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Untilization of Handheld XRF Gun as a Quick Analyzer in Monitoring Flotation Plant Tailing Leaching of Gold Ore in Pahang, Malaysia

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Abstract

This study examines the use of handheld XRF as an alternative method for determining gold content in dried tailing slurry from the resin in leach process, addressing the time constraints of AAS analysis in gold ore flotation. The flotation method was employed to enhance the gold concentration in samples collected every 2 hours from the feed, final concentrate, and final tailing areas. XRF Gun analysis was performed for 1 minute, while fire assay fusion was conducted at a maximum temperature of 1000°C, followed by cupellation for 1 hour. The results showed a significant correlation in Au values measured only in the concentrate, with an adjusted R Square of 0.494, indicating that XRF variables influenced 49.4% of the AAS results. Each unit increase in XRF corresponded to a 0.601 increase in AAS. Handheld XRF offers speed and portability, whereas AAS provides high accuracy and precision. Factors affecting measurement accuracy include the detection limit, sample matrix composition, sample homogeneity, and instrument calibration for XRF, and sample preparation, reagent quality, operational conditions, and chemical interference for AAS. This research contributes to rapid and portable gold content monitoring methods in the mining industry.

Keywords: Gold; Flotation; Handheld XRF; Atomic Absorption Spectroscopy; Mineral Processing

Introduction

Indonesia, which is located on the magmatic arc path, has its own advantages with abundant epithermal deposit potential, one of which is the wealth of producing gold in nature. Gold (Au) is a metal that has high economic value, so that is why gold metal mining is carried out both on a small and large scale (Cheng & Iwasaki, 1992). In the mining process, removing gold is not completely free from impurities (Fedotov et al., 2022). Therefore, processing is needed to remove valuable minerals in the form of Au as a concentrate and other impurities as tailings that are mixed by utilizing the surface

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properties of minerals, this is because one of the beneficiation processes that is widely carried out on base metals is flotation (Palit et al., 2022).

The flotation method has a working principle based on the difference in surface properties of minerals between hydrophilic and hydrophobic which is assisted by chemical reagents (Satria Umar Dani, 2023; Soemali et al., 2022). The ore to be processed experiences an increase in content, so that from the results of the processing it is expected to obtain benefits such as reducing transportation from the processing site to the smelting site, reducing smelting costs, and reducing additives (flux) during smelting, because the higher the content released means the level of impurity minerals is smaller, so the flux needed is also less (Latief, 2024).

The method of fire assay analysis is one of the gravimetric methods that involve the smelting process (smelting), and this method is only known to determine the content of precious metals such as gold and silver (Joseph Haffty, 1977). X-ray Fluorescence (XRF) is effective for measuring elements ranging from beryllium to uranium elements at trace element levels to below ppm levels (Sry Putri et al., 2023). XRF testing is used to analyze the chemical content of the main elements of minerals such as Al, Au, Ca, Na, K, Si, Mn, and other elements (Oyedotun, 2018). According to research (Spearman et al., 2022). XRF testing can be used as an alternative in measuring the initial levels of AAS testing. The handled XRF method has the advantage of being used in in situ analysis, non-destructive, and fast measurements (Frydrych & Jurowski, 2023). The tailing leaching process using the flotation method requires monitoring so that the results obtained reach the target such as content and recovery (Huang et al., 2022). However, in the gold content check at that time, it was carried out using AAS which took about 6 hours to get the calculation results (Mu & Peng, 2021). Of course, it also took a long time because the flotation plant has a continuous circuit so monitoring and fast action are needed from operators and metallurgists in maintaining performance at the plant (Forrest ~ et al., 2001). To overcome this, an alternative to checking the content using a handheld XRF is carried out generally used in world geology to test mineral rocks. This study will explain the use of a handheld XRF gun with fast analysis in monitoring flotation plants on leachate tailings releasing gold when compared to AAS (Lee et al., 2022; Naklicki et al., 2002)

Research Methods

The sample used for this study was tailing slurry from dried gold resin in leach. In this study, the flotation method was used to increase the gold content in the sample. This flotation process takes place continuously (Afolabi et al., 2013). The feed comes from the lake which is the tailing from the leaching process which is then pumped to the RIL tank. The feed that has entered the RIL tank is then distributed to the flotation plant. In this flotation plant there are 2 conditioning tanks, 5 cell roughers, 5 cell scavengers #1, 4 cell

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scavengers #2, 4 cell scavengers #3, 3 cell cleaners #1, 2 cell cleaners #2, 1 cell cleaner #3, 2 cell cleaners #4, and 1 cell cleaner #5 which then becomes the final concentrate. The feed process that comes from RIL will later enter conditioning tank #1 and conditioning tank #2, in this conditioning tank the feed is added with reagents. After the conditioning tank, the feed will enter the rougher cell, scavenger cell, and cleaner cell, until the final process becomes concentrate. The circuit in this flotation plant is continuous where the underflow from the rougher will return to the scavenger and so on.

Samples are tested in a cake state and taken every 2 hours. Sampling is done by the grab sampling method. Grab sampling is done by taking a slurry (Hassanzadeh & Hasanzadeh, 2016). Grab sampling is taken manually. Grab sampling is done by taking samples at several specific points and taking representative proportions. In this stage, grab sampling is done in the feed area, final concentrate, and final tailings then be analyzed in the laboratory. The analysis process using a Handheld XRF Analyzer is carried out for 1 minute. Melting in the fire assay process is carried out with a maximum temperature of 1000 ° C, followed by a cupellation process carried out for 1 hour, and AAS is carried out as a follow-up stage of the fire assay to analyze (Forrest ~ et al., 2001).

Research Results and Discussion

In this study, a flotation processing method has been carried out to obtain the gold content in the leaching tailings slurry. There are limited data that can be used as data for the results of this study. Analysis of the content in the flotation process was carried out with two variations, namely using the Handheld XRF Analyzer and Atomic Absorption Spectroscopy. The difference in the analysis results of the two tools will be compared to determine the effectiveness of use and factors that affect the accuracy and precision of the two tools in monitoring the flotation plant tailings leaching gold ore.

To determine the initial gold content (head grade) in the tailing slurry sample that will be used as feed in this study using two tools, namely the Handheld XRF Analyzer and Atomic Absorption Spectroscopy (AAS). The results of the initial gold content analysis in the tailing slurry sample can be seen in Table 1, and the two sets of data from the analysis results are plotted in a regression graph shown in Figure 1 below.

Table 1. Feed Analysis Results

Feed		
Measuring Au (ppm) using Handheld XRF	Actual Au (ppm) using AAS	Actual Au (ppm) using AAS
5,8	0,51	
5,9	0,43	
5,8	0,41	

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6,4	0,36
5,6	0,42
6,1	0,44
5,9	0,34
5,5	0,41
5,7	0,44
5,5	0,40
5,5	0,42
5,7	0,47
5,5	0,46
5,4	0,44
6,2	0,36
5,8	0,40
5,6	0,26
5,1	0,27
5,9	0,31
5,9	0,30
5,8	0,37

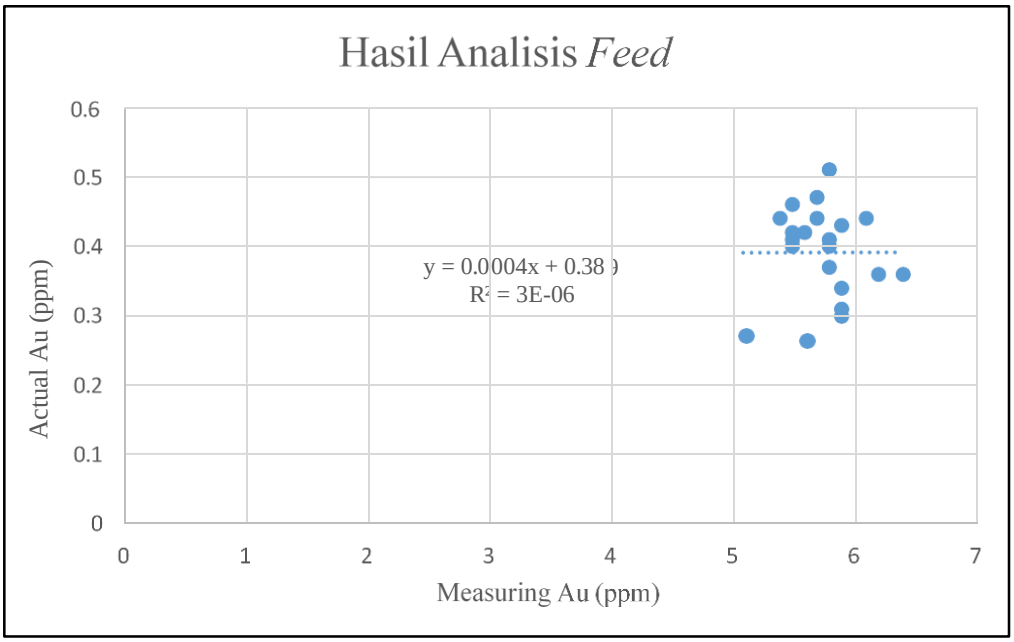

Figure 1 Regression Graph of Feed Analysis Results

Analysis was carried out on the flotation concentrate using two tools, namely the handheld XRF Analyzer and Atomic Absorption Spectroscopy (AAS) to determine the

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gold content in the flotation concentrate. From the test results, the gold content value was obtained as shown in Table 2, and the two sets of analysis data were plotted in a regression graph shown in Figure 2.

Table 2. Concentrate Analysis Results

Concentrate		
Measuring Au (ppm) *using Handheld XRF*	*Actual Au (ppm) using AAS*	*Actual* Au (ppm) *using AAS*
19,5	21	
10	11,6	
24,7	15,8	
39,4	27,8	
25	12,4	
33,5	24	
26,3	15,6	
32	13,8	
28	17,4	
19	9	
22,1	7,8	
5,1	7	
5,4	6,2	

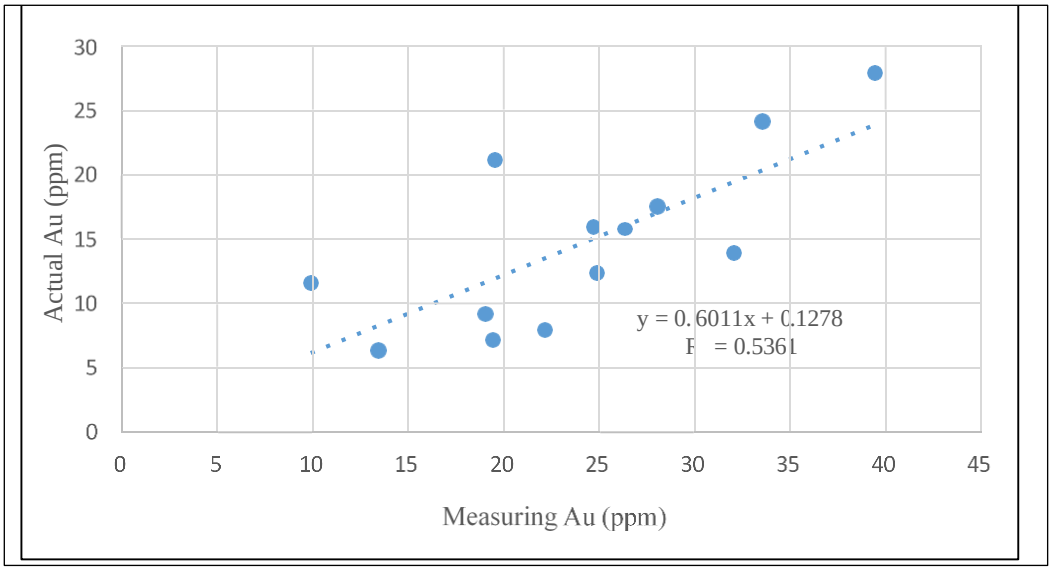

Figure 2 Regression Graph of Concentrate Analysis Results

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Analysis was also carried out on the flotation tailings using two tools, namely the handheld XRF Analyzer and Atomic Absorption Spectroscopy (AAS) to determine the gold content still contained in the flotation tailings. From the test results, the gold content values were obtained as shown in Table 3, and the two sets of analysis data were plotted in a regression graph shown in Figure 3.

Table 3. Tailing Analysis Results

Tailing		
Measuring Au (ppm) using Handheld XRF	Actual Au (ppm) using AAS	Actual Au (ppm) using AAS
6,1	0,26	
5,7	0,23	
5,8	0,28	
6,2	0,41	
5,6	0,3	
5,2	0,3	
11	0,33	
5,3	0,29	
5,4	0,28	
5,8	0,3	
5,4	0,29	
5,2	0,26	
5	0,2	
5,2	0,25	
5,1	0,25	
5,4	0,17	
4,5	0,16	
5,6	0,18	
5,1	0,2	

To answer the objectives of this study, a discussion was conducted based on the research results that have been obtained in the research that has been conducted. In this discussion, an application is used to process statistical data, namely the SPSS application.

In this study, a correlation analysis was carried out between gold content measurements (Au) using Handheld XRF and gold content measurements using Atomic Absorption Spectroscopy (AAS). Handheld XRF is a tool that allows fast and non-destructive measurements in the field, while AAS is known to have high accuracy in

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measuring the concentration of elements in samples. High gold content measurements are very important because they determine the economic value and efficiency of the gold extraction process.

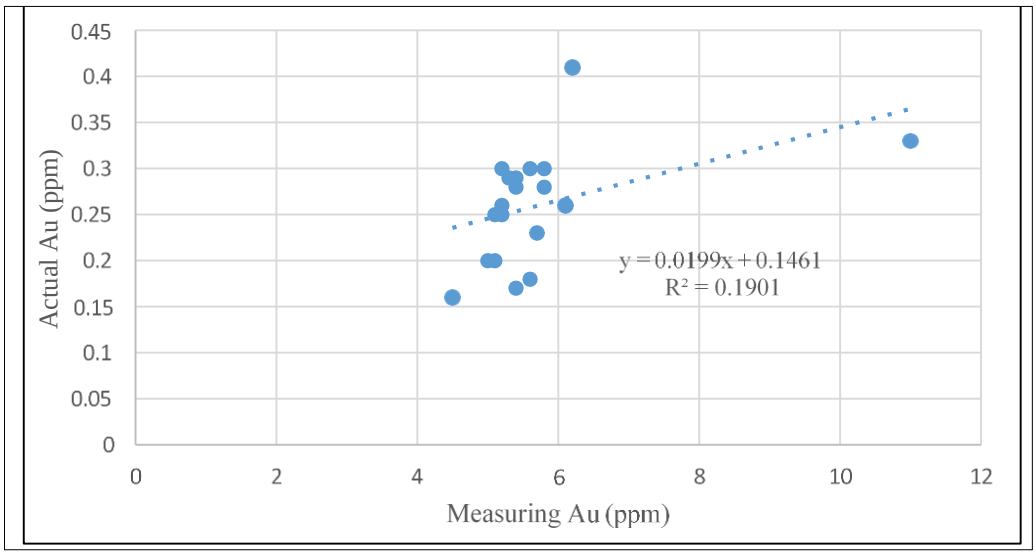

Figure 3 Regression Graph of Tailing Analysis Results

Table 4 to Table 10 are the testing steps carried out on the feed. The first step is to carry out a Normality Test on the feed, Asymp 2 tailed above 0.05 which means that the data above is normally distributed. Then Autocorrelation is carried out using the Run Test method, the results of the Run Test significance are above 0.05, so the Autocorrelation test passes. At the testing stage, the Multicollinearity Test is seen from the VIF value which means it passes because the VIF value is 1 and less than 10, the test limit is 1 to 10, meaning it passes the Multicollinearity Test. In the Heteroscedacity Test, the Glejser Test method is used. The Glejser Test shows a sig above 0.05, which means that there is no heteroskadity symptom. Furthermore, the Anova Test is carried out, based on the Test above, XRF does not affect AAS with the feed sample because the sig is above 0.05. Finally, the R Square Test is carried out and the R Square value is -0.53, so the feed has no effect.

Table 4 Feed Normality Test

One-Sample Kolmogorov-Smirnov Test		
		Unstandardized Residual
N		21
Asymp. (2-tailed)	Sig.	.114[c]

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Table 5 Feed Autocorrelation Test

Runs Test		
		Unstandardized Residual
Total Cases		21
Asymp. (2-tailed)	Sig.	.182

Table 6 Feed Multicollinearity Test

Model		Collinearity Statistics	
		Tolerance	VIF
1	(Constant)		
	X	1.000	1.000

Table 7 Feed Heteroscedacity Test
Glejser Test

Model		Sig.
1	(Constant)	.194
	X	.319

Table 8 Simple Linear Regression Test
Feed

Model		Unstandardized Coefficients	
		B	Std. Error
1	(Constant)	.389	.301
	X	.000	.052

Table 9 Anova Feed Test

Model		F	Sig.
1	*Regression*	.000	.994[b]

Table 10 R Square Feed Test

Model	Adjusted R Square
1	-.053

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Table 11 Concentrate Normality Test	
One-Sample Kolmogorov-Smirnov Test	
	Unstandardized Residual
N	13
Asymp. Sig. (2-tailed)	.200[c,d]

Table 12 Concentrate Autocorrelation Test	
Runs Test	
	Unstandardized Residual
Asymp. Sig. (2-tailed)	.575

Table 13 Concentrate Multicollinearity Test			
Model		Collinearity Statistics	
		Tolerance	VIF
1	(Constant)		
	X	1.000	1.000

Table 14 Concentrate Heteroscedacity Test Glejser Test			
Model		t	Sig.
1	(Constant)	2.044	.194
	X	-.517	.319

Table 15 Simple Linear Regression Test Concentrate		
Model	Unstandardized Coefficients	
	B	Std. Error
1 (Constant)	.128	4.259
X	.601	.169

Table 16 Anova Concentrate Test		
Model	F	Sig.
1 *Regression*	12.714	.004[b]

Table 17 R Square Concentrate Test

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Model	R	R Square	Adjusted R Square
1	.732	.536	.494

Table 11 to Table 17 are the testing steps carried out on the concentrate. The first step is to carry out the Normality Test on the concentrate, Asymp 2-tailed above 0.05 which means that the data above is normally distributed. Then autocorrelation is carried out using the Run Test method, the results of the Run Test significance above 0.05 then the Autocorrelation test passes. At the Multicollinearity Test testing stage, it is seen from the VIF value which means it passes because the VIF value is 1 and less than 10, the test limit is 1 to 10 which means it passes the Multicollinearity Test. In the Heteroscedacity Test, the Glejser Test method is used. The Glejser Test shows a sig above 0.05 which means there are no symptoms of heteroscedasticity. Next, the Anova test was carried out. From the Anova test, the significance value is 0.004, which means that XRF has a significant effect on AAS. Because the limit of the Anova test is if the sig value is below 0.05, the test is declared to have an effect and vice versa. Finally, the R Square test was carried out to see the effect between the 2 variables. The R Square test, or coefficient of determination, is used to measure how well the handheld XRF measurement data can be explained by the AAS measurement data. The R Square value ranges from 0 to 1, with values closer to 1 indicating that the regression model has good predictive ability. In the context of this study, a high R Square value indicates that handheld XRF measurements have a strong correlation with AAS measurement results, so they can be used as a reliable indicator for rapid analysis in the field. The R Square test is seen from the Adjusted R Square value which shows a value of 0.494, so XRF has an effect on AAS of 49.4%.

Simple regression test is used to determine the linear relationship between independent variables and dependent variables (Harsiti et al., 2022), in this case between the results of gold content measurements using handheld XRF and AAS. The simple regression equation is in the form of y = const + βx, where y is the dependent variable (AAS results), x is the independent variable (handheld XRF results), α is the intercept, and β is the regression coefficient. Through a simple regression test, we can identify how much the change in AAS measurement results (y) is explained by the results of handheld XRF measurements (x). The regression coefficient (β) provides an overview of the strength and direction of the relationship between the two variables. So in this study, the equation y = 0.128 + 0.601x is produced. This defines the constant value of the regression test if the AAS value is 1, then the XRF value is 0.601 and the XRF regression coefficient is 0.601 with a positive direction which means that for every 0.601 increase in XRF value, the AAS value also increases by 0.601 units. AAS = Const + BX
AAS = 0.128 + 0.601

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XRF Coefficient
For every 1 Unit increase in XRF, AAS increases by 0.601.
XRF = 1 AAS = 0.601
XRF = 2 AAS = 1.202
XRF = 3 AAS = 1.803
XRF = 4 AAS = 2.404, and so on.

Table 18 Tailing Normality Test

		Unstandardized Residual
N		19
Asymp. (2-tailed)	Sig.	.200[c,d]

Table 19 Tailing Autocorrelation Test

Runs Test

		Unstandardized Residual
Total Cases		19
Asymp. (2-tailed)	Sig.	.159

Table 20 Tailing Multicollinearity Test

Model		Collinearity Statistics	
		Tolerance	VIF
1	(Constant)		
	X	1.000	1.000

Table 21 Tailing Heteroscedacity Test
Glejser Test

Model		Sig.
1	(Constant)	.250
	X	.995

Table 22 Simple Linear Regression Test
Tailing

Model	Unstandardized Coefficients	
	B	Std. Error
1 (Constant)	.146	058

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X	.020	.010

Table 23 Anova Tailing Test

Model		F	Sig.
1	*Regression*	3.992	.062[b]

Table 24 R Square Tailing Test

Model	Adjusted R Square
1	.143

Table 18 to Table 24 are the testing steps carried out on the tailings. The first step is to carry out the Normality Test on the tailings, Asymp 2 tailed above 0.05 which means that the data above is normally distributed. Then Autocorrelation is carried out using the Run Test method, the results of the Run Test significance is above 0.05 then the Autocorrelation test passes. At the Multicollinearity Test testing stage, it is seen from the VIF value which means it passes because the VIF value is 1 and less than 10, the test limit is 1 to 10 which means it passes the Multicollinearity Test. In the Heteroscedacity Test, the Glejser Test method is used. The Glejser Test shows a sig above 0.05 which means that there is no. Heteroscedacity symptoms. Furthermore, the Anova test was carried out, based on the above test, XRF did not affect AAS with tailing samples because the results of the Anova test significance of 0.062 which means it is greater than the Anova test limit.

In all of these tests, it can be concluded that XRF can only affect the test on the concentrate. Many factors can influence this, including sample homogeneity and matrix composition also affect the correlation between the two methods. Variability in the distribution of gold particles and the presence of other elements in the sample can cause interference that affects the results of handheld XRF measurements. Therefore, to obtain better correlation, it is important to ensure better sample homogeneity and reduce matrix interference through proper sample preparation techniques.

One factor that affects the measurement results is the sensitivity of Handheld XRF to low gold content. Handheld XRF has a higher detection limit, so that at low gold concentrations, the resulting signal is often near the detection limit of the tool. This causes higher variability in measurement results and has the potential to produce less accurate data. In contrast, AAS with lower detection limits and more complex sample preparation methods, can provide more accurate and precise results at low concentrations.

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Conclusion

Based on the results of testing and data analysis in this study, the following conclusions were obtained:

1. The results of the analysis of gold content (Au) using Handheld Analyzer and Atomic Absorption Spectroscopy (AAS) showed a significant correlation between the Au values measured only in concentrate. In this study of concentrate, the adjusted R Square value was 0.494 or 49.4%, which is the variable x (XRF) which has a 49.4% effect on y (AAS). The results obtained for every 1 unit increase in XRF feed AAS increased by 0.601. While for feed and tailing there was no effect.
2. Handheld XRF Analyzer provides advantages in terms of speed and portability, enabling real-time monitoring that can assist in quick decision-making and direct process adjustments. Meanwhile, AAS offers high accuracy and precision, crucial for verification analysis and ensuring long-term data quality.
3. Several factors affect the accuracy and precision of gold content measurements using Handheld XRF Analyzers and atomic absorption spectroscopy (AAS). For the Handheld XRF Analyzer, these factors include the instrument's detection limit, sample matrix composition, sample homogeneity, and instrument calibration. Meanwhile, for AAS, the influencing factors include the sample preparation process, cleanliness and quality of reagents, operational conditions such as temperature and light source stability, and the presence of chemical interference in the sample.

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