Optimization of ilmenite ore processing using induced roll magnetic separator

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Abstract. PT Timah Tbk has been processing residual ore (SHP) with a low tin grade of ± 10-30% wt. To increase tin grade and associated mineral products to be a high grade (> 70% wt), an evaluation and optimization process is needed on Induced Roll Magnetic Separator processing equipment. The evaluation and optimization process was carried out on magnetic products, especially ilmenite minerals. Sampling is done on the feed and the product based on the tool parameter settings. The feed rate is set at 380, 320, 250, 420, and 470 gr/10s. The splitter opening is set at 10, 15, 20 mm of magnetic rollers. While the electric current is set at 2, 4, 6, 8, 10, 12, 14 amperes. Mass and grade data are then analyzed by regression and variance statistical methods and optimized by the response surface method. The evaluation results show that only the splitter opening parameters and electric current strength are significant in explaining the product results obtained with a level of hypothesis error of 5%. The results of IRMS optimization show that the best parameter conditions are in the 2-4 ampere of electric current and 10-15 mm of splitter openings with ilmenite grade capable of > 80% wt in the second order of central composite design.

1. Introduction
As a company engaged in the tin mining sector, PT Timah Tbk has carried out the processing of associated minerals in tin ore. Suprapto (2008) said that in the process of mining and processing tin ore (cassiterite) products containing other valuable minerals are also produced. These minerals such as monazite, ilmenite, zircon, xenotime, and others are economically feasible to be processed. This is then in line with the mining program launched by PT Timah Tbk in 2018 to increase mining recovery for the remaining ore processing (Aji, 2019). However, the production of tin concentrate and associated minerals is still below the company’s production target of 70% (high grade) and >90% recovery [1-7]. The low mineral grade of SHP ore (<30%) makes it difficult for the processing process to increase the levels of tin and other associated minerals at high-grade levels. From the condition of the problem of production capacity and product quality, it is necessary to have a technical evaluation of the tin ore processing itself. Therefore, the researchers tried to optimize the processing process with statistical models to obtain optimal mineral grades and recovery results [8-11].
2. Literature Review

2.1. Mineral Dressing and Good Mining Practice
According to Wills (2006), mineral processing is an activity that aims to separate valuable minerals economically based on existing technology for an industry in their utilization. Mineral processing is the process of mechanically separating valuable minerals from worthless minerals to produce products that are rich in valuable minerals (concentrates) and products with low mineral grade (tailings).

The separation process is highly dependent on the physical and chemical properties of the minerals contained in the ore. Therefore, to separate the ore from the accompanying minerals, knowledge of the characteristics of each mineral is required [4]. Information or mineral data required in the processing include the type and composition of the minerals in the ore, the grade of each mineral in the minerals, the distribution and grain size, the degree of liberation of the minerals, and the physical properties of the minerals such as specific gravity, magnetism, and electrical conductivity, adsorption and adsorption power and chemical properties of mineral ores [5].

According to the Regulation of the Minister of Energy and Mineral Resources number 26 of 2018, Good Mining Practice includes six aspects, namely:
1. Mining technical
2. Mineral and coal conservation
3. Mining Occupational Safety and Health
4. Mining Operation Safety
5. Mining, Reclamation, Post-Mining, and Post-Operation Environmental Management
6. Technology Utilization, Engineering Capability, Design, Development, and Application Mining Technology.

2.2. Induced Roll Magnetic Separator
According to Tagghart (1954) and Svoboda (2004) Induced Roll Magnetic Separator is one of the tools used in mineral/material processing based on differences in magnetic properties of the material (or in tin ore) [6]. IRMS is a mineral separation tool that uses a strong magnetic force (high-intensity magnetic separator). In addition, the IRMS model utilizes a vertical feeding system so that in addition to magnetic power, IRMS also utilizes gravity [8].

2.3. Statistical Regression and Response Surface Methodology
According to Montgomery (2013), regression analysis is a method or technique used to see how far the change in the value of the dependent variable, if the value of the independent variable is changed or increased lower. The resulting regression equation is then used to predict the pattern of a dependent variable.

Response surface methodology is a method that combines mathematical techniques with statistical techniques used to model and analyze a response that is influenced by several variables in order to optimize the response. The basic idea of this method is to use experimental design with the help of statistics to find the optimal value of a process response [11].

3. Methodology
The research method is by adjusting the parameter variations of the IRMS tool. The feed rate parameters are 250, 320, 380, 420, and 470 gr/10s. The splitter opening parameters are set at 10, 15, and 20 mm from the magnetic roller. As for the electric current, it is set at 2, 4, 6, 8, 10, 12, 14 amperes. Then the sampling of the product represents the setting of the tool parameters. Next is the calculation of grades using the method of grain counting analysis and the value of recovery and processing efficiency. The results of these calculations were then analyzed using statistical techniques. The significant tool parameters are then used to optimize the processing using the surface response method. The optimization results from the tool are then applied to the processing simulation process.
4. Results

4.1. Feed Grade

The grade analysis showed that the mineral composition of cassiterite was more dominant, namely 43.11% wt in the IRMS feed. Then the ratio of %wt mineral composition that is paramagnetic (ilmenite & monazite) to diamagnetic minerals (cassiterite, pyrite, zircon, tourmaline & quartz) in both feeds is above 40%. The ratio of paramagnetic minerals to diamagnetic minerals is 41.64%. A total of 1 ton of feed was used in this experiment.

| Feed | Mineral Grade (%wt) |
|------|----------------------|
| IRMS | Cst  | Ilm | Mnz | Py | Zrn | Tur | Qtz |
|      | 43.11 | 14.24 | 15.16 | 7.19 | 4.48 | 3.05 | 12.74 |

Cst: Cassiterite, Ilm: Ilmenite, Mnz: Monazite, Zrn: Zircon, Tur: Tourmaline, Qtz: Quartz, Py: Pyrite

4.2. Magnetic Product Processing

The graph of the processing of magnetic products shows that the mineral composition is dominated by ilmenite mineral with an average grade of 70% wt and monazite mineral with an average grade of 20% wt. The graph tends to fluctuate based on the electric current strength parameter with the highest ilmenite grade of >85 %wt and the lowest of 51 %wt.

![Figure 1. Minerals content in magnetic product.](image)

The graph of the processing of magnetic products shows that the mineral composition is dominated by ilmenite mineral with an average grade of 70% wt and monazite mineral with an average grade of 20% wt. The graph tends to fluctuate based on the electric current strength parameter with the highest ilmenite grade of >85 %wt and the lowest of 51 %wt. The decrease or increase in ilmenite levels may be caused by the influence of a magnetic field (electric current).

4.3. Regression Analysis of Conductor Products

Analysis of variance and regression was carried out on the processed magnet products. The analysis of variance:

| Source               | DF | Adj SS  | Adj MS  | F-Value | P-Value |
|----------------------|----|---------|---------|---------|---------|
| Regression           | 3  | 2275.22 | 758.41  | 49.09   | 0.000   |
| Feed Rate (gr)       | 1  | 56.73   | 56.73   | 3.67    | 0.065   |
| Splitter Opening (mm)| 1  | 240.51  | 240.51  | 15.57   | 0.000   |
| Current (A)          | 1  | 1678.10 | 1678.10 | 108.61  | 0.000   |
| Error                | 31 | 478.97  | 15.45   |         |         |
| Total                | 34 | 2754.20 |         |         |         |
Analysis of variance showed that only the splitter opening and electric current were significant with the null hypothesis rejection error rate of 5%. The value of the splitter aperture parameter and the electric current are inversely proportional to the ilmenite mineral grade produced. The three parameters tested were able to explain the response of the ilmenite mineral obtained with a correlation of 80-82%. The following regression equation (1):

\[ y = 95.77 - 1.012X_1 - 1.75X_2 \]  

\[ y = \text{ilmenite grade (wt\%)} \]  
\[ X_1 = \text{splitter opening (mm)} \]  
\[ X_2 = \text{electrical current (ampere)} \]

The regression equation formed shows that the level of ilmenite that can be achieved at the intercept is 95.77% wt. The decrease in ilmenite grade from the intercept value is 1.012 times the value of the splitter opening and also 1.75 times the value of the given electric current.

4.4. Parameters Correlation

The results of the correlation analysis showed that the three independent parameters were simultaneously able to explain the response of ilmenite levels of 82.61%. This means that 82.61% of the effect of the resulting ilmenite grade can be explained by the rise and fall of the three parameters feed rate, electric current strength, and splitter opening. Meanwhile, only 17.39% are influenced by factors beyond control. Because the feed rate parameter is not significant and must be eliminated from the regression equation, the relationship between the electric current and the splitter opening is 79.33%. The splitter aperture parameter has an influence contribution of 18.16% and the largest is the electric current, which is 62.31% of the resulting ilmenite grade. This shows that the effect of the feed rate in explaining the ilmenite grade is very small, which is only 1.6%, or is considered to have no effect at all.

4.5. Optimization of Mineral Processing

The principle of optimization of the processing process on the IRMS tool is to determine the optimum conditions of significant parameters based on the results of technical evaluation. With this experimental design, the results can be known as the best parameter conditions for optimal processing. The selection of the lowest limit for the splitter opening is 10 mm and the highest limit is 20 mm. While the lower limit of the electric current is 2 amperes and the upper limit is 6 amperes. For the error to be estimated, the center point in the design is then replicated 4 times. The composite center design is the result of a modification to the full factorial design by adding 4 axial run points. It aims to obtain a rotatable design. Table 3 composite center design was used.

In the composite center design, the lower limit for the splitter aperture parameter is 10 mm and the upper limit is 20 mm. While the lower limit of the electric current parameter is 2 amperes and the upper limit is 6 amperes. There are 4 replication center points, namely 15 mm and 4 amperes. While the 4 axial run points are 1.41421 from the upper and lower limits of the two parameters. The lowest limit of axial run for splitter opening parameter is 7.928932 and the highest limit is 22.07107. Meanwhile, for the axial run point, the electric current strength parameter has the lowest limit at 1.171573 amperes and the highest limit at 6.828427.

The test results of the model show that all the main, quadratic, and interaction effects have a significant effect on the response. In the main effect, both the splitter opening parameters and the electric current produced a probability value of 0 or less than the 5% error level. For the quadratic effect, the splitter opening parameter produces a P value of 0 and for the electric current of 0.001. While the interaction effect of the two parameters produces a P-value of 0.032. The second-order regression model that was formed was suitable because the P-value of Lack of Fit was 0.163. The following is a second-order regression equation (2):
\[ y = 74.50 + 2.005X_1 + 0.649X_2 - 0.1224(X_1^2) - 0.5656(X_2^2) + 0.1225(X_1)(X_2) \]  

(2)

\[ \begin{align*}
    y &= \text{ilmenite grade (%wt)} \\
    X_1 &= \text{splitter opening (mm)} \\
    X_2 &= \text{electric current (ampere)}
\end{align*} \]

**Table 3. Central Composite Design of IRMS**

| A   | B     | Splitter Opening | Electric Current |
|-----|-------|------------------|------------------|
| -   | -     | 10               | 2                |
| +   | -     | 20               | 2                |
| -   | +     | 10               | 6                |
| +   | +     | 20               | 6                |
| -1.41421 | 0   | 7.9289           | 4                |
| 1.41421  | 0   | 22.071           | 4                |
| 0    | -1.41421 | 15             | 1.715            |
| 0    | 1.41421  | 15             | 6.8284           |
| 0    | 0     | 15               | 4                |
| 0    | 0     | 15               | 4                |
| 0    | 0     | 15               | 4                |

4.6. **Optimization of Mineral Processing**

Based on the contour shape obtained, the maximum area of %wt ilmenite obtained is in the area of 2-4 amperes electric current and a splitter opening of 10-15 mm. In the optimum area, both parameters were able to produce ilmenite grade of >80% wt. The parameter value that is greater than this range will cause the %wt ilmenite obtained to decrease. The following is an image of the second-order response surface contour and the 3D model:

**Figure 2. Optimizing contour of processing**

**Figure 3. 3D Surface response of processing.**

5. **Conclusion**

Based on the results of the technical evaluation of the IRMS tool, only the splitter opening and the electric current were significant with the null hypothesis rejection error rate of 5%. The value of the
splitter aperture and the electric current parameters are inversely proportional to the ilmenite mineral grade produced. The three parameters tested were able to explain the response of the ilmenite mineral obtained with a correlation of 80-82%.

Using the surface response method, the best IRMS parameter conditions to produce ilmenite mineral are in the area of 1-4 amperes for strong electric current and 10-15 mm for splitter openings. The results of the second-order regression optimization can approximate the ilmenite grade up to >80 %wt.

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