4	37.0
2	Feb-23	54.7	23.5	95.9	37.5
3	Feb-23	56.2	26.3	96.6	41.2

Table A4
Cumulative grades in the zinc concentrate.

Test Number	Month	Cu Grade (%)	Fe Grade (%)	Zn Grade (%)	S Grade (%)
1	Mar-22	0.45	25.73	23.14	31.26
2	Mar-22	0.41	26.56	19.18	30.36
3	Mar-22	0.49	26.03	22.28	30.86
1	Apr-22	0.47	25.69	21.63	30.03
2	Apr-22	0.46	24.43	24.90	30.71
3	Apr-22	0.56	26.15	23.85	30.73
1	May-22	1.36	25.04	23.72	29.35
2	May-22	0.65	28.16	16.60	27.62
3	May-22	0.61	25.56	20.02	27.79
1	Jun-22	0.67	25.08	22.33	27.37
2	Jun-22	0.62	28.30	19.28	27.45
3	Jun-22	0.78	23.25	21.01	26.19
1	Jul-22	0.67	28.62	12.40	26.38
2	Jul-22	0.64	28.95	9.82	26.07
3	Jul-22	1.36	27.75	16.64	30.10
1	Aug-22	0.78	27.69	14.03	26.19
2	Aug-22	0.69	26.61	14.18	27.42
3	Aug-22	0.65	27.67	15.42	28.68
1	Sep-22	0.39	28.64	13.40	27.42
2	Sep-22	0.30	21.89	8.95	27.31
3	Sep-22	0.44	24.99	14.99	27.32
1	Oct-22	0.40	26.81	19.23	28.83
2	Oct-22	0.43	25.75	18.99	29.14
3	Oct-22	0.58	28.53	18.74	31.18
1	Nov-22	0.44	26.61	17.55	28.17
2	Nov-22	0.49	28.57	15.80	29.51
3	Nov-22	0.52	26.71	17.49	27.98
1	Dec-22	0.54	25.95	21.07	30.11
2	Dec-22	0.41	25.85	20.14	29.76
3	Dec-22	0.54	23.88	23.32	30.20
1	Jan-23	0.49	26.66	20.45	28.95
2	Jan-23	0.43	25.63	20.33	28.02
3	Jan-23	0.34	24.23	20.07	27.10
1	Feb-23	0.43	24.86	21.73	29.67
2	Feb-23	0.37	24.69	17.97	28.07
3	Feb-23	0.33	24.45	18.12	27.52

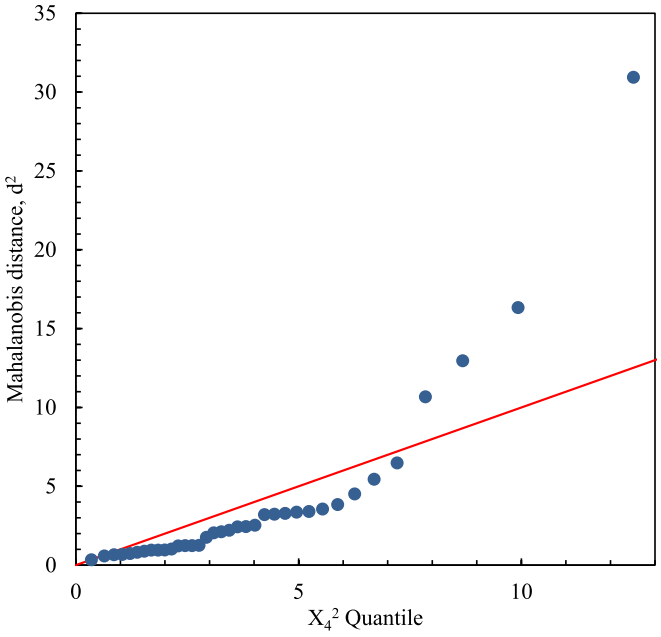

Figure A1. Q-Q plot of copper concentrate recovery.

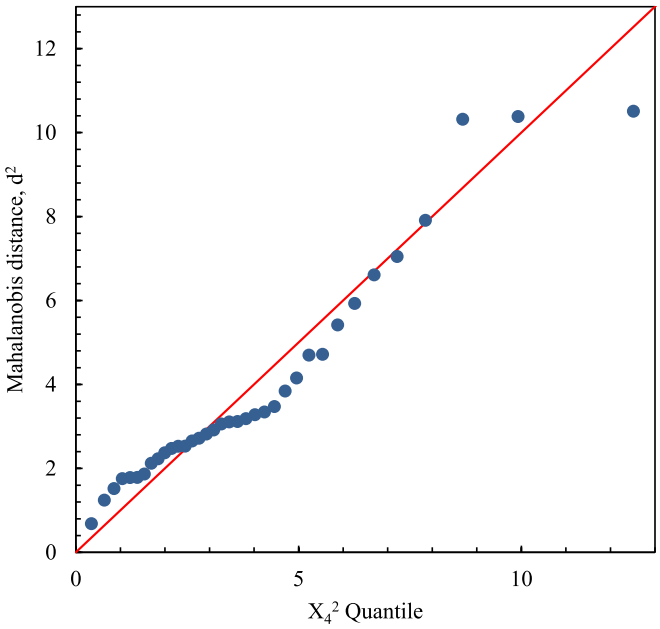

Figure A2. Q-Q plot of copper concentrate grade.

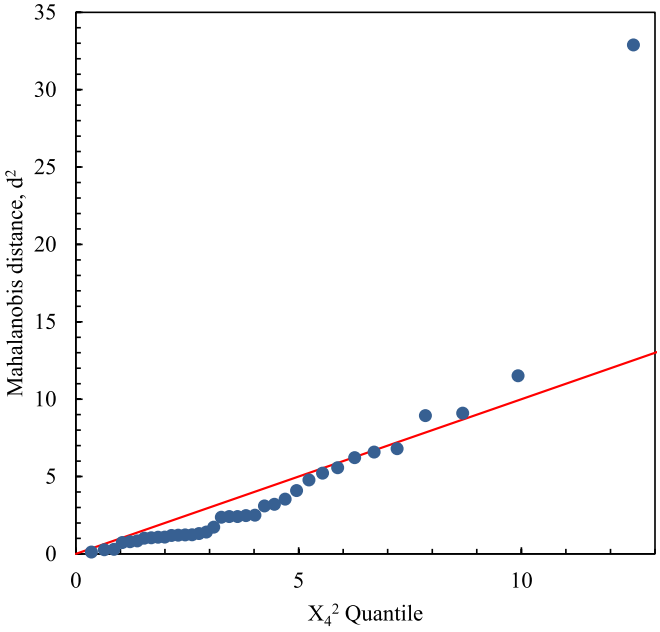

Figure A3. Q-Q plot of zinc concentrate recovery.

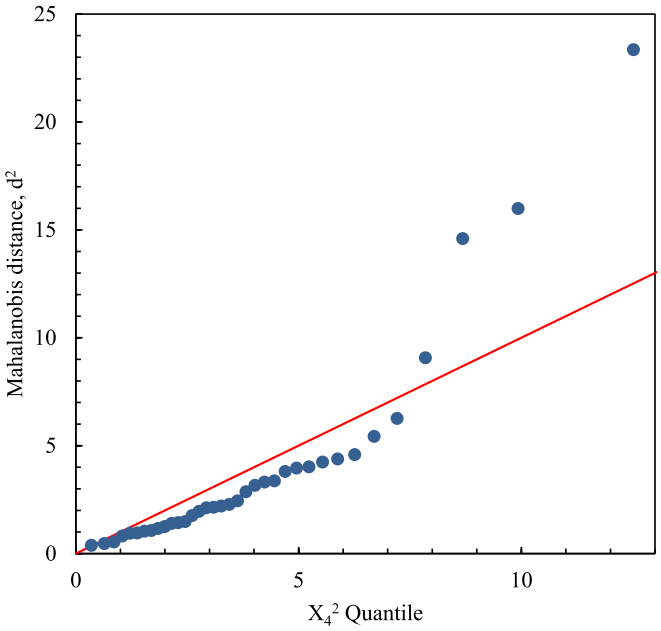

Figure A4. Q-Q plot of zinc concentrate grade.

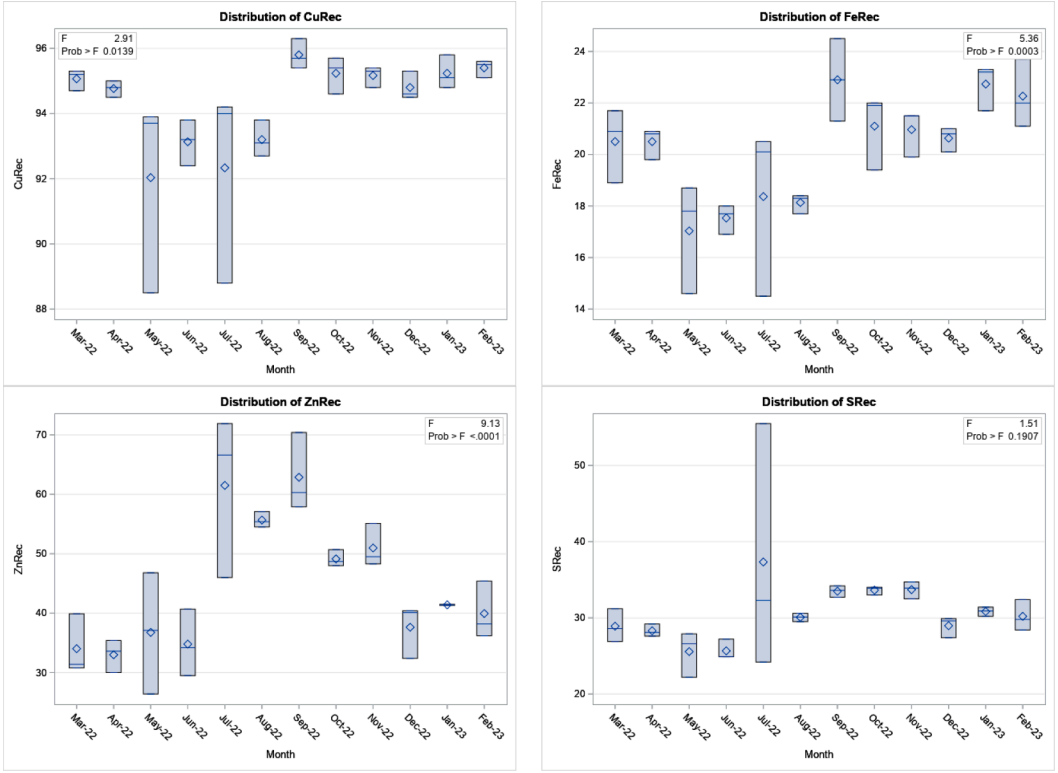

Figure A5. Distribution graphs for copper concentrate recovery.

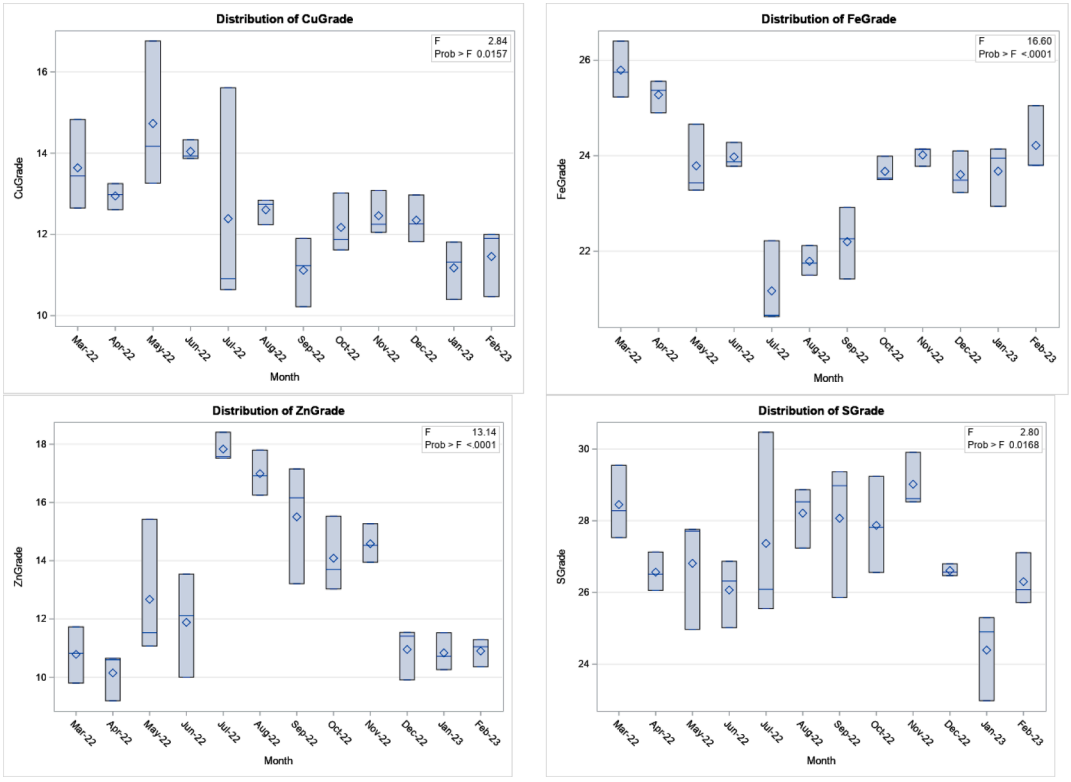

Figure A6. Distribution graphs for copper concentrate grade.

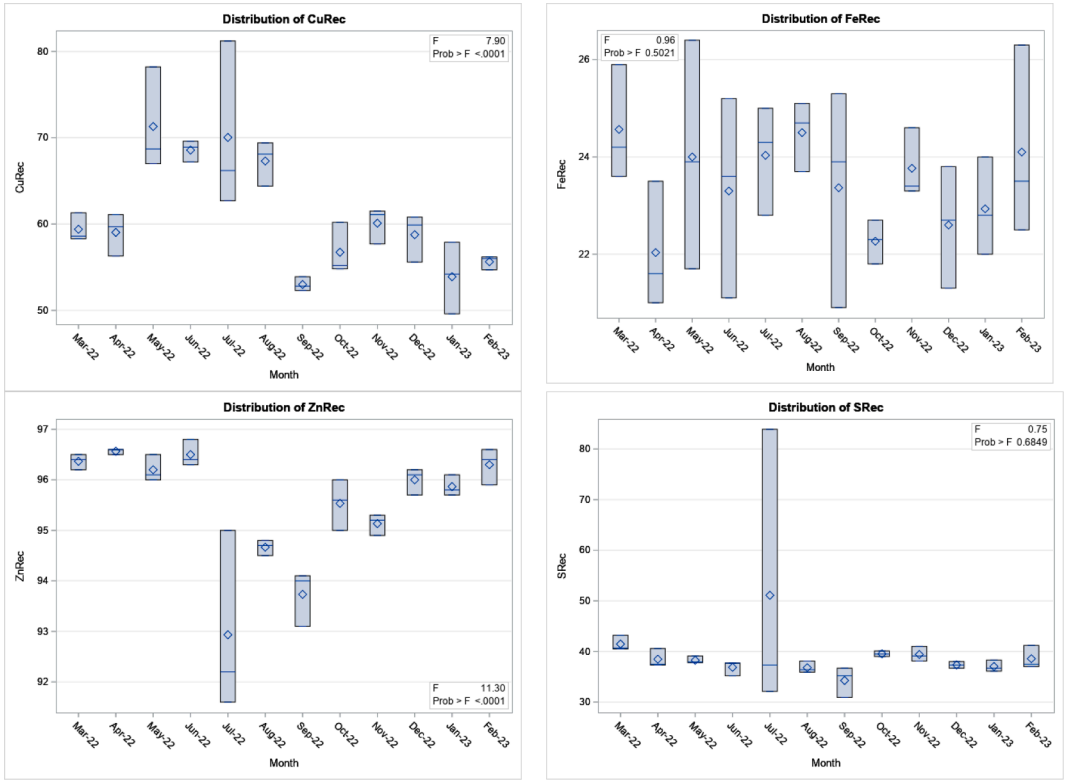

Figure A7. Distribution graphs for zinc concentrate recovery.

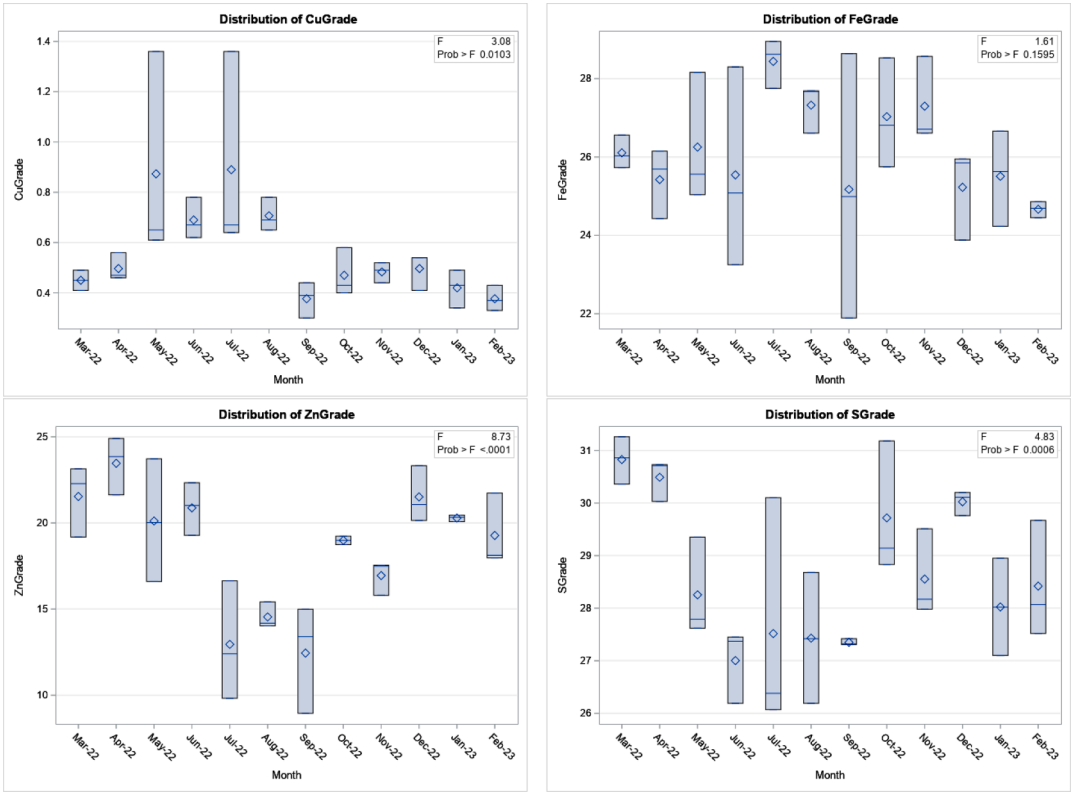

Figure A8. Distribution graphs for zinc concentrate grade.

Table A5
Pairwise Two-Sided Multiple Comparison Analysis. Dwass, Steel, Critchlow-Fligner Method for Copper Recovery in Copper Concentrate.

Month	Wilcoxon Z	DSCF Value	Pr > DSCF
Mar-22 vs. Apr-22	1.0911	1.543	0.9951
Mar-22 vs. May-22	1.964	2.7775	0.7181
Mar-22 vs. Jun-22	1.964	2.7775	0.7181
Mar-22 vs. Jul-22	1.964	2.7775	0.7181
Mar-22 vs. Aug-22	1.964	2.7775	0.7181
Mar-22 vs. Sep-22	-1.964	2.7775	0.7181
Mar-22 vs. Oct-22	-0.6547	0.9258	1
Mar-22 vs. Nov-22	-0.8856	1.2524	0.9993
Mar-22 vs. Dec-22	0.8856	1.2524	0.9993
Mar-22 vs. Jan-23	-0.2182	0.3086	1
Mar-22 vs. Feb-23	-1.0911	1.543	0.9951
Apr-22 vs. May-22	1.964	2.7775	0.7181
Apr-22 vs. Jun-22	1.964	2.7775	0.7181
Apr-22 vs. Jul-22	1.964	2.7775	0.7181
Apr-22 vs. Aug-22	1.964	2.7775	0.7181
Apr-22 vs. Sep-22	-1.964	2.7775	0.7181
Apr-22 vs. Oct-22	-1.0911	1.543	0.9951
Apr-22 vs. Nov-22	-1.3284	1.8787	0.9756
Apr-22 vs. Dec-22	0	0	1
Apr-22 vs. Jan-23	-1.3284	1.8787	0.9756
Apr-22 vs. Feb-23	-1.964	2.7775	0.7181
May-22 vs. Jun-22	0.2182	0.3086	1
May-22 vs. Jul-22	-1.0911	1.543	0.9951
May-22 vs. Aug-22	0.2182	0.3086	1
May-22 vs. Sep-22	-1.964	2.7775	0.7181
May-22 vs. Oct-22	-1.964	2.7775	0.7181
May-22 vs. Nov-22	-1.964	2.7775	0.7181
May-22 vs. Dec-22	-1.964	2.7775	0.7181
May-22 vs. Jan-23	-1.964	2.7775	0.7181
May-22 vs. Feb-23	-1.964	2.7775	0.7181
Jun-22 vs. Jul-22	-0.6547	0.9258	1

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Table A5 (*continued*)

Month	Wilcoxon Z	DSCF Value	Pr > DSCF
Jun-22 vs. Aug-22	0	0	1
Jun-22 vs. Sep-22	-1.964	2.7775	0.7181
Jun-22 vs. Oct-22	-1.964	2.7775	0.7181
Jun-22 vs. Nov-22	-1.964	2.7775	0.7181
Jun-22 vs. Dec-22	-1.964	2.7775	0.7181
Jun-22 vs. Jan-23	-1.964	2.7775	0.7181
Jun-22 vs. Feb-23	-1.964	2.7775	0.7181
Jul-22 vs. Aug-22	0.6547	0.9258	1
Jul-22 vs. Sep-22	-1.964	2.7775	0.7181
Jul-22 vs. Oct-22	-1.964	2.7775	0.7181
Jul-22 vs. Nov-22	-1.964	2.7775	0.7181
Jul-22 vs. Dec-22	-1.964	2.7775	0.7181
Jul-22 vs. Jan-23	-1.964	2.7775	0.7181
Jul-22 vs. Feb-23	-1.964	2.7775	0.7181
Aug-22 vs. Sep-22	-1.964	2.7775	0.7181
Aug-22 vs. Oct-22	-1.964	2.7775	0.7181
Aug-22 vs. Nov-22	-1.964	2.7775	0.7181
Aug-22 vs. Dec-22	-1.964	2.7775	0.7181
Aug-22 vs. Jan-23	-1.964	2.7775	0.7181
Aug-22 vs. Feb-23	-1.964	2.7775	0.7181
Sep-22 vs. Oct-22	1.1237	1.5891	0.9937
Sep-22 vs. Nov-22	1.7712	2.5049	0.8339
Sep-22 vs. Dec-22	1.964	2.7775	0.7181
Sep-22 vs. Jan-23	1.0911	1.543	0.9951
Sep-22 vs. Feb-23	1.0911	1.543	0.9951
Oct-22 vs. Nov-22	0.4428	0.6262	1
Oct-22 vs. Dec-22	1.3284	1.8787	0.9756
Oct-22 vs. Jan-23	-0.2182	0.3086	1
Oct-22 vs. Feb-23	-0.2182	0.3086	1
Nov-22 vs. Dec-22	1.3284	1.8787	0.9756
Nov-22 vs. Jan-23	0	0	1
Nov-22 vs. Feb-23	-1.0911	1.543	0.9951
Dec-22 vs. Jan-23	-1.0911	1.543	0.9951
Dec-22 vs. Feb-23	-1.5275	2.1602	0.9333
Jan-23 vs. Feb-23	-0.4428	0.6262	1

Table A6
Pairwise Two-Sided Multiple Comparison Analysis. Dwass, Steel, Critchlow-Fligner Method for Iron Recovery in Copper Concentrate.

Month	Wilcoxon Z	DSCF Value	Pr > DSCF
Mar-22 vs. Apr-22	0.4428	0.6262	1
Mar-22 vs. May-22	1.964	2.7775	0.7181
Mar-22 vs. Jun-22	1.964	2.7775	0.7181
Mar-22 vs. Jul-22	1.0911	1.543	0.9951
Mar-22 vs. Aug-22	1.964	2.7775	0.7181
Mar-22 vs. Sep-22	-1.5275	2.1602	0.9333
Mar-22 vs. Oct-22	-1.0911	1.543	0.9951
Mar-22 vs. Nov-22	-0.2214	0.3131	1
Mar-22 vs. Dec-22	0.2182	0.3086	1
Mar-22 vs. Jan-23	-1.7712	2.5049	0.8339
Mar-22 vs. Feb-23	-1.5275	2.1602	0.9333
Apr-22 vs. May-22	1.964	2.7775	0.7181
Apr-22 vs. Jun-22	1.964	2.7775	0.7181
Apr-22 vs. Jul-22	1.0911	1.543	0.9951
Apr-22 vs. Aug-22	1.964	2.7775	0.7181
Apr-22 vs. Sep-22	-1.964	2.7775	0.7181
Apr-22 vs. Oct-22	-0.6547	0.9258	1
Apr-22 vs. Nov-22	-1.107	1.5656	0.9945
Apr-22 vs. Dec-22	-0.4428	0.6262	1
Apr-22 vs. Jan-23	-1.964	2.7775	0.7181
Apr-22 vs. Feb-23	-1.964	2.7775	0.7181
May-22 vs. Jun-22	0.2182	0.3086	1
May-22 vs. Jul-22	-0.6547	0.9258	1
May-22 vs. Aug-22	-0.2182	0.3086	1
May-22 vs. Sep-22	-1.964	2.7775	0.7181
May-22 vs. Oct-22	-1.964	2.7775	0.7181
May-22 vs. Nov-22	-1.9926	2.818	0.6987
May-22 vs. Dec-22	-1.964	2.7775	0.7181
May-22 vs. Jan-23	-1.964	2.7775	0.7181
May-22 vs. Feb-23	-1.964	2.7775	0.7181
Jun-22 vs. Jul-22	-0.6547	0.9258	1
Jun-22 vs. Aug-22	-1.3284	1.8787	0.9756

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Table A6 (*continued*)

Month	Wilcoxon Z	DSCF Value	Pr > DSCF
Jun-22 vs. Sep-22	-1.964	2.7775	0.7181
Jun-22 vs. Oct-22	-1.964	2.7775	0.7181
Jun-22 vs. Nov-22	-1.9926	2.818	0.6987
Jun-22 vs. Dec-22	-1.964	2.7775	0.7181
Jun-22 vs. Jan-23	-1.964	2.7775	0.7181
Jun-22 vs. Feb-23	-1.964	2.7775	0.7181
Jul-22 vs. Aug-22	0.6547	0.9258	1
Jul-22 vs. Sep-22	-1.964	2.7775	0.7181
Jul-22 vs. Oct-22	-1.0911	1.543	0.9951
Jul-22 vs. Nov-22	-1.107	1.5656	0.9945
Jul-22 vs. Dec-22	-1.3284	1.8787	0.9756
Jul-22 vs. Jan-23	-1.964	2.7775	0.7181
Jul-22 vs. Feb-23	-1.964	2.7775	0.7181
Aug-22 vs. Sep-22	-1.964	2.7775	0.7181
Aug-22 vs. Oct-22	-1.964	2.7775	0.7181
Aug-22 vs. Nov-22	-1.9926	2.818	0.6987
Aug-22 vs. Dec-22	-1.964	2.7775	0.7181
Aug-22 vs. Jan-23	-1.964	2.7775	0.7181
Aug-22 vs. Feb-23	-1.964	2.7775	0.7181
Sep-22 vs. Oct-22	1.0911	1.543	0.9951
Sep-22 vs. Nov-22	1.107	1.5656	0.9945
Sep-22 vs. Dec-22	1.964	2.7775	0.7181
Sep-22 vs. Jan-23	-0.2182	0.3086	1
Sep-22 vs. Feb-23	0.6547	0.9258	1
Oct-22 vs. Nov-22	0.6642	0.9393	1
Oct-22 vs. Dec-22	0.6547	0.9258	1
Oct-22 vs. Jan-23	-1.0911	1.543	0.9951
Oct-22 vs. Feb-23	-0.8856	1.2524	0.9993
Nov-22 vs. Dec-22	0.6642	0.9393	1
Nov-22 vs. Jan-23	-1.9926	2.818	0.6987
Nov-22 vs. Feb-23	-1.107	1.5656	0.9945
Dec-22 vs. Jan-23	-1.964	2.7775	0.7181
Dec-22 vs. Feb-23	-1.964	2.7775	0.7181
Jan-23 vs. Feb-23	0.2182	0.3086	1

Table A7
Pairwise Two-Sided Multiple Comparison Analysis. Dwass, Steel, Critchlow-Fligner Method for Zinc Recovery in Copper Concentrate.

Month	Wilcoxon Z	DSCF Value	Pr > DSCF
Mar-22 vs. Apr-22	0.2182	0.3086	1
Mar-22 vs. May-22	-0.2182	0.3086	1
Mar-22 vs. Jun-22	-0.2182	0.3086	1
Mar-22 vs. Jul-22	-1.964	2.7775	0.7181
Mar-22 vs. Aug-22	-1.964	2.7775	0.7181
Mar-22 vs. Sep-22	-1.964	2.7775	0.7181
Mar-22 vs. Oct-22	-1.964	2.7775	0.7181
Mar-22 vs. Nov-22	-1.964	2.7775	0.7181
Mar-22 vs. Dec-22	-1.5275	2.1602	0.9333
Mar-22 vs. Jan-23	-1.964	2.7775	0.7181
Mar-22 vs. Feb-23	-1.0911	1.543	0.9951
Apr-22 vs. May-22	-0.6547	0.9258	1
Apr-22 vs. Jun-22	-0.2182	0.3086	1
Apr-22 vs. Jul-22	-1.964	2.7775	0.7181
Apr-22 vs. Aug-22	-1.964	2.7775	0.7181
Apr-22 vs. Sep-22	-1.964	2.7775	0.7181
Apr-22 vs. Oct-22	-1.964	2.7775	0.7181
Apr-22 vs. Nov-22	-1.964	2.7775	0.7181
Apr-22 vs. Dec-22	-1.0911	1.543	0.9951
Apr-22 vs. Jan-23	-1.964	2.7775	0.7181
Apr-22 vs. Feb-23	-1.964	2.7775	0.7181
May-22 vs. Jun-22	0.2182	0.3086	1
May-22 vs. Jul-22	-1.5275	2.1602	0.9333
May-22 vs. Aug-22	-1.964	2.7775	0.7181
May-22 vs. Sep-22	-1.964	2.7775	0.7181
May-22 vs. Oct-22	-1.964	2.7775	0.7181
May-22 vs. Nov-22	-1.964	2.7775	0.7181
May-22 vs. Dec-22	-0.2182	0.3086	1
May-22 vs. Jan-23	-0.6547	0.9258	1
May-22 vs. Feb-23	-0.2182	0.3086	1
Jun-22 vs. Jul-22	-1.964	2.7775	0.7181
Jun-22 vs. Aug-22	-1.964	2.7775	0.7181
Jun-22 vs. Sep-22	-1.964	2.7775	0.7181

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Table A7 (*continued*)

Month	Wilcoxon Z	DSCF Value	Pr > DSCF
Jun-22 vs. Oct-22	-1.964	2.7775	0.7181
Jun-22 vs. Nov-22	-1.964	2.7775	0.7181
Jun-22 vs. Dec-22	-0.2182	0.3086	1
Jun-22 vs. Jan-23	-1.964	2.7775	0.7181
Jun-22 vs. Feb-23	-1.0911	1.543	0.9951
Jul-22 vs. Aug-22	0.6547	0.9258	1
Jul-22 vs. Sep-22	0.2182	0.3086	1
Jul-22 vs. Oct-22	0.6547	0.9258	1
Jul-22 vs. Nov-22	0.6547	0.9258	1
Jul-22 vs. Dec-22	1.964	2.7775	0.7181
Jul-22 vs. Jan-23	1.964	2.7775	0.7181
Jul-22 vs. Feb-23	1.964	2.7775	0.7181
Aug-22 vs. Sep-22	-1.964	2.7775	0.7181
Aug-22 vs. Oct-22	1.964	2.7775	0.7181
Aug-22 vs. Nov-22	1.5275	2.1602	0.9333
Aug-22 vs. Dec-22	1.964	2.7775	0.7181
Aug-22 vs. Jan-23	1.964	2.7775	0.7181
Aug-22 vs. Feb-23	1.964	2.7775	0.7181
Sep-22 vs. Oct-22	1.964	2.7775	0.7181
Sep-22 vs. Nov-22	1.964	2.7775	0.7181
Sep-22 vs. Dec-22	1.964	2.7775	0.7181
Sep-22 vs. Jan-23	1.964	2.7775	0.7181
Sep-22 vs. Feb-23	1.964	2.7775	0.7181
Oct-22 vs. Nov-22	-0.6547	0.9258	1
Oct-22 vs. Dec-22	1.964	2.7775	0.7181
Oct-22 vs. Jan-23	1.964	2.7775	0.7181
Oct-22 vs. Feb-23	1.964	2.7775	0.7181
Nov-22 vs. Dec-22	1.964	2.7775	0.7181
Nov-22 vs. Jan-23	1.964	2.7775	0.7181
Nov-22 vs. Feb-23	1.964	2.7775	0.7181
Dec-22 vs. Jan-23	-1.964	2.7775	0.7181
Dec-22 vs. Feb-23	-0.2182	0.3086	1
Jan-23 vs. Feb-23	0.6547	0.9258	1

Table A8
Pairwise Two-Sided Multiple Comparison Analysis. Dwass, Steel, Critchlow-Fligner Method for Sulphur Recovery in Copper Concentrate.

Month	Wilcoxon Z	DSCF Value	Pr > DSCF
Mar-22 vs. Apr-22	0.2182	0.3086	1
Mar-22 vs. May-22	1.5275	2.1602	0.9333
Mar-22 vs. Jun-22	1.5498	2.1918	0.9265
Mar-22 vs. Jul-22	-0.6547	0.9258	1
Mar-22 vs. Aug-22	-0.6547	0.9258	1
Mar-22 vs. Sep-22	-1.964	2.7775	0.7181
Mar-22 vs. Oct-22	-1.964	2.7775	0.7181
Mar-22 vs. Nov-22	-1.964	2.7775	0.7181
Mar-22 vs. Dec-22	-0.2182	0.3086	1
Mar-22 vs. Jan-23	-1.0911	1.543	0.9951
Mar-22 vs. Feb-23	-0.6547	0.9258	1
Apr-22 vs. May-22	1.5275	2.1602	0.9333
Apr-22 vs. Jun-22	1.9926	2.818	0.6987
Apr-22 vs. Jul-22	-0.6547	0.9258	1
Apr-22 vs. Aug-22	-1.964	2.7775	0.7181
Apr-22 vs. Sep-22	-1.964	2.7775	0.7181
Apr-22 vs. Oct-22	-1.964	2.7775	0.7181
Apr-22 vs. Nov-22	-1.964	2.7775	0.7181
Apr-22 vs. Dec-22	-0.6547	0.9258	1
Apr-22 vs. Jan-23	-1.964	2.7775	0.7181
Apr-22 vs. Feb-23	-1.5275	2.1602	0.9333
May-22 vs. Jun-22	0.2214	0.3131	1
May-22 vs. Jul-22	-1.0911	1.543	0.9951
May-22 vs. Aug-22	-1.964	2.7775	0.7181
May-22 vs. Sep-22	-1.964	2.7775	0.7181
May-22 vs. Oct-22	-1.964	2.7775	0.7181
May-22 vs. Nov-22	-1.964	2.7775	0.7181
May-22 vs. Dec-22	-1.5275	2.1602	0.9333
May-22 vs. Jan-23	-1.964	2.7775	0.7181
May-22 vs. Feb-23	-1.964	2.7775	0.7181
Jun-22 vs. Jul-22	-0.6642	0.9393	1
Jun-22 vs. Aug-22	-1.9926	2.818	0.6987
Jun-22 vs. Sep-22	-1.9926	2.818	0.6987
Jun-22 vs. Oct-22	-1.9926	2.818	0.6987

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Table A8 (*continued*)

Month	Wilcoxon Z	DSCF Value	Pr > DSCF
Jun-22 vs. Nov-22	-1.9926	2.818	0.6987
Jun-22 vs. Dec-22	-1.9926	2.818	0.6987
Jun-22 vs. Jan-23	-1.9926	2.818	0.6987
Jun-22 vs. Feb-23	-1.9926	2.818	0.6987
Jul-22 vs. Aug-22	0.6547	0.9258	1
Jul-22 vs. Sep-22	-0.6547	0.9258	1
Jul-22 vs. Oct-22	-0.6547	0.9258	1
Jul-22 vs. Nov-22	-0.6547	0.9258	1
Jul-22 vs. Dec-22	0.6547	0.9258	1
Jul-22 vs. Jan-23	0.6547	0.9258	1
Jul-22 vs. Feb-23	0.2182	0.3086	1
Aug-22 vs. Sep-22	-1.964	2.7775	0.7181
Aug-22 vs. Oct-22	-1.964	2.7775	0.7181
Aug-22 vs. Nov-22	-1.964	2.7775	0.7181
Aug-22 vs. Dec-22	1.0911	1.543	0.9951
Aug-22 vs. Jan-23	-1.5275	2.1602	0.9333
Aug-22 vs. Feb-23	0.2182	0.3086	1
Sep-22 vs. Oct-22	-0.2182	0.3086	1
Sep-22 vs. Nov-22	-0.2182	0.3086	1
Sep-22 vs. Dec-22	1.964	2.7775	0.7181
Sep-22 vs. Jan-23	1.964	2.7775	0.7181
Sep-22 vs. Feb-23	1.964	2.7775	0.7181
Oct-22 vs. Nov-22	0	0	1
Oct-22 vs. Dec-22	1.964	2.7775	0.7181
Oct-22 vs. Jan-23	1.964	2.7775	0.7181
Oct-22 vs. Feb-23	1.964	2.7775	0.7181
Nov-22 vs. Dec-22	1.964	2.7775	0.7181
Nov-22 vs. Jan-23	1.964	2.7775	0.7181
Nov-22 vs. Feb-23	1.964	2.7775	0.7181
Dec-22 vs. Jan-23	-1.964	2.7775	0.7181
Dec-22 vs. Feb-23	-0.6547	0.9258	1
Jan-23 vs. Feb-23	0.6547	0.9258	1

Table A9
Pairwise Two-Sided Multiple Comparison Analysis. Dwass, Steel, Critchlow-Fligner Method for Copper recovery in Zinc Concentrate.

Month	Wilcoxon Z	DSCF Value	Pr > DSCF
Mar-22 vs. Apr-22	0.2182	0.3086	1.0000
Mar-22 vs. May-22	-1.9640	2.7775	0.7181
Mar-22 vs. Jun-22	-1.9640	2.7775	0.7181
Mar-22 vs. Jul-22	-1.9640	2.7775	0.7181
Mar-22 vs. Aug-22	-1.9640	2.7775	0.7181
Mar-22 vs. Sep-22	1.9640	2.7775	0.7181
Mar-22 vs. Oct-22	1.0911	1.5430	0.9951
Mar-22 vs. Nov-22	-0.2182	0.3086	1.0000
Mar-22 vs. Dec-22	0.2182	0.3086	1.0000
Mar-22 vs. Jan-23	1.9640	2.7775	0.7181
Mar-22 vs. Feb-23	1.9640	2.7775	0.7181
Apr-22 vs. May-22	-1.9640	2.7775	0.7181
Apr-22 vs. Jun-22	-1.9640	2.7775	0.7181
Apr-22 vs. Jul-22	-1.9640	2.7775	0.7181
Apr-22 vs. Aug-22	-1.9640	2.7775	0.7181
Apr-22 vs. Sep-22	1.9640	2.7775	0.7181
Apr-22 vs. Oct-22	1.0911	1.5430	0.9951
Apr-22 vs. Nov-22	-0.8856	1.2524	0.9993
Apr-22 vs. Dec-22	0.2182	0.3086	1.0000
Apr-22 vs. Jan-23	1.5275	2.1602	0.9333
Apr-22 vs. Feb-23	1.9640	2.7775	0.7181
May-22 vs. Jun-22	-0.2182	0.3086	1.0000
May-22 vs. Jul-22	0.6547	0.9258	1.0000
May-22 vs. Aug-22	0.6547	0.9258	1.0000
May-22 vs. Sep-22	1.9640	2.7775	0.7181
May-22 vs. Oct-22	1.9640	2.7775	0.7181
May-22 vs. Nov-22	1.9640	2.7775	0.7181
May-22 vs. Dec-22	1.9640	2.7775	0.7181
May-22 vs. Jan-23	1.9640	2.7775	0.7181
May-22 vs. Feb-23	1.9640	2.7775	0.7181
Jun-22 vs. Jul-22	0.6547	0.9258	1.0000
Jun-22 vs. Aug-22	0.6547	0.9258	1.0000
Jun-22 vs. Sep-22	1.9640	2.7775	0.7181
Jun-22 vs. Oct-22	1.9640	2.7775	0.7181
Jun-22 vs. Nov-22	1.9640	2.7775	0.7181

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Table A9 (*continued*)

Month	Wilcoxon Z	DSCF Value	Pr > DSCF
Jun-22 vs. Dec-22	1.9640	2.7775	0.7181
Jun-22 vs. Jan-23	1.9640	2.7775	0.7181
Jun-22 vs. Feb-23	1.9640	2.7775	0.7181
Jul-22 vs. Aug-22	-0.2182	0.3086	1.0000
Jul-22 vs. Sep-22	1.9640	2.7775	0.7181
Jul-22 vs. Oct-22	1.9640	2.7775	0.7181
Jul-22 vs. Nov-22	1.9640	2.7775	0.7181
Jul-22 vs. Dec-22	1.9640	2.7775	0.7181
Jul-22 vs. Jan-23	1.9640	2.7775	0.7181
Jul-22 vs. Feb-23	1.9640	2.7775	0.7181
Aug-22 vs. Sep-22	1.9640	2.7775	0.7181
Aug-22 vs. Oct-22	1.9640	2.7775	0.7181
Aug-22 vs. Nov-22	1.9640	2.7775	0.7181
Aug-22 vs. Dec-22	1.9640	2.7775	0.7181
Aug-22 vs. Jan-23	1.9640	2.7775	0.7181
Aug-22 vs. Feb-23	1.9640	2.7775	0.7181
Sep-22 vs. Oct-22	-1.9640	2.7775	0.7181
Sep-22 vs. Nov-22	-1.9640	2.7775	0.7181
Sep-22 vs. Dec-22	-1.9640	2.7775	0.7181
Sep-22 vs. Jan-23	-0.6547	0.9258	1.0000
Sep-22 vs. Feb-23	-1.9640	2.7775	0.7181
Oct-22 vs. Nov-22	-1.5275	2.1602	0.9333
Oct-22 vs. Dec-22	-1.0911	1.5430	0.9951
Oct-22 vs. Jan-23	1.0911	1.5430	0.9951
Oct-22 vs. Feb-23	0.2182	0.3086	1.0000
Nov-22 vs. Dec-22	1.0911	1.5430	0.9951
Nov-22 vs. Jan-23	1.5275	2.1602	0.9333
Nov-22 vs. Feb-23	1.9640	2.7775	0.7181
Dec-22 vs. Jan-23	1.5275	2.1602	0.9333
Dec-22 vs. Feb-23	1.0911	1.5430	0.9951
Jan-23 vs. Feb-23	-0.6547	0.9258	1.0000

Table A10
Pairwise Two-Sided Multiple Comparison Analysis. Dwass, Steel, Critchlow-Fligner Method for Iron recovery in Zinc Concentrate.

Month	Wilcoxon Z	DSCF Value	Pr > DSCF
Mar-22 vs. Apr-22	1.9640	2.7775	0.7181
Mar-22 vs. May-22	0.2182	0.3086	1.0000
Mar-22 vs. Jun-22	0.8856	1.2524	0.9993
Mar-22 vs. Jul-22	0.2182	0.3086	1.0000
Mar-22 vs. Aug-22	-0.2182	0.3086	1.0000
Mar-22 vs. Sep-22	0.6547	0.9258	1.0000
Mar-22 vs. Oct-22	1.9640	2.7775	0.7181
Mar-22 vs. Nov-22	1.0911	1.5430	0.9951
Mar-22 vs. Dec-22	1.5275	2.1602	0.9333
Mar-22 vs. Jan-23	1.5275	2.1602	0.9333
Mar-22 vs. Feb-23	0.6547	0.9258	1.0000
Apr-22 vs. May-22	-1.5275	2.1602	0.9333
Apr-22 vs. Jun-22	-1.0911	1.5430	0.9951
Apr-22 vs. Jul-22	-1.5275	2.1602	0.9333
Apr-22 vs. Aug-22	-1.9640	2.7775	0.7181
Apr-22 vs. Sep-22	-0.6547	0.9258	1.0000
Apr-22 vs. Oct-22	-0.6547	0.9258	1.0000
Apr-22 vs. Nov-22	-1.0911	1.5430	0.9951
Apr-22 vs. Dec-22	-0.6547	0.9258	1.0000
Apr-22 vs. Jan-23	-1.0911	1.5430	0.9951
Apr-22 vs. Feb-23	-1.3284	1.8787	0.9756
May-22 vs. Jun-22	0.6547	0.9258	1.0000
May-22 vs. Jul-22	-0.2182	0.3086	1.0000
May-22 vs. Aug-22	-0.2182	0.3086	1.0000
May-22 vs. Sep-22	0.4428	0.6262	1.0000
May-22 vs. Oct-22	0.6547	0.9258	1.0000
May-22 vs. Nov-22	0.2182	0.3086	1.0000
May-22 vs. Dec-22	1.0911	1.5430	0.9951
May-22 vs. Jan-23	0.2182	0.3086	1.0000
May-22 vs. Feb-23	0.2182	0.3086	1.0000
Jun-22 vs. Jul-22	-0.2182	0.3086	1.0000
Jun-22 vs. Aug-22	-0.6547	0.9258	1.0000
Jun-22 vs. Sep-22	-0.2182	0.3086	1.0000
Jun-22 vs. Oct-22	0.6547	0.9258	1.0000
Jun-22 vs. Nov-22	0.2182	0.3086	1.0000
Jun-22 vs. Dec-22	0.2182	0.3086	1.0000

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Table A10 (*continued*)

Month	Wilcoxon Z	DSCF Value	Pr > DSCF
Jun-22 vs. Jan-23	0.2182	0.3086	1.0000
Jun-22 vs. Feb-23	-0.2182	0.3086	1.0000
Jul-22 vs. Aug-22	-0.6547	0.9258	1.0000
Jul-22 vs. Sep-22	0.2182	0.3086	1.0000
Jul-22 vs. Oct-22	1.9640	2.7775	0.7181
Jul-22 vs. Nov-22	0.2182	0.3086	1.0000
Jul-22 vs. Dec-22	1.5275	2.1602	0.9333
Jul-22 vs. Jan-23	1.3284	1.8787	0.9756
Jul-22 vs. Feb-23	0.2182	0.3086	1.0000
Aug-22 vs. Sep-22	0.2182	0.3086	1.0000
Aug-22 vs. Oct-22	1.9640	2.7775	0.7181
Aug-22 vs. Nov-22	1.5275	2.1602	0.9333
Aug-22 vs. Dec-22	1.5275	2.1602	0.9333
Aug-22 vs. Jan-23	1.5275	2.1602	0.9333
Aug-22 vs. Feb-23	0.6547	0.9258	1.0000
Sep-22 vs. Oct-22	0.6547	0.9258	1.0000
Sep-22 vs. Nov-22	0.2182	0.3086	1.0000
Sep-22 vs. Dec-22	0.6547	0.9258	1.0000
Sep-22 vs. Jan-23	0.2182	0.3086	1.0000
Sep-22 vs. Feb-23	-0.2182	0.3086	1.0000
Oct-22 vs. Nov-22	-1.9640	2.7775	0.7181
Oct-22 vs. Dec-22	-0.4428	0.6262	1.0000
Oct-22 vs. Jan-23	-1.0911	1.5430	0.9951
Oct-22 vs. Feb-23	-1.5275	2.1602	0.9333
Nov-22 vs. Dec-22	1.0911	1.5430	0.9951
Nov-22 vs. Jan-23	1.0911	1.5430	0.9951
Nov-22 vs. Feb-23	-0.2182	0.3086	1.0000
Dec-22 vs. Jan-23	-0.6547	0.9258	1.0000
Dec-22 vs. Feb-23	-0.6547	0.9258	1.0000
Jan-23 vs. Feb-23	-0.6547	0.9258	1.0000

Table A11
Pairwise Two-Sided Multiple Comparison Analysis. Dwass, Steel, Critchlow-Fligner Method for Zinc recovery in Zinc Concentrate.

Month	Wilcoxon Z	DSCF Value	Pr > DSCF
Mar-22 vs. Apr-22	-1.7979	2.5426	0.8196
Mar-22 vs. May-22	0.8856	1.2524	0.9993
Mar-22 vs. Jun-22	-0.4428	0.6262	1.0000
Mar-22 vs. Jul-22	1.9640	2.7775	0.7181
Mar-22 vs. Aug-22	1.9640	2.7775	0.7181
Mar-22 vs. Sep-22	1.9640	2.7775	0.7181
Mar-22 vs. Oct-22	1.9640	2.7775	0.7181
Mar-22 vs. Nov-22	1.9640	2.7775	0.7181
Mar-22 vs. Dec-22	1.7712	2.5049	0.8339
Mar-22 vs. Jan-23	1.9640	2.7775	0.7181
Mar-22 vs. Feb-23	0.0000	0.0000	1.0000
Apr-22 vs. May-22	1.7979	2.5426	0.8196
Apr-22 vs. Jun-22	0.6642	0.9393	1.0000
Apr-22 vs. Jul-22	1.9926	2.8180	0.6987
Apr-22 vs. Aug-22	1.9926	2.8180	0.6987
Apr-22 vs. Sep-22	1.9926	2.8180	0.6987
Apr-22 vs. Oct-22	1.9926	2.8180	0.6987
Apr-22 vs. Nov-22	1.9926	2.8180	0.6987
Apr-22 vs. Dec-22	1.9926	2.8180	0.6987
Apr-22 vs. Jan-23	1.9926	2.8180	0.6987
Apr-22 vs. Feb-23	1.1593	1.6396	0.9918
May-22 vs. Jun-22	-1.0911	1.5430	0.9951
May-22 vs. Jul-22	1.9640	2.7775	0.7181
May-22 vs. Aug-22	1.9640	2.7775	0.7181
May-22 vs. Sep-22	1.9640	2.7775	0.7181
May-22 vs. Oct-22	1.7712	2.5049	0.8339
May-22 vs. Nov-22	1.9640	2.7775	0.7181
May-22 vs. Dec-22	0.4428	0.6262	1.0000
May-22 vs. Jan-23	1.3284	1.8787	0.9756
May-22 vs. Feb-23	-0.2182	0.3086	1.0000
Jun-22 vs. Jul-22	1.9640	2.7775	0.7181
Jun-22 vs. Aug-22	1.9640	2.7775	0.7181
Jun-22 vs. Sep-22	1.9640	2.7775	0.7181
Jun-22 vs. Oct-22	1.9640	2.7775	0.7181
Jun-22 vs. Nov-22	1.9640	2.7775	0.7181
Jun-22 vs. Dec-22	1.9640	2.7775	0.7181
Jun-22 vs. Jan-23	1.9640	2.7775	0.7181

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Table A11 (*continued*)

Month	Wilcoxon Z	DSCF Value	Pr > DSCF
Jun-22 vs. Feb-23	0.4428	0.6262	1.0000
Jul-22 vs. Aug-22	-0.6547	0.9258	1.0000
Jul-22 vs. Sep-22	-0.6547	0.9258	1.0000
Jul-22 vs. Oct-22	-1.7712	2.5049	0.8339
Jul-22 vs. Nov-22	-1.5275	2.1602	0.9333
Jul-22 vs. Dec-22	-1.9640	2.7775	0.7181
Jul-22 vs. Jan-23	-1.9640	2.7775	0.7181
Jul-22 vs. Feb-23	-1.9640	2.7775	0.7181
Aug-22 vs. Sep-22	1.9640	2.7775	0.7181
Aug-22 vs. Oct-22	-1.9640	2.7775	0.7181
Aug-22 vs. Nov-22	-1.9640	2.7775	0.7181
Aug-22 vs. Dec-22	-1.9640	2.7775	0.7181
Aug-22 vs. Jan-23	-1.9640	2.7775	0.7181
Aug-22 vs. Feb-23	-1.9640	2.7775	0.7181
Sep-22 vs. Oct-22	-1.9640	2.7775	0.7181
Sep-22 vs. Nov-22	-1.9640	2.7775	0.7181
Sep-22 vs. Dec-22	-1.9640	2.7775	0.7181
Sep-22 vs. Jan-23	-1.9640	2.7775	0.7181
Sep-22 vs. Feb-23	-1.9640	2.7775	0.7181
Oct-22 vs. Nov-22	1.0911	1.5430	0.9951
Oct-22 vs. Dec-22	-1.5275	2.1602	0.9333
Oct-22 vs. Jan-23	-1.0911	1.5430	0.9951
Oct-22 vs. Feb-23	-1.5275	2.1602	0.9333
Nov-22 vs. Dec-22	-1.9640	2.7775	0.7181
Nov-22 vs. Jan-23	-1.9640	2.7775	0.7181
Nov-22 vs. Feb-23	-1.9640	2.7775	0.7181
Dec-22 vs. Jan-23	0.6742	0.9535	0.9999
Dec-22 vs. Feb-23	-1.0911	1.5430	0.9951
Jan-23 vs. Feb-23	-1.5275	2.1602	0.9333

Table A12
Pairwise Two-Sided Multiple Comparison Analysis. Dwass, Steel, Critchlow-Fligner Method for Sulphur recovery in Zinc Concentrate.

Month	Wilcoxon Z	DSCF Value	Pr > DSCF
Mar-22 vs. Apr-22	1.5275	2.1602	0.9333
Mar-22 vs. May-22	1.9640	2.7775	0.7181
Mar-22 vs. Jun-22	1.9926	2.8180	0.6987
Mar-22 vs. Jul-22	0.6547	0.9258	1.0000
Mar-22 vs. Aug-22	1.9640	2.7775	0.7181
Mar-22 vs. Sep-22	1.9640	2.7775	0.7181
Mar-22 vs. Oct-22	1.9640	2.7775	0.7181
Mar-22 vs. Nov-22	1.0911	1.5430	0.9951
Mar-22 vs. Dec-22	1.9640	2.7775	0.7181
Mar-22 vs. Jan-23	1.9640	2.7775	0.7181
Mar-22 vs. Feb-23	1.0911	1.5430	0.9951
Apr-22 vs. May-22	-0.6547	0.9258	1.0000
Apr-22 vs. Jun-22	0.2214	0.3131	1.0000
Apr-22 vs. Jul-22	0.4428	0.6262	1.0000
Apr-22 vs. Aug-22	1.0911	1.5430	0.9951
Apr-22 vs. Sep-22	1.9640	2.7775	0.7181
Apr-22 vs. Oct-22	-0.6547	0.9258	1.0000
Apr-22 vs. Nov-22	-1.0911	1.5430	0.9951
Apr-22 vs. Dec-22	0.8856	1.2524	0.9993
Apr-22 vs. Jan-23	1.0911	1.5430	0.9951
Apr-22 vs. Feb-23	0.0000	0.0000	1.0000
May-22 vs. Jun-22	1.9926	2.8180	0.6987
May-22 vs. Jul-22	0.6547	0.9258	1.0000
May-22 vs. Aug-22	1.0911	1.5430	0.9951
May-22 vs. Sep-22	1.9640	2.7775	0.7181
May-22 vs. Oct-22	-1.5275	2.1602	0.9333
May-22 vs. Nov-22	-1.3284	1.8787	0.9756
May-22 vs. Dec-22	1.0911	1.5430	0.9951
May-22 vs. Jan-23	1.0911	1.5430	0.9951
May-22 vs. Feb-23	0.6547	0.9258	1.0000
Jun-22 vs. Jul-22	0.2214	0.3131	1.0000
Jun-22 vs. Aug-22	-0.2214	0.3131	1.0000
Jun-22 vs. Sep-22	1.3484	1.9069	0.9726
Jun-22 vs. Oct-22	-1.9926	2.8180	0.6987
Jun-22 vs. Nov-22	-1.9926	2.8180	0.6987
Jun-22 vs. Dec-22	-0.2214	0.3131	1.0000
Jun-22 vs. Jan-23	-0.2214	0.3131	1.0000
Jun-22 vs. Feb-23	-0.2214	0.3131	1.0000

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Table A12 (*continued*)

Month	Wilcoxon Z	DSCF Value	Pr > DSCF
Jul-22 vs. Aug-22	0.2182	0.3086	1.0000
Jul-22 vs. Sep-22	1.0911	1.5430	0.9951
Jul-22 vs. Oct-22	-0.6547	0.9258	1.0000
Jul-22 vs. Nov-22	-0.6547	0.9258	1.0000
Jul-22 vs. Dec-22	0.0000	0.0000	1.0000
Jul-22 vs. Jan-23	0.2182	0.3086	1.0000
Jul-22 vs. Feb-23	-0.2182	0.3086	1.0000
Aug-22 vs. Sep-22	1.0911	1.5430	0.9951
Aug-22 vs. Oct-22	-1.9640	2.7775	0.7181
Aug-22 vs. Nov-22	-1.7712	2.5049	0.8339
Aug-22 vs. Dec-22	-0.6547	0.9258	1.0000
Aug-22 vs. Jan-23	-0.6547	0.9258	1.0000
Aug-22 vs. Feb-23	-1.0911	1.5430	0.9951
Sep-22 vs. Oct-22	-1.9640	2.7775	0.7181
Sep-22 vs. Nov-22	-1.9640	2.7775	0.7181
Sep-22 vs. Dec-22	-1.7712	2.5049	0.8339
Sep-22 vs. Jan-23	-1.3284	1.8787	0.9756
Sep-22 vs. Feb-23	-1.9640	2.7775	0.7181
Oct-22 vs. Nov-22	0.2182	0.3086	1.0000
Oct-22 vs. Dec-22	1.9640	2.7775	0.7181
Oct-22 vs. Jan-23	1.9640	2.7775	0.7181
Oct-22 vs. Feb-23	0.6547	0.9258	1.0000
Nov-22 vs. Dec-22	1.9640	2.7775	0.7181
Nov-22 vs. Jan-23	1.5275	2.1602	0.9333
Nov-22 vs. Feb-23	0.6547	0.9258	1.0000
Dec-22 vs. Jan-23	0.4428	0.6262	1.0000
Dec-22 vs. Feb-23	-0.6547	0.9258	1.0000
Jan-23 vs. Feb-23	-1.0911	1.5430	0.9951

Table A13
Pairwise Two-Sided Multiple Comparison Analysis. Dwass, Steel, Critchlow-Fligner Method for Copper grade in Copper Concentrate.

Month	Wilcoxon Z	DSCF Value	Pr > DSCF
Mar-22 vs. Apr-22	1.0911	1.5430	0.9951
Mar-22 vs. May-22	-0.6547	0.9258	1.0000
Mar-22 vs. Jun-22	-0.6547	0.9258	1.0000
Mar-22 vs. Jul-22	0.6547	0.9258	1.0000
Mar-22 vs. Aug-22	1.0911	1.5430	0.9951
Mar-22 vs. Sep-22	1.9640	2.7775	0.7181
Mar-22 vs. Oct-22	1.5275	2.1602	0.9333
Mar-22 vs. Nov-22	1.5275	2.1602	0.9333
Mar-22 vs. Dec-22	1.5275	2.1602	0.9333
Mar-22 vs. Jan-23	1.9640	2.7775	0.7181
Mar-22 vs. Feb-23	1.9640	2.7775	0.7181
Apr-22 vs. May-22	-1.9640	2.7775	0.7181
Apr-22 vs. Jun-22	-1.9640	2.7775	0.7181
Apr-22 vs. Jul-22	0.6547	0.9258	1.0000
Apr-22 vs. Aug-22	1.0911	1.5430	0.9951
Apr-22 vs. Sep-22	1.9640	2.7775	0.7181
Apr-22 vs. Oct-22	1.0911	1.5430	0.9951
Apr-22 vs. Nov-22	1.0911	1.5430	0.9951
Apr-22 vs. Dec-22	1.5275	2.1602	0.9333
Apr-22 vs. Jan-23	1.9640	2.7775	0.7181
Apr-22 vs. Feb-23	1.9640	2.7775	0.7181
May-22 vs. Jun-22	0.2182	0.3086	1.0000
May-22 vs. Jul-22	1.0911	1.5430	0.9951
May-22 vs. Aug-22	1.9640	2.7775	0.7181
May-22 vs. Sep-22	1.9640	2.7775	0.7181
May-22 vs. Oct-22	1.9640	2.7775	0.7181
May-22 vs. Nov-22	1.9640	2.7775	0.7181
May-22 vs. Dec-22	1.9640	2.7775	0.7181
May-22 vs. Jan-23	1.9640	2.7775	0.7181
May-22 vs. Feb-23	1.9640	2.7775	0.7181
Jun-22 vs. Jul-22	0.6547	0.9258	1.0000
Jun-22 vs. Aug-22	1.9640	2.7775	0.7181
Jun-22 vs. Sep-22	1.9640	2.7775	0.7181
Jun-22 vs. Oct-22	1.9640	2.7775	0.7181
Jun-22 vs. Nov-22	1.9640	2.7775	0.7181
Jun-22 vs. Dec-22	1.9640	2.7775	0.7181
Jun-22 vs. Jan-23	1.9640	2.7775	0.7181
Jun-22 vs. Feb-23	1.9640	2.7775	0.7181
Jul-22 vs. Aug-22	-0.6547	0.9258	1.0000

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Table A13 (*continued*)

Month	Wilcoxon Z	DSCF Value	Pr > DSCF
Jul-22 vs. Sep-22	0.2182	0.3086	1.0000
Jul-22 vs. Oct-22	-0.6547	0.9258	1.0000
Jul-22 vs. Nov-22	-0.6547	0.9258	1.0000
Jul-22 vs. Dec-22	-0.6547	0.9258	1.0000
Jul-22 vs. Jan-23	0.2182	0.3086	1.0000
Jul-22 vs. Feb-23	0.2182	0.3086	1.0000
Aug-22 vs. Sep-22	1.9640	2.7775	0.7181
Aug-22 vs. Oct-22	0.6547	0.9258	1.0000
Aug-22 vs. Nov-22	0.2182	0.3086	1.0000
Aug-22 vs. Dec-22	0.2182	0.3086	1.0000
Aug-22 vs. Jan-23	1.9640	2.7775	0.7181
Aug-22 vs. Feb-23	1.9640	2.7775	0.7181
Sep-22 vs. Oct-22	-1.0911	1.5430	0.9951
Sep-22 vs. Nov-22	-1.9640	2.7775	0.7181
Sep-22 vs. Dec-22	-1.5275	2.1602	0.9333
Sep-22 vs. Jan-23	-0.2182	0.3086	1.0000
Sep-22 vs. Feb-23	-0.8856	1.2524	0.9993
Oct-22 vs. Nov-22	-1.0911	1.5430	0.9951
Oct-22 vs. Dec-22	-0.2182	0.3086	1.0000
Oct-22 vs. Jan-23	1.5275	2.1602	0.9333
Oct-22 vs. Feb-23	0.2182	0.3086	1.0000
Nov-22 vs. Dec-22	0.2182	0.3086	1.0000
Nov-22 vs. Jan-23	1.9640	2.7775	0.7181
Nov-22 vs. Feb-23	1.9640	2.7775	0.7181
Dec-22 vs. Jan-23	1.9640	2.7775	0.7181
Dec-22 vs. Feb-23	1.0911	1.5430	0.9951
Jan-23 vs. Feb-23	-1.0911	1.5430	0.9951

Table A14
Pairwise Two-Sided Multiple Comparison Analysis. Dwass, Steel, Critchlow-Fligner Method for Iron grade in Copper Concentrate.

Month	Wilcoxon Z	DSCF Value	Pr > DSCF
Mar-22 vs. Apr-22	1.0911	1.5430	0.9951
Mar-22 vs. May-22	1.9640	2.7775	0.7181
Mar-22 vs. Jun-22	1.9640	2.7775	0.7181
Mar-22 vs. Jul-22	1.9640	2.7775	0.7181
Mar-22 vs. Aug-22	1.9640	2.7775	0.7181
Mar-22 vs. Sep-22	1.9640	2.7775	0.7181
Mar-22 vs. Oct-22	1.9640	2.7775	0.7181
Mar-22 vs. Nov-22	1.9640	2.7775	0.7181
Mar-22 vs. Dec-22	1.9640	2.7775	0.7181
Mar-22 vs. Jan-23	1.9640	2.7775	0.7181
Mar-22 vs. Feb-23	1.9926	2.8180	0.6987
Apr-22 vs. May-22	1.9640	2.7775	0.7181
Apr-22 vs. Jun-22	1.9640	2.7775	0.7181
Apr-22 vs. Jul-22	1.9640	2.7775	0.7181
Apr-22 vs. Aug-22	1.9640	2.7775	0.7181
Apr-22 vs. Sep-22	1.9640	2.7775	0.7181
Apr-22 vs. Oct-22	1.9640	2.7775	0.7181
Apr-22 vs. Nov-22	1.9640	2.7775	0.7181
Apr-22 vs. Dec-22	1.9640	2.7775	0.7181
Apr-22 vs. Jan-23	1.9640	2.7775	0.7181
Apr-22 vs. Feb-23	1.5498	2.1918	0.9265
May-22 vs. Jun-22	-0.6547	0.9258	1.0000
May-22 vs. Jul-22	1.9640	2.7775	0.7181
May-22 vs. Aug-22	1.9640	2.7775	0.7181
May-22 vs. Sep-22	1.9640	2.7775	0.7181
May-22 vs. Oct-22	-0.6547	0.9258	1.0000
May-22 vs. Nov-22	-0.6547	0.9258	1.0000
May-22 vs. Dec-22	0.2182	0.3086	1.0000
May-22 vs. Jan-23	0.2182	0.3086	1.0000
May-22 vs. Feb-23	-1.1070	1.5656	0.9945
Jun-22 vs. Jul-22	1.9640	2.7775	0.7181
Jun-22 vs. Aug-22	1.9640	2.7775	0.7181
Jun-22 vs. Sep-22	1.9640	2.7775	0.7181
Jun-22 vs. Oct-22	1.0911	1.5430	0.9951
Jun-22 vs. Nov-22	0.0000	0.0000	1.0000
Jun-22 vs. Dec-22	1.0911	1.5430	0.9951
Jun-22 vs. Jan-23	0.2182	0.3086	1.0000
Jun-22 vs. Feb-23	-0.2214	0.3131	1.0000
Jul-22 vs. Aug-22	-0.6547	0.9258	1.0000
Jul-22 vs. Sep-22	-1.5275	2.1602	0.9333

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Table A14 (*continued*)

Month	Wilcoxon Z	DSCF Value	Pr > DSCF
Jul-22 vs. Oct-22	-1.9640	2.7775	0.7181
Jul-22 vs. Nov-22	-1.9640	2.7775	0.7181
Jul-22 vs. Dec-22	-1.9640	2.7775	0.7181
Jul-22 vs. Jan-23	-1.9640	2.7775	0.7181
Jul-22 vs. Feb-23	-1.9926	2.8180	0.6987
Aug-22 vs. Sep-22	-0.6547	0.9258	1.0000
Aug-22 vs. Oct-22	-1.9640	2.7775	0.7181
Aug-22 vs. Nov-22	-1.9640	2.7775	0.7181
Aug-22 vs. Dec-22	-1.9640	2.7775	0.7181
Aug-22 vs. Jan-23	-1.9640	2.7775	0.7181
Aug-22 vs. Feb-23	-1.9926	2.8180	0.6987
Sep-22 vs. Oct-22	-1.9640	2.7775	0.7181
Sep-22 vs. Nov-22	-1.9640	2.7775	0.7181
Sep-22 vs. Dec-22	-1.9640	2.7775	0.7181
Sep-22 vs. Jan-23	-1.9640	2.7775	0.7181
Sep-22 vs. Feb-23	-1.9926	2.8180	0.6987
Oct-22 vs. Nov-22	-1.5275	2.1602	0.9333
Oct-22 vs. Dec-22	0.6547	0.9258	1.0000
Oct-22 vs. Jan-23	-0.2182	0.3086	1.0000
Oct-22 vs. Feb-23	-1.1070	1.5656	0.9945
Nov-22 vs. Dec-22	1.5275	2.1602	0.9333
Nov-22 vs. Jan-23	0.4428	0.6262	1.0000
Nov-22 vs. Feb-23	-0.2214	0.3131	1.0000
Dec-22 vs. Jan-23	-0.2182	0.3086	1.0000
Dec-22 vs. Feb-23	-1.1070	1.5656	0.9945
Jan-23 vs. Feb-23	-0.2214	0.3131	1.0000

Table A15
Pairwise Two-Sided Multiple Comparison Analysis. Dwass, Steel, Critchlow-Fligner Method for Zinc grade in Copper Concentrate.

Month	Wilcoxon Z	DSCF Value	Pr > DSCF
Mar-22 vs. Apr-22	1.0911	1.5430	0.9951
Mar-22 vs. May-22	-1.0911	1.5430	0.9951
Mar-22 vs. Jun-22	-1.0911	1.5430	0.9951
Mar-22 vs. Jul-22	-1.9640	2.7775	0.7181
Mar-22 vs. Aug-22	-1.9640	2.7775	0.7181
Mar-22 vs. Sep-22	-1.9640	2.7775	0.7181
Mar-22 vs. Oct-22	-1.9640	2.7775	0.7181
Mar-22 vs. Nov-22	-1.9640	2.7775	0.7181
Mar-22 vs. Dec-22	-0.2182	0.3086	1.0000
Mar-22 vs. Jan-23	0.2182	0.3086	1.0000
Mar-22 vs. Feb-23	-0.2182	0.3086	1.0000
Apr-22 vs. May-22	-1.9640	2.7775	0.7181
Apr-22 vs. Jun-22	-1.0911	1.5430	0.9951
Apr-22 vs. Jul-22	-1.9640	2.7775	0.7181
Apr-22 vs. Aug-22	-1.9640	2.7775	0.7181
Apr-22 vs. Sep-22	-1.9640	2.7775	0.7181
Apr-22 vs. Oct-22	-1.9640	2.7775	0.7181
Apr-22 vs. Nov-22	-1.9640	2.7775	0.7181
Apr-22 vs. Dec-22	-1.0911	1.5430	0.9951
Apr-22 vs. Jan-23	-1.0911	1.5430	0.9951
Apr-22 vs. Feb-23	-1.0911	1.5430	0.9951
May-22 vs. Jun-22	0.2182	0.3086	1.0000
May-22 vs. Jul-22	-1.9640	2.7775	0.7181
May-22 vs. Aug-22	-1.9640	2.7775	0.7181
May-22 vs. Sep-22	-1.5275	2.1602	0.9333
May-22 vs. Oct-22	-1.0911	1.5430	0.9951
May-22 vs. Nov-22	-0.6547	0.9258	1.0000
May-22 vs. Dec-22	0.6547	0.9258	1.0000
May-22 vs. Jan-23	1.3284	1.8787	0.9756
May-22 vs. Feb-23	1.5275	2.1602	0.9333
Jun-22 vs. Jul-22	-1.9640	2.7775	0.7181
Jun-22 vs. Aug-22	-1.9640	2.7775	0.7181
Jun-22 vs. Sep-22	-1.5275	2.1602	0.9333
Jun-22 vs. Oct-22	-1.5275	2.1602	0.9333
Jun-22 vs. Nov-22	-1.9640	2.7775	0.7181
Jun-22 vs. Dec-22	1.0911	1.5430	0.9951
Jun-22 vs. Jan-23	0.6547	0.9258	1.0000
Jun-22 vs. Feb-23	0.6547	0.9258	1.0000
Jul-22 vs. Aug-22	1.0911	1.5430	0.9951
Jul-22 vs. Sep-22	1.9640	2.7775	0.7181
Jul-22 vs. Oct-22	1.9640	2.7775	0.7181

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Table A15 (*continued*)

Month	Wilcoxon Z	DSCF Value	Pr > DSCF
Jul-22 vs. Nov-22	1.9640	2.7775	0.7181
Jul-22 vs. Dec-22	1.9640	2.7775	0.7181
Jul-22 vs. Jan-23	1.9640	2.7775	0.7181
Jul-22 vs. Feb-23	1.9640	2.7775	0.7181
Aug-22 vs. Sep-22	1.0911	1.5430	0.9951
Aug-22 vs. Oct-22	1.9640	2.7775	0.7181
Aug-22 vs. Nov-22	1.9640	2.7775	0.7181
Aug-22 vs. Dec-22	1.9640	2.7775	0.7181
Aug-22 vs. Jan-23	1.9640	2.7775	0.7181
Aug-22 vs. Feb-23	1.9640	2.7775	0.7181
Sep-22 vs. Oct-22	1.0911	1.5430	0.9951
Sep-22 vs. Nov-22	0.6547	0.9258	1.0000
Sep-22 vs. Dec-22	1.9640	2.7775	0.7181
Sep-22 vs. Jan-23	1.9640	2.7775	0.7181
Sep-22 vs. Feb-23	1.9640	2.7775	0.7181
Oct-22 vs. Nov-22	-0.6547	0.9258	1.0000
Oct-22 vs. Dec-22	1.9640	2.7775	0.7181
Oct-22 vs. Jan-23	1.9640	2.7775	0.7181
Oct-22 vs. Feb-23	1.9640	2.7775	0.7181
Nov-22 vs. Dec-22	1.9640	2.7775	0.7181
Nov-22 vs. Jan-23	1.9640	2.7775	0.7181
Nov-22 vs. Feb-23	1.9640	2.7775	0.7181
Dec-22 vs. Jan-23	0.2182	0.3086	1.0000
Dec-22 vs. Feb-23	0.6547	0.9258	1.0000
Jan-23 vs. Feb-23	-0.2182	0.3086	1.0000

Table A16
Pairwise Two-Sided Multiple Comparison Analysis. Dwass, Steel, Critchlow-Fligner Method for Sulphur grade in Copper Concentrate.

Month	Wilcoxon Z	DSCF Value	Pr > DSCF
Mar-22 vs. Apr-22	1.9640	2.7775	0.7181
Mar-22 vs. May-22	1.0911	1.5430	0.9951
Mar-22 vs. Jun-22	1.9640	2.7775	0.7181
Mar-22 vs. Jul-22	0.6547	0.9258	1.0000
Mar-22 vs. Aug-22	0.2182	0.3086	1.0000
Mar-22 vs. Sep-22	0.2182	0.3086	1.0000
Mar-22 vs. Oct-22	0.6547	0.9258	1.0000
Mar-22 vs. Nov-22	-1.0911	1.5430	0.9951
Mar-22 vs. Dec-22	1.9640	2.7775	0.7181
Mar-22 vs. Jan-23	1.9640	2.7775	0.7181
Mar-22 vs. Feb-23	1.9640	2.7775	0.7181
Apr-22 vs. May-22	-0.6547	0.9258	1.0000
Apr-22 vs. Jun-22	0.6547	0.9258	1.0000
Apr-22 vs. Jul-22	0.2182	0.3086	1.0000
Apr-22 vs. Aug-22	-1.9640	2.7775	0.7181
Apr-22 vs. Sep-22	-0.6547	0.9258	1.0000
Apr-22 vs. Oct-22	-1.5275	2.1602	0.9333
Apr-22 vs. Nov-22	-1.9640	2.7775	0.7181
Apr-22 vs. Dec-22	-0.2182	0.3086	1.0000
Apr-22 vs. Jan-23	1.9640	2.7775	0.7181
Apr-22 vs. Feb-23	0.6547	0.9258	1.0000
May-22 vs. Jun-22	0.6547	0.9258	1.0000
May-22 vs. Jul-22	-0.2182	0.3086	1.0000
May-22 vs. Aug-22	-1.0911	1.5430	0.9951
May-22 vs. Sep-22	-1.0911	1.5430	0.9951
May-22 vs. Oct-22	-1.0911	1.5430	0.9951
May-22 vs. Nov-22	-1.9640	2.7775	0.7181
May-22 vs. Dec-22	0.6547	0.9258	1.0000
May-22 vs. Jan-23	1.5275	2.1602	0.9333
May-22 vs. Feb-23	0.6547	0.9258	1.0000
Jun-22 vs. Jul-22	-0.2182	0.3086	1.0000
Jun-22 vs. Aug-22	-1.9640	2.7775	0.7181
Jun-22 vs. Sep-22	-1.0911	1.5430	0.9951
Jun-22 vs. Oct-22	-1.5275	2.1602	0.9333
Jun-22 vs. Nov-22	-1.9640	2.7775	0.7181
Jun-22 vs. Dec-22	-0.6547	0.9258	1.0000
Jun-22 vs. Jan-23	1.5275	2.1602	0.9333
Jun-22 vs. Feb-23	-0.2182	0.3086	1.0000
Jul-22 vs. Aug-22	-0.6547	0.9258	1.0000
Jul-22 vs. Sep-22	-0.2182	0.3086	1.0000
Jul-22 vs. Oct-22	-0.6547	0.9258	1.0000
Jul-22 vs. Nov-22	-0.6547	0.9258	1.0000

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Table A16 (*continued*)

Month	Wilcoxon Z	DSCF Value	Pr > DSCF
Jul-22 vs. Dec-22	-0.6547	0.9258	1.0000
Jul-22 vs. Jan-23	1.9640	2.7775	0.7181
Jul-22 vs. Feb-23	0.2182	0.3086	1.0000
Aug-22 vs. Sep-22	-0.6547	0.9258	1.0000
Aug-22 vs. Oct-22	0.2182	0.3086	1.0000
Aug-22 vs. Nov-22	-0.8856	1.2524	0.9993
Aug-22 vs. Dec-22	1.9640	2.7775	0.7181
Aug-22 vs. Jan-23	1.9640	2.7775	0.7181
Aug-22 vs. Feb-23	1.9640	2.7775	0.7181
Sep-22 vs. Oct-22	0.2182	0.3086	1.0000
Sep-22 vs. Nov-22	-0.2182	0.3086	1.0000
Sep-22 vs. Dec-22	0.6547	0.9258	1.0000
Sep-22 vs. Jan-23	1.9640	2.7775	0.7181
Sep-22 vs. Feb-23	1.0911	1.5430	0.9951
Oct-22 vs. Nov-22	-1.0911	1.5430	0.9951
Oct-22 vs. Dec-22	1.0911	1.5430	0.9951
Oct-22 vs. Jan-23	1.9640	2.7775	0.7181
Oct-22 vs. Feb-23	1.5275	2.1602	0.9333
Nov-22 vs. Dec-22	1.9640	2.7775	0.7181
Nov-22 vs. Jan-23	1.9640	2.7775	0.7181
Nov-22 vs. Feb-23	1.9640	2.7775	0.7181
Dec-22 vs. Jan-23	1.9640	2.7775	0.7181
Dec-22 vs. Feb-23	0.6547	0.9258	1.0000
Jan-23 vs. Feb-23	-1.9640	2.7775	0.7181

Table A17
Pairwise Two-Sided Multiple Comparison Analysis. Dwass, Steel, Critchlow-Fligner Method for Copper Grade in Zinc Concentrate.

Month	Wilcoxon Z	DSCF Value	Pr > DSCF
Mar-22 vs. Apr-22	-1.0911	1.5430	0.9951
Mar-22 vs. May-22	-1.9640	2.7775	0.7181
Mar-22 vs. Jun-22	-1.9640	2.7775	0.7181
Mar-22 vs. Jul-22	-1.9640	2.7775	0.7181
Mar-22 vs. Aug-22	-1.9640	2.7775	0.7181
Mar-22 vs. Sep-22	1.5275	2.1602	0.9333
Mar-22 vs. Oct-22	0.2182	0.3086	1.0000
Mar-22 vs. Nov-22	-0.8856	1.2524	0.9993
Mar-22 vs. Dec-22	-0.8989	1.2713	0.9991
Mar-22 vs. Jan-23	0.4428	0.6262	1.0000
Mar-22 vs. Feb-23	1.5275	2.1602	0.9333
Apr-22 vs. May-22	-1.9640	2.7775	0.7181
Apr-22 vs. Jun-22	-1.9640	2.7775	0.7181
Apr-22 vs. Jul-22	-1.9640	2.7775	0.7181
Apr-22 vs. Aug-22	-1.9640	2.7775	0.7181
Apr-22 vs. Sep-22	1.9640	2.7775	0.7181
Apr-22 vs. Oct-22	0.6547	0.9258	1.0000
Apr-22 vs. Nov-22	0.2182	0.3086	1.0000
Apr-22 vs. Dec-22	0.2214	0.3131	1.0000
Apr-22 vs. Jan-23	1.0911	1.5430	0.9951
Apr-22 vs. Feb-23	1.9640	2.7775	0.7181
May-22 vs. Jun-22	-0.2182	0.3086	1.0000
May-22 vs. Jul-22	-0.4428	0.6262	1.0000
May-22 vs. Aug-22	-0.4428	0.6262	1.0000
May-22 vs. Sep-22	1.9640	2.7775	0.7181
May-22 vs. Oct-22	1.9640	2.7775	0.7181
May-22 vs. Nov-22	1.9640	2.7775	0.7181
May-22 vs. Dec-22	1.9926	2.8180	0.6987
May-22 vs. Jan-23	1.9640	2.7775	0.7181
May-22 vs. Feb-23	1.9640	2.7775	0.7181
Jun-22 vs. Jul-22	-0.4428	0.6262	1.0000
Jun-22 vs. Aug-22	-0.4428	0.6262	1.0000
Jun-22 vs. Sep-22	1.9640	2.7775	0.7181
Jun-22 vs. Oct-22	1.9640	2.7775	0.7181
Jun-22 vs. Nov-22	1.9640	2.7775	0.7181
Jun-22 vs. Dec-22	1.9926	2.8180	0.6987
Jun-22 vs. Jan-23	1.9640	2.7775	0.7181
Jun-22 vs. Feb-23	1.9640	2.7775	0.7181
Jul-22 vs. Aug-22	-0.2182	0.3086	1.0000
Jul-22 vs. Sep-22	1.9640	2.7775	0.7181
Jul-22 vs. Oct-22	1.9640	2.7775	0.7181
Jul-22 vs. Nov-22	1.9640	2.7775	0.7181
Jul-22 vs. Dec-22	1.9926	2.8180	0.6987

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Table A17 (*continued*)

Month	Wilcoxon Z	DSCF Value	Pr > DSCF
Jul-22 vs. Jan-23	1.9640	2.7775	0.7181
Jul-22 vs. Feb-23	1.9640	2.7775	0.7181
Aug-22 vs. Sep-22	1.9640	2.7775	0.7181
Aug-22 vs. Oct-22	1.9640	2.7775	0.7181
Aug-22 vs. Nov-22	1.9640	2.7775	0.7181
Aug-22 vs. Dec-22	1.9926	2.8180	0.6987
Aug-22 vs. Jan-23	1.9640	2.7775	0.7181
Aug-22 vs. Feb-23	1.9640	2.7775	0.7181
Sep-22 vs. Oct-22	-1.0911	1.5430	0.9951
Sep-22 vs. Nov-22	-1.7712	2.5049	0.8339
Sep-22 vs. Dec-22	-1.5498	2.1918	0.9265
Sep-22 vs. Jan-23	-0.6547	0.9258	1.0000
Sep-22 vs. Feb-23	0.2182	0.3086	1.0000
Oct-22 vs. Nov-22	-0.6547	0.9258	1.0000
Oct-22 vs. Dec-22	-0.2214	0.3131	1.0000
Oct-22 vs. Jan-23	0.4428	0.6262	1.0000
Oct-22 vs. Feb-23	1.3284	1.8787	0.9756
Nov-22 vs. Dec-22	-0.6642	0.9393	1.0000
Nov-22 vs. Jan-23	1.3284	1.8787	0.9756
Nov-22 vs. Feb-23	1.9640	2.7775	0.7181
Dec-22 vs. Jan-23	1.1070	1.5656	0.9945
Dec-22 vs. Feb-23	1.5498	2.1918	0.9265
Jan-23 vs. Feb-23	0.8856	1.2524	0.9993

Table A18
Pairwise Two-Sided Multiple Comparison Analysis. Dwass, Steel, Critchlow-Fligner Method for Iron Grade in Zinc Concentrate.

Month	Wilcoxon Z	DSCF Value	Pr > DSCF
Mar-22 vs. Apr-22	1.0911	1.5430	0.9951
Mar-22 vs. May-22	0.6547	0.9258	1.0000
Mar-22 vs. Jun-22	0.6547	0.9258	1.0000
Mar-22 vs. Jul-22	-1.9640	2.7775	0.7181
Mar-22 vs. Aug-22	-1.9640	2.7775	0.7181
Mar-22 vs. Sep-22	0.6547	0.9258	1.0000
Mar-22 vs. Oct-22	-1.0911	1.5430	0.9951
Mar-22 vs. Nov-22	-1.9640	2.7775	0.7181
Mar-22 vs. Dec-22	1.0911	1.5430	0.9951
Mar-22 vs. Jan-23	0.6547	0.9258	1.0000
Mar-22 vs. Feb-23	1.9640	2.7775	0.7181
Apr-22 vs. May-22	-0.2182	0.3086	1.0000
Apr-22 vs. Jun-22	0.2182	0.3086	1.0000
Apr-22 vs. Jul-22	-1.9640	2.7775	0.7181
Apr-22 vs. Aug-22	-1.9640	2.7775	0.7181
Apr-22 vs. Sep-22	0.2182	0.3086	1.0000
Apr-22 vs. Oct-22	-1.5275	2.1602	0.9333
Apr-22 vs. Nov-22	-1.9640	2.7775	0.7181
Apr-22 vs. Dec-22	0.2182	0.3086	1.0000
Apr-22 vs. Jan-23	0.2182	0.3086	1.0000
Apr-22 vs. Feb-23	0.6547	0.9258	1.0000
May-22 vs. Jun-22	0.2182	0.3086	1.0000
May-22 vs. Jul-22	-1.5275	2.1602	0.9333
May-22 vs. Aug-22	-0.6547	0.9258	1.0000
May-22 vs. Sep-22	0.6547	0.9258	1.0000
May-22 vs. Oct-22	-1.0911	1.5430	0.9951
May-22 vs. Nov-22	-1.0911	1.5430	0.9951
May-22 vs. Dec-22	0.2182	0.3086	1.0000
May-22 vs. Jan-23	0.2182	0.3086	1.0000
May-22 vs. Feb-23	1.9640	2.7775	0.7181
Jun-22 vs. Jul-22	-1.5275	2.1602	0.9333
Jun-22 vs. Aug-22	-0.6547	0.9258	1.0000
Jun-22 vs. Sep-22	0.2182	0.3086	1.0000
Jun-22 vs. Oct-22	-1.0911	1.5430	0.9951
Jun-22 vs. Nov-22	-1.0911	1.5430	0.9951
Jun-22 vs. Dec-22	-0.2182	0.3086	1.0000
Jun-22 vs. Jan-23	-0.2182	0.3086	1.0000
Jun-22 vs. Feb-23	0.6547	0.9258	1.0000
Jul-22 vs. Aug-22	1.9640	2.7775	0.7181
Jul-22 vs. Sep-22	1.0911	1.5430	0.9951
Jul-22 vs. Oct-22	1.5275	2.1602	0.9333
Jul-22 vs. Nov-22	1.5275	2.1602	0.9333
Jul-22 vs. Dec-22	1.9640	2.7775	0.7181
Jul-22 vs. Jan-23	1.9640	2.7775	0.7181

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Table A18 (*continued*)

Month	Wilcoxon Z	DSCF Value	Pr > DSCF
Jul-22 vs. Feb-23	1.9640	2.7775	0.7181
Aug-22 vs. Sep-22	0.6547	0.9258	1.0000
Aug-22 vs. Oct-22	0.2182	0.3086	1.0000
Aug-22 vs. Nov-22	0.0000	0.0000	1.0000
Aug-22 vs. Dec-22	1.9640	2.7775	0.7181
Aug-22 vs. Jan-23	1.5275	2.1602	0.9333
Aug-22 vs. Feb-23	1.9640	2.7775	0.7181
Sep-22 vs. Oct-22	-0.6547	0.9258	1.0000
Sep-22 vs. Nov-22	-0.6547	0.9258	1.0000
Sep-22 vs. Dec-22	-0.2182	0.3086	1.0000
Sep-22 vs. Jan-23	-0.2182	0.3086	1.0000
Sep-22 vs. Feb-23	0.6547	0.9258	1.0000
Oct-22 vs. Nov-22	-0.2182	0.3086	1.0000
Oct-22 vs. Dec-22	1.0911	1.5430	0.9951
Oct-22 vs. Jan-23	1.5275	2.1602	0.9333
Oct-22 vs. Feb-23	1.9640	2.7775	0.7181
Nov-22 vs. Dec-22	1.9640	2.7775	0.7181
Nov-22 vs. Jan-23	1.5275	2.1602	0.9333
Nov-22 vs. Feb-23	1.9640	2.7775	0.7181
Dec-22 vs. Jan-23	-0.2182	0.3086	1.0000
Dec-22 vs. Feb-23	0.6547	0.9258	1.0000
Jan-23 vs. Feb-23	0.6547	0.9258	1.0000

Table A19
Pairwise Two-Sided Multiple Comparison Analysis. Dwass, Steel, Critchlow-Fligner Method for Zinc Grade in Zinc Concentrate.

Month	Wilcoxon Z	DSCF Value	Pr > DSCF
Mar-22 vs. Apr-22	-1.0911	1.5430	0.9951
Mar-22 vs. May-22	0.2182	0.3086	1.0000
Mar-22 vs. Jun-22	0.2182	0.3086	1.0000
Mar-22 vs. Jul-22	1.9640	2.7775	0.7181
Mar-22 vs. Aug-22	1.9640	2.7775	0.7181
Mar-22 vs. Sep-22	1.9640	2.7775	0.7181
Mar-22 vs. Oct-22	1.5275	2.1602	0.9333
Mar-22 vs. Nov-22	1.9640	2.7775	0.7181
Mar-22 vs. Dec-22	-0.2182	0.3086	1.0000
Mar-22 vs. Jan-23	0.6547	0.9258	1.0000
Mar-22 vs. Feb-23	1.5275	2.1602	0.9333
Apr-22 vs. May-22	1.5275	2.1602	0.9333
Apr-22 vs. Jun-22	1.5275	2.1602	0.9333
Apr-22 vs. Jul-22	1.9640	2.7775	0.7181
Apr-22 vs. Aug-22	1.9640	2.7775	0.7181
Apr-22 vs. Sep-22	1.9640	2.7775	0.7181
Apr-22 vs. Oct-22	1.9640	2.7775	0.7181
Apr-22 vs. Nov-22	1.9640	2.7775	0.7181
Apr-22 vs. Dec-22	1.5275	2.1602	0.9333
Apr-22 vs. Jan-23	1.9640	2.7775	0.7181
Apr-22 vs. Feb-23	1.5275	2.1602	0.9333
May-22 vs. Jun-22	-0.2182	0.3086	1.0000
May-22 vs. Jul-22	1.5275	2.1602	0.9333
May-22 vs. Aug-22	1.9640	2.7775	0.7181
May-22 vs. Sep-22	1.9640	2.7775	0.7181
May-22 vs. Oct-22	0.6547	0.9258	1.0000
May-22 vs. Nov-22	1.0911	1.5430	0.9951
May-22 vs. Dec-22	-0.6547	0.9258	1.0000
May-22 vs. Jan-23	-0.6547	0.9258	1.0000
May-22 vs. Feb-23	0.2182	0.3086	1.0000
Jun-22 vs. Jul-22	1.9640	2.7775	0.7181
Jun-22 vs. Aug-22	1.9640	2.7775	0.7181
Jun-22 vs. Sep-22	1.9640	2.7775	0.7181
Jun-22 vs. Oct-22	1.9640	2.7775	0.7181
Jun-22 vs. Nov-22	1.9640	2.7775	0.7181
Jun-22 vs. Dec-22	-0.6547	0.9258	1.0000
Jun-22 vs. Jan-23	0.6547	0.9258	1.0000
Jun-22 vs. Feb-23	1.0911	1.5430	0.9951
Jul-22 vs. Aug-22	-0.6547	0.9258	1.0000
Jul-22 vs. Sep-22	0.2182	0.3086	1.0000
Jul-22 vs. Oct-22	-1.9640	2.7775	0.7181
Jul-22 vs. Nov-22	-1.5275	2.1602	0.9333
Jul-22 vs. Dec-22	-1.9640	2.7775	0.7181
Jul-22 vs. Jan-23	-1.9640	2.7775	0.7181
Jul-22 vs. Feb-23	-1.9640	2.7775	0.7181

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Table A19 (*continued*)

Month	Wilcoxon Z	DSCF Value	Pr > DSCF
Aug-22 vs. Sep-22	1.0911	1.5430	0.9951
Aug-22 vs. Oct-22	-1.9640	2.7775	0.7181
Aug-22 vs. Nov-22	-1.9640	2.7775	0.7181
Aug-22 vs. Dec-22	-1.9640	2.7775	0.7181
Aug-22 vs. Jan-23	-1.9640	2.7775	0.7181
Aug-22 vs. Feb-23	-1.9640	2.7775	0.7181
Sep-22 vs. Oct-22	-1.9640	2.7775	0.7181
Sep-22 vs. Nov-22	-1.9640	2.7775	0.7181
Sep-22 vs. Dec-22	-1.9640	2.7775	0.7181
Sep-22 vs. Jan-23	-1.9640	2.7775	0.7181
Sep-22 vs. Feb-23	-1.9640	2.7775	0.7181
Oct-22 vs. Nov-22	1.9640	2.7775	0.7181
Oct-22 vs. Dec-22	-1.9640	2.7775	0.7181
Oct-22 vs. Jan-23	-1.9640	2.7775	0.7181
Oct-22 vs. Feb-23	0.6547	0.9258	1.0000
Nov-22 vs. Dec-22	-1.9640	2.7775	0.7181
Nov-22 vs. Jan-23	-1.9640	2.7775	0.7181
Nov-22 vs. Feb-23	-1.9640	2.7775	0.7181
Dec-22 vs. Jan-23	1.0911	1.5430	0.9951
Dec-22 vs. Feb-23	1.0911	1.5430	0.9951
Jan-23 vs. Feb-23	0.6547	0.9258	1.0000

Table A20
Pairwise Two-Sided Multiple Comparison Analysis. Dwass, Steel, Critchlow-Fligner Method for Sulphur Grade in Zinc Concentrate.

Month	Wilcoxon Z	DSCF Value	Pr > DSCF
Mar-22 vs. Apr-22	1.0911	1.5430	0.9951
Mar-22 vs. May-22	1.9640	2.7775	0.7181
Mar-22 vs. Jun-22	1.9640	2.7775	0.7181
Mar-22 vs. Jul-22	1.9640	2.7775	0.7181
Mar-22 vs. Aug-22	1.9640	2.7775	0.7181
Mar-22 vs. Sep-22	1.9640	2.7775	0.7181
Mar-22 vs. Oct-22	1.0911	1.5430	0.9951
Mar-22 vs. Nov-22	1.9640	2.7775	0.7181
Mar-22 vs. Dec-22	1.9640	2.7775	0.7181
Mar-22 vs. Jan-23	1.9640	2.7775	0.7181
Mar-22 vs. Feb-23	1.9640	2.7775	0.7181
Apr-22 vs. May-22	1.9640	2.7775	0.7181
Apr-22 vs. Jun-22	1.9640	2.7775	0.7181
Apr-22 vs. Jul-22	1.5275	2.1602	0.9333
Apr-22 vs. Aug-22	1.9640	2.7775	0.7181
Apr-22 vs. Sep-22	1.9640	2.7775	0.7181
Apr-22 vs. Oct-22	0.6547	0.9258	1.0000
Apr-22 vs. Nov-22	1.9640	2.7775	0.7181
Apr-22 vs. Dec-22	1.0911	1.5430	0.9951
Apr-22 vs. Jan-23	1.9640	2.7775	0.7181
Apr-22 vs. Feb-23	1.9640	2.7775	0.7181
May-22 vs. Jun-22	1.9640	2.7775	0.7181
May-22 vs. Jul-22	0.6547	0.9258	1.0000
May-22 vs. Aug-22	1.0911	1.5430	0.9951
May-22 vs. Sep-22	1.9640	2.7775	0.7181
May-22 vs. Oct-22	-1.0911	1.5430	0.9951
May-22 vs. Nov-22	-1.0911	1.5430	0.9951
May-22 vs. Dec-22	-1.9640	2.7775	0.7181
May-22 vs. Jan-23	0.2182	0.3086	1.0000
May-22 vs. Feb-23	-0.2182	0.3086	1.0000
Jun-22 vs. Jul-22	0.2182	0.3086	1.0000
Jun-22 vs. Aug-22	-0.4428	0.6262	1.0000
Jun-22 vs. Sep-22	0.2182	0.3086	1.0000
Jun-22 vs. Oct-22	-1.9640	2.7775	0.7181
Jun-22 vs. Nov-22	-1.9640	2.7775	0.7181
Jun-22 vs. Dec-22	-1.9640	2.7775	0.7181
Jun-22 vs. Jan-23	-1.0911	1.5430	0.9951
Jun-22 vs. Feb-23	-1.9640	2.7775	0.7181
Jul-22 vs. Aug-22	-0.2182	0.3086	1.0000
Jul-22 vs. Sep-22	-0.6547	0.9258	1.0000
Jul-22 vs. Oct-22	-1.0911	1.5430	0.9951
Jul-22 vs. Nov-22	-0.6547	0.9258	1.0000
Jul-22 vs. Dec-22	-1.5275	2.1602	0.9333
Jul-22 vs. Jan-23	-0.6547	0.9258	1.0000
Jul-22 vs. Feb-23	-0.6547	0.9258	1.0000
Aug-22 vs. Sep-22	0.4428	0.6262	1.0000

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Table A20 (*continued*)

Month	Wilcoxon Z	DSCF Value	Pr > DSCF
Aug-22 vs. Oct-22	-1.9640	2.7775	0.7181
Aug-22 vs. Nov-22	-1.0911	1.5430	0.9951
Aug-22 vs. Dec-22	-1.9640	2.7775	0.7181
Aug-22 vs. Jan-23	-0.6547	0.9258	1.0000
Aug-22 vs. Feb-23	-1.0911	1.5430	0.9951
Sep-22 vs. Oct-22	-1.9640	2.7775	0.7181
Sep-22 vs. Nov-22	-1.9640	2.7775	0.7181
Sep-22 vs. Dec-22	-1.9640	2.7775	0.7181
Sep-22 vs. Jan-23	-0.6547	0.9258	1.0000
Sep-22 vs. Feb-23	-1.9640	2.7775	0.7181
Oct-22 vs. Nov-22	1.0911	1.5430	0.9951
Oct-22 vs. Dec-22	-0.6547	0.9258	1.0000
Oct-22 vs. Jan-23	1.5275	2.1602	0.9333
Oct-22 vs. Feb-23	1.0911	1.5430	0.9951
Nov-22 vs. Dec-22	-1.9640	2.7775	0.7181
Nov-22 vs. Jan-23	0.6547	0.9258	1.0000
Nov-22 vs. Feb-23	0.2182	0.3086	1.0000
Dec-22 vs. Jan-23	1.9640	2.7775	0.7181
Dec-22 vs. Feb-23	1.9640	2.7775	0.7181
Jan-23 vs. Feb-23	-0.6547	0.9258	1.0000

Appendix B

Water Quality

Table B1
Kidd process water ICP-AES scan results.

Element	Concentration (mg/L)											
	March	April	May	June	July	August	Sept	Oct	Nov	Dec	Jan	Feb
Ag	<0.046	<0.046	<0.0095	<0.046	<0.049	<0.075	<0.039	<0.044	<0.044	<0.045	<0.045	<0.054
Al	<0.37	<0.37	0.131	<0.37	<0.26	<0.21	0.2	0.343	<0.33	0.296	0.206	<0.089
As	<0.75	<0.75	<0.65	<0.75	<0.91	<0.36	<0.55	<0.74	<0.74	<0.40	<0.40	<0.50
B	0.0455	<0.036	<0.52	0.0443	<0.52	0.0466	<0.049	<0.042	<0.042	<0.024	0.0275	0.0581
Ba	0.0111	0.0096	0.0122	0.0176	0.0169	0.0216	0.0139	0.0112	0.0096	0.0105	0.0094	0.0081
Be	<0.0045	<0.0045	<0.0011	<0.0045	<0.0045	0.0007	0.0003	<0.0045	<0.0045	0	0	<0.0045
Bi	<0.27	<0.27	<0.22	<0.27	<0.90	<0.28	<0.69	<0.26	0.275	<0.20	<0.20	<0.81
Ca	276	252	253.4	335	435.9	422.1	440	359	368	288	322	377
Cd	<0.052	<0.052	<0.021	<0.052	<0.046	<0.031	<0.039	<0.028	<0.028	<0.034	<0.034	<0.038
Co	<0.13	<0.13	<0.053	<0.13	0.02	<0.060	<0.023	<0.070	<0.070	<0.040	<0.040	<0.086
Cr	<0.082	<0.082	<0.039	<0.082	<0.066	<0.065	<0.029	<0.033	<0.033	<0.034	<0.034	<0.025
Cu	<0.11	<0.11	<0.0071	<0.11	<0.17	<0.075	<0.047	<0.053	<0.053	<0.065	<0.065	<0.15
Fe	<0.041	0.0609	0.0555	<0.041	<0.073	<0.051	0.281	0.143	0.458	0.221	0.138	0.14
K	10.11	5.58	9.67	9.69	11.28	10.68	8.98	9.98	9.52	8.26	17.46	17.29
Li	<0.025	<0.025	<0.55	<0.025	<0.27	<0.24	<0.27	<0.24	<0.24	<0.23	<0.23	<0.23
Mg	14.67	7.77	14.12	8.42	4.19	4.73	5.2	5.23	2.68	22.05	17.06	19.23
Mn	0.024	<0.016	0.0215	<0.016	<0.0089	0.0291	0.0182	<0.014	0.025	0.0086	<0.0055	<0.022
Mo	<0.19	<0.19	<0.36	<0.19	<0.20	<0.15	<0.15	<0.15	<0.15	<0.10	<0.10	<0.11
Na	47.64	23.86	46.19	42.19	49.93	48.46	40.19	33.32	36.39	38.33	61.34	70.94
Ni	<0.24	<0.24	<0.082	<0.24	<0.18	<0.038	<0.14	<0.12	<0.12	<0.10	<0.10	<0.15
P	<0.38	<0.38	<0.29	<0.38	<1.56	<0.47	<0.54	<0.35	<0.35	<0.56	<0.56	<0.47
Pb	<0.53	<0.53	<0.42	<0.53	<0.78	<0.31	<0.58	<0.33	<0.33	<0.30	<0.30	<0.18
S	268	233	<0.043	309	400	382	406	325	337	292	341	396
Sb	<0.42	<0.42	257.3	<0.42	<1.17	<0.35	<0.38	<0.76	<0.76	<0.52	<0.52	<0.55
Se	<1.26	<1.26	<0.54	<1.26	<1.80	<0.87	<0.37	<0.67	<0.67	<1.02	<1.02	<1.14
Si	1.09	0.427	<2.49	1.15	0.826	1.43	0.947	0.885	0.856	1.38	1.04	0.622
Sr	0.523	0.445	1.01	0.671	0.865	0.879	0.778	0.625	0.655	0.577	0.633	0.728
Te	<1.01	<1.01	0.531	<1.01	<0.12	<0.56	<0.90	<0.72	<0.72	<0.38	<0.38	<1.14
Ti	<0.011	<0.011	<0.44	<0.011	<1.57	<0.0089	<0.0084	<0.018	<0.018	<0.021	<0.021	<0.026
Tl	<0.87	<0.87	<0.012	<0.87	<0.018	<0.38	<0.79	<0.50	<0.50	<0.68	<0.68	<0.62
V	<0.033	<0.033	<0.33	<0.033	<0.99	<0.029	<0.022	<0.024	<0.024	<0.028	<0.028	<0.048
Zn	<0.015	<0.015	0.0372	<0.015	<0.093	<0.020	0.0819	0.0483	0.112	0.0463	0.0196	<0.022
Zr	<0.041	<0.041	<0.025	<0.041	<0.043	<0.046	<0.038	<0.038	<0.038	<0.018	<0.018	<0.022

References

Aljobaily, Hend. 2018. Non-parametric analysis of the variance in SAS®. *SAS Conference Proceedings: Western Users of SAS Software 2018*, 1-10. Sacramento, CA, United States. https://www.lexjansen.com/wuss/2018/26_Final_Paper_PDF.pdf.

Basilio, C.I., Kartio, JI., Yoon, R.H., 1996. Lead activation of sphalerite during galena flotation. Miner. Eng. 9 (8), 869–879. https://doi.org/10.1016/0892-6875(96)00078-7.

Bıçak, Ö., Ekmekçi, Z., Can, M., Öztürk, Y., 2012. The effect of water chemistry on froth stability and surface chemistry of the flotation of a Cu–Zn sulfide ore. Int. J. Miner. Process. 102–103, 32–37. https://doi.org/10.1016/j.minpro.2011.09.005.

Bıçak, Ö., Cakir, E., Ozcelik, S., Ekmekçi, Z., 2023. The impact of pulp temperature on the flotation performance of copper-lead-zinc sulphide ore. Minerals 13 (9), 1181. https://doi.org/10.3390/min13091181.
Broman, P.G., 1980. Water reuse at sulphide ore concentrators in Sweden: Practice, experience and current developments. In: Jones, M.J. (Ed.), Complex Sulphide Ores. Institution of Mining and Metallurgy, pp. 28–39.
Bulut, G., Yenial, Ü., 2016. Effects of major ions in recycled water on sulfide minerals flotation. Miner. Metall. Process 33 (3), 137–143. https://doi.org/10.19150/mmp.6750.
Corin, K.C., Reddy, A., Miyen, L., Wiese, J.G., Harris, P.J., 2011. The effect of ionic strength of plant water on valuable mineral and gangue recovery in a platinum bearing ore from the Merensky reef. Miner. Eng. 24 (2), 131–137. https://doi.org/10.1016/j.mineng.2010.10.015.
Corin, K.C., Tetlow, S., Manono, M., 2022. Considering the action of frothers under degrading water quality. Miner. Eng. 181, 107546 https://doi.org/10.1016/j.mineng.2022.107546.
Corin, K.C., Charamba, A., Manono, M.S., 2024. Water quality impact on flotation response: a focus on specific ions and temperature. Miner. Eng. 207, 108549 https://doi.org/10.1016/j.mineng.2023.108549.
Critchlow, D.E., Fligner, M.A., 1991. On distribution-free multiple comparisons in the one-way analysis of variance. Communications in Statistics—Theory and Methods 20, 127–139.
Deng, J., Mao, Y., Wen, S., Liu, J., Xian, Y., Feng, Q., 2015. New influence factor inducing difficulty in selective flotation separation of Cu-Zn mixed sulfide minerals. Int. J. Miner. Metall. Mater. 22 (2), 111–115. https://doi.org/10.1007/s12613-015-1050-x.
Di Feo, A., Hill-Svehla, C.M., Hart, B.R., Volchek, K., Morin, L., Demers, A., 2021. The effects of water recycling on flotation at a North American concentrator. Miner. Eng. 170, 107037 https://doi.org/10.1016/j.mineng.2021.107037.
Di Feo, T., Lastra, R., 2019. Effects of collectors and frothers on copper and molybdenum coarse particle recoveries—a statistical approach. J. Miner. Mater. Charact. Eng. 7, 117–136. https://doi.org/10.4236/jmmce.2019.73009.
Dwass, M., 1960. Some k-Sample Rank-Order Tests. In: Olkin, I., Ghurye, S.G., Hoeffding, W., Madow, W.G., Mann, H.B. (Eds.), Contributions to Probability and Statistics: Essays in Honor of Harold Hotelling. Stanford University Press, Stanford, CA, pp. 198–202.
Dzingai, M., Manono, M., Corin, K., 2020. Simulating the effect of water recirculation on flotation through ion-spiking: effect of Ca2+ and Mg2+. Minerals 10 (11), 1033. https://doi.org/10.3390/min10111033.
Dzingai, M., Manono, M., Corin, K.C., 2021. Probing the effect of water recycling on flotation through anion spiking using a low-grade Cu–Ni–PGM ore: The effect of NO3−, SO42− and S2O32−. Minerals 11 (4), 340. https://doi.org/10.3390/min11040340.
Fernandes, I.I.R. 2016. *Influence of temperature on sulphide ore flotation* [PhD Thesis] University of Lisbon.
Gerson, A., Napier-Munn, T., 2013. Integrated approaches for the study of real mineral flotation systems. Minerals 3 (1), 1–15. https://doi.org/10.3390/min3010001.
He, F. 2013. *Nonparametric MANOVA approaches for non-normal multivariate outcomes* [PhD Thesis]. University of Pittsburgh.
Ji, Y., Lu, Q., Liu, Q., Zeng, H., 2013. Effect of solution salinity on settling of mineral tailings by polymer flocculants. Colloids Surf A Physicochem Eng. Asp. 430, 29–38. https://doi.org/10.1016/j.colsurfa.2013.04.006.
Johnson, R.A., Wichern, D.W., 2019. Applied multivariate statistical analysis, (6th Ed.). Pearson Prentice Hall.
Kelebek, S., Beauchamp, J.B., Murphy, D.A., Marrs, Macnamara, D.D., 1996. Column flotation practice in Cu-Ni separation at Falconbridge. In C. O. Gomez and J. A. Finch (Eds.), *Column'96, Proceedings of the Int. Symp. on Column Flotation at the 35th Annual Conf. of Metallurgists*, CIM, 119-134.
Le, T.M.K., Schreithofer, N., Dahl, O., 2020. Dissolution test protocol for estimating water quality changes in minerals processing plants operating with closed water circulation. Minerals 10 (8), 653. https://doi.org/10.3390/min10080653.
Levanaho, J., Hoover, K., Spence, C., Bachewich, B., 2005. Effect of pulp temperature on copper and gold collectors at Hudson Bay Mining and Smelting. Proce. Canadian Mineral Processors 481–496.
Lin, I.J., 1989. The effect of seasonal variations in temperature on the performance of mineral processing plants. Miner. Eng. 2 (1), 47–54. https://doi.org/10.1016/0892-6875(89)90064-2.
Liu, L., Rao, S.R., Finch, J.A., 1993. Technical note laboratory study of effect of recycle water on flotation of a Cu/Zn sulphide ore. Miner. Eng. 6 (11), 1183–1190. https://doi.org/10.1016/0892-6875(93)90095-5.
Manenzhe, R.M., Manono, M.S., Wiese, J.G., Musuku, B., Corin, K.C., 2023. Exploring the effects of different process water sources on xanthate adsorption and flotation performance. Miner. Eng. 204, 108376 https://doi.org/10.1016/j.mineng.2023.108376.
Manono, M., Corin, K.C., Wiese, J.G., 2012. An investigation into the effect of various ions and their ionic strength on the flotation performance of a platinum bearing ore from the Merensky reef. Miner. Eng. 36–38, 231–236. https://doi.org/10.1016/j.mineng.2012.03.035.
Manono, M., Corin, K.C., Wiese, J.G., 2013. The effect of ionic strength of plant water on foam stability: a 2-phase flotation study. Miner. Eng. 40, 42–47. https://doi.org/10.1016/j.mineng.2012.09.009.
Moimane, T.M., Corin, K.C., Wiese, J.G., 2016. The effect of varying pulp reagent chemistry on the flotation performance of a South African PGM ore. Miner. Eng. 95, 155–160. https://doi.org/10.1016/j.mineng.2016.07.002.
Muzinda, I., Schreithofer, N., 2018. Water quality effects on flotation: Impacts and control of residual xanthates. Miner. Eng. 125, 34–41. https://doi.org/10.1016/j.mineng.2018.03.032.
Nesset, J.E., Gomez, C.O., Finch, J.A., Hernandez-Aguilar, J., DiFeo, A., 2005. The use of gas dispersion measurements to improve flotation performance. Proceedings of the Canadian Mineral Processors 2005, 401–421.
O'Connor, C.T., Dunne, R.C., Botelho de Sousa, A.M.R., 1984. The effect of temperature on the flotation of pyrite. J. S. Afr. Inst. Min. Metall. 84 (12), 389–394.
O'Connor, C., Mills, P.J., 1990. The effect of temperature on the pulp and froth phases in the flotation of pyrite. Miner. Eng. 3 (6), 615–624. https://doi.org/10.1016/0892-6875(90)90006-w.
Özçelik, S., Ekmekçi, Z., 2022. Reducing negative effects of oxidation on flotation of complex Cu–Zn sulfide ores. Minerals 12 (8), 1016. https://doi.org/10.3390/min12081016.
Pashkevich, D., Li, R., Waters, K., 2022. Temperature and climate-induced fluctuations in froth flotation: an overview of different ore types. Can. Metall. Q. 62 (3), 511–548. https://doi.org/10.1080/00084433.2022.2127788.
Pugh, R.J., Weissenborn, P., Paulson, O., 1997. Flotation in inorganic electrolytes; the relationship between recover of hydrophobic particles, surface tension, bubble coalescence and gas solubility. Int. J. Miner. Process. 51 (1–4), 125–138. https://doi.org/10.1016/S0301-7516(97)00021-5.
Rao, S.R., Finch, J.A., 1989. A review of water re-use in flotation. Miner. Eng. 2 (1), 65–85. https://doi.org/10.1016/0892-6875(89)90066-6.
Roberts, J., Deredin, C., Paulin, J-G., 2008. Process improvement update at Brunswick Mine. of the CIM, Ottawa, ON, Canada, pp. 27–49.
Steel, R.G.D., 1960. A Rank Sum Test for Comparing All Pairs of Treatments. Technometrics 2, 197–207.
Tang, M., Wen, S., 2019. Effects of cations/anions in recycled tailing water on cationic reverse flotation of iron oxides. Minerals 9 (3), 161. https://doi.org/10.3390/min9030161.
Taylor, J., White, S., Leggett, T., 2020. Glencore – The Kidd Concentrator. In: Bobicki, E. R., Gibson, C.E., Boulanger, J.F. (Eds.), *Canadian milling practice*, 2020 Edition. Canadian Institute of Mining, Metallurgy and Petroleum, pp. 34–41.
Weissenborn, P.K., Pugh, R.J., 1995. Surface tension and bubble coalescence phenomena of aqueous solutions of electrolytes. Langmuir 11 (5), 1422–1426. https://doi.org/10.1021/la00005a002.
Xu, M., Wilson, S., 2000. Investigation of seasonal metallurgical shift at Inco's Clarabelle mill. Miner. Eng. 13 (12), 1207–1218. https://doi.org/10.1016/S0892-6875(00)00105-9.
XLSTAT Help Center. 2023. How to interpret contradictory results between ANOVA and multiple pairwise comparisons?. XLSTAT. https://help.xlstat.com/6741-how-interpret-contradictory-results-between-anova-and.

Further reading

Marais, P., 1980. Some practical considerations in the design and operation of a plant for the differential flotation of mixed sulphides, especially copper and zinc. J. South African Institute of Mining and Metallurgy 72 (11), 385–394.