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Shaking Table Deck Inclination Variation in SHP Reprocessing: X-Ray Fluorescence-Based Analysis of Sn Concentrate Grade

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ABSTRACT

Processing residue from tin beneficiation still contains unrecovered cassiterite that can be upgraded through gravity concentration. This study describes the variation in tin (Sn) concentrate grade obtained from Sisa Hasil Pengolahan (SHP) at PT Timah Tbk under different shaking table deck inclination settings and actual plant operating conditions. Experiments were conducted at a constant water flow rate of 0.43 L/s using three deck inclinations: 1.5°, 2.0°, and 2.5°. Each condition was tested in three repetitions. Feed and concentrate samples were dried, homogenized, ground, and analyzed using X-ray fluorescence (XRF). The mean concentrate grade increased from 4.77% Sn at 1.5° to 11.58% Sn at 2.0° and 13.02% Sn at 2.5°. These results indicate that higher deck inclination within the tested range corresponded to improved concentrate grade. However, the findings remain descriptive because recovery, mass balance, and inferential statistical analysis were not included.

Keywords
shaking table; cassiterite; gravity concentration; deck inclination; SHP reprocessing

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INTRODUCTION

Tin ore beneficiation commonly relies on gravity concentration because this method separates valuable minerals from gangue minerals based on differences in specific gravity without requiring intensive chemical reagents. In tin processing, cassiterite (SnO_2) is the primary tin-bearing mineral and has a substantially higher specific gravity than associated gangue minerals such as quartz and other silicates. This density contrast makes gravity concentration one of the most widely applied and economically practical methods for upgrading cassiterite-bearing materials [1], [2]. In addition, cassiterite processing generally involves beneficiation and extraction stages to increase the economic value of tin-bearing ores and secondary processing materials [3].

Among various gravity concentration units, shaking tables are commonly used in the final concentration stage because they can separate mineral particles through the combined action of table motion, water flow, riffles, and density differences. The performance of a shaking table is not determined by mineral density alone, but also by operational parameters such as deck inclination, water flow rate, feed particle size, stroke length, and material distribution on the deck surface [4], [5]. When these parameters are properly controlled, particle stratification can be improved and cassiterite particles are more likely to report to the concentrate stream. Conversely, inappropriate parameter settings may reduce concentrate quality or cause valuable particles to be misplaced into the tailings stream.

In the tin processing industry, Sisa Hasil Pengolahan (SHP), or processing residue, may still contain unrecovered cassiterite from previous beneficiation stages. Therefore, SHP has the potential to be reprocessed using gravity concentration to improve the utilization of remaining tin-bearing minerals. Previous work on SHP reprocessing at PT Timah Tbk has shown that operating variables such as deck inclination, stroke length, and water flow rate are closely related to changes in Sn grade and recovery during shaking table separation [6], [7]. These findings indicate that operational control is important in SHP reprocessing, particularly when the objective is to improve concentrate grade while maintaining stable separation behavior.

Deck inclination is one of the key parameters controlling the movement of particles on a shaking table. A higher inclination generally increases the flow velocity of material across the deck, while a lower inclination extends the residence time of particles on the table surface. Both conditions may influence the opportunity for high-density cassiterite particles to stratify and separate from lower-density gangue minerals. Previous studies have reported that deck inclination, water flow rate, stroke setting, and feed particle characteristics can affect Sn grade and recovery in shaking table-based gravity concentration systems [8]–[10]. In tin processing, an appropriate deck inclination may support better separation between cassiterite and gangue minerals, whereas an excessively steep or shallow inclination can reduce separation quality by either accelerating particle transport or allowing excessive material accumulation on the table surface.

The particle stratification mechanism on a shaking table is illustrated in Figure 1. This mechanism occurs because dense particles tend to settle closer to the deck surface and interact with the riffles, while lighter particles are more easily transported by the water flow toward the tailings stream. Cassiterite, with a relatively high specific gravity, tends to remain in the lower particle layer and move toward the concentrate channel when the table motion, water flow, and deck inclination are properly balanced [11], [12].

Figure 1. Particle stratification process on a shaking table

As shown in Figure 1, the separation zone on the shaking table reflects the interaction between water flow, deck motion, and mineral density. Heavy mineral particles are retained and directed toward the concentrate path, while lighter gangue minerals are transported farther across the deck. This behavior is consistent with the principle of gravity concentration, where differences in specific gravity and particle movement patterns determine the separation pathway of mineral particles. Previous research on cassiterite concentration also shows that changes in operating parameters can influence the cassiterite content of the final product [13].

In addition to operational control, reliable grade analysis is required to evaluate the quality of the concentrate produced from the shaking table. X-ray fluorescence (XRF) is widely used for elemental analysis of geological and mineral materials because it enables rapid and relatively non-destructive measurement of elemental composition with simple sample preparation [14], [15]. In the context of SHP reprocessing, XRF-based Sn grade analysis provides a practical approach for comparing feed and concentrate samples obtained under different shaking table operating conditions. However, grade analysis alone cannot fully describe total separation performance because recovery, mass balance, and concentration ratio are also important indicators in mineral processing evaluation.

Although previous studies have investigated the influence of shaking table operating parameters on tin concentration, many of them have focused on primary ore, laboratory-scale conditions, or recovery-based evaluation. Limited studies have specifically examined deck inclination variation in SHP reprocessing under actual plant operating conditions using XRF-based Sn grade analysis. Therefore, this study evaluates the variation of shaking table deck inclination on Sn concentrate grade from SHP at PT Timah Tbk under a constant water flow rate of 0.43 L/s. The contribution of this study is to provide preliminary field-based insight into how moderate changes in deck inclination correspond to changes in concentrate Sn grade. The interpretation is limited to descriptive grade variation and does not claim overall process optimization because recovery, mass balance, and inferential statistical testing were not included.

METHOD

This study was conducted at the tin processing unit of PT Timah Tbk in April 2026 using the existing shaking table installed in the processing plant for SHP reprocessing. The study was designed as a field experiment under actual industrial operating conditions. The water flow rate was maintained at a constant value of 0.43 L/s, while the shaking table deck inclination was varied at 1.5°, 2.0°, and 2.5°. Each deck inclination condition was tested in three independent replicates. Other plant operating conditions, including feed characteristics, equipment configuration, and routine operating practices, followed the standard operating procedures of PT Timah Tbk and were not intentionally modified during the study. Because the experiment was conducted under routine industrial conditions, detailed equipment specifications, such as the shaking table model, deck dimensions, riffle configuration, and stroke settings, were not available to the researchers.

The overall methodological sequence is presented in Figure 2. The flowchart summarizes the research location and period, research design, variables, equipment and materials, operating conditions, deck inclination adjustment, sampling procedure, sample preparation, XRF analysis, data recording, data analysis, and research output. This flowchart was used to clarify the chronological stages of the study and to ensure that the experimental procedure could be followed systematically.

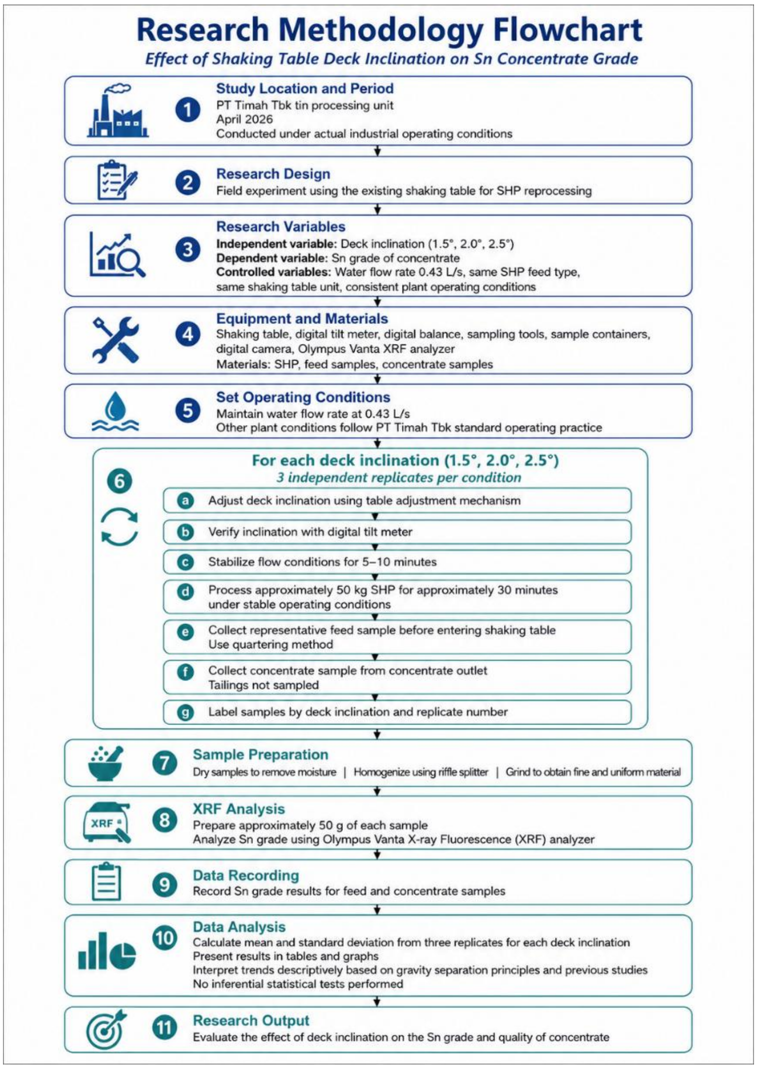

Figure 2. Research methodology flowchart for evaluating shaking table deck inclination variation on Sn concentrate grade

Equipment and Materials

The equipment used in this study consisted of the shaking table installed at the PT Timah Tbk processing plant, a digital tilt meter for measuring deck inclination, a digital balance for sample weighing, sampling tools, sample containers, a digital camera for documentation, and an Olympus Vanta X-ray fluorescence (XRF) analyzer for determining the Sn grade of the samples. The research materials consisted of SHP, feed samples, and concentrate samples collected under different deck inclination conditions. All measurements were performed using the instruments available at the processing plant and laboratory by following the standard operating procedures established by PT Timah Tbk. The measuring instruments were routinely maintained and calibrated prior to use according to the laboratory quality assurance procedures.

Research Variables

The independent variable in this study was the shaking table deck inclination, which was varied at 1.5°, 2.0°, and 2.5°. The dependent variable was the Sn grade of the resulting concentrate determined through XRF analysis. The controlled variables included a constant water flow rate of 0.43 L/s, the same SHP feed type, the same shaking table unit, and consistent plant operating conditions throughout all experimental runs. Approximately 50 kg of SHP was processed in each experimental run, although the exact feed mass varied slightly depending on routine plant operating conditions. Other operating parameters, including the stroke setting and feed characteristics, followed the standard operating conditions of the PT Timah Tbk processing plant and were not intentionally modified during the study.

Experimental Procedure

Before each experimental run, the shaking table deck inclination was adjusted to the predetermined angle of 1.5°, 2.0°, or 2.5° using the table adjustment mechanism. The inclination was then verified using a digital tilt meter to ensure that the required angle had been reached before sample processing. After the deck inclination was set, the flow condition was stabilized for approximately 5–10 minutes to obtain a steady operating condition before sampling. The adjustment and verification process of the deck inclination is documented in Figure 3.

Figure 3. Adjustment and verification of shaking table deck inclination before each experimental run

For each deck inclination, SHP was processed for approximately 30 minutes under stable operating conditions. Feed samples were collected before the material entered the shaking table, while concentrate samples were collected directly from the concentrate outlet after the separation process. Representative feed samples were obtained using the quartering method to minimize sampling bias. Tailings were not sampled because the objective of this study was limited to evaluating the change in concentrate Sn grade under different deck inclination conditions. All feed and concentrate samples were labeled according to the corresponding deck inclination and replicate number before being prepared for XRF analysis.

Sample Preparation and XRF Analysis

The collected feed and concentrate samples were prepared following the standard sample preparation procedure used at the PT Timah Tbk processing facility. The samples were dried to remove moisture, homogenized using a riffle splitter, and ground to obtain fine and uniform material suitable for XRF analysis. Approximately 50 g of each prepared sample was placed into an XRF sample cup fitted with a clean XRF film at the base and compacted to obtain a flat and homogeneous surface for measurement. The main stages of sampling, sample preparation, and XRF analysis are shown in Figure 4.

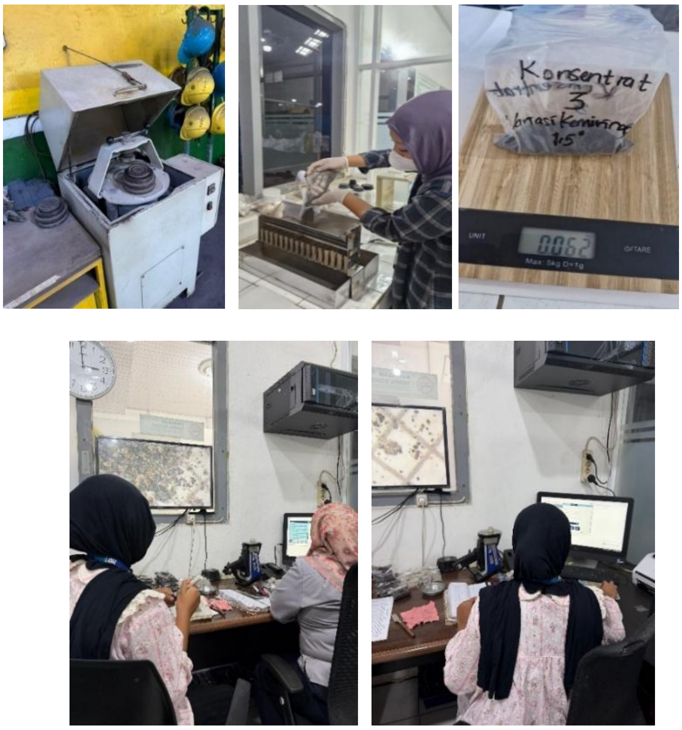

Figure 4. Sampling, sample preparation, and XRF analysis stages for determining Sn grade

The Sn grade of each prepared sample was analyzed using an Olympus Vanta X-ray fluorescence (XRF) analyzer at the PT Timah Tbk laboratory. XRF analysis was selected because it provides rapid elemental analysis and is widely used for characterizing geological and mineral materials [14], [15]. The analysis was conducted following the laboratory standard operating procedures under the supervision of qualified laboratory personnel. The resulting Sn grade data were then used to compare the concentrate quality obtained under the three deck inclination conditions.

Data Analysis

The Sn grade data obtained from each deck inclination condition were analyzed using descriptive statistical methods. For each operating condition, the mean and standard deviation were calculated from three independent replicates and presented in tables and graphs to facilitate comparison. The observed trends were interpreted based on gravity concentration principles and relevant previous studies on shaking table operation [5], [6]. No inferential statistical tests were performed because this study was intended to describe operational trends under actual industrial conditions rather than to establish statistical significance or determine an optimum operating condition.

RESULTS AND DISCUSSION

Results

Results of Shaking Table Inclination Variation Tests and Tin Grade Analysis Using XRF

The Sn grades of the feed and concentrate samples were determined using X-ray fluorescence (XRF) analysis for three independent replicates at each shaking table deck inclination: 1.5°, 2.0°, and 2.5°. Table 1 presents the feed and concentrate Sn grades obtained from each replicate, together with the mean and standard deviation for each operating condition. These data were used to describe the variation in concentrate grade under different deck inclination settings at a constant water flow rate of 0.43 L/s.

Table 1. Results of Sn grade analysis for feed and concentrate at different shaking table deck inclinations under a constant water flow rate of 0.43 L/s.

Inclination (°)	Replicate	Feed Grade (%Sn)	Concentrate Grade (%Sn)
1.5°	I	1.36%	3.46%
	II	1.18%	4.35%
	III	1.18%	6.49%
	Mean ± SD	**1.24 ± 0.10**	**4.77 ± 1.59**
2.0°	I	1.45%	11.76%
	II	1.04%	11.60%
	III	1.07%	11.39%
	Mean ± SD	**1.19 ± 0.23**	**11.58 ± 0.19**
2.5°	I	1.36%	13.63%
	II	1.82%	12.80%
	III	1.33%	12.62%
	Mean ± SD	**1.50 ± 0.28**	**13.02 ± 0.54**

Based on Table 1, the mean feed grades at deck inclinations of 1.5°, 2.0°, and 2.5° were 1.24 ± 0.10% Sn, 1.19 ± 0.23% Sn, and 1.50 ± 0.28% Sn, respectively. The corresponding mean concentrate grades were 4.77 ± 1.59% Sn, 11.58 ± 0.19% Sn, and 13.02 ± 0.54% Sn. These results show that the mean concentrate grade increased as the deck inclination increased within the tested range.

The lowest mean concentrate grade was obtained at a deck inclination of 1.5°, while the highest mean concentrate grade was obtained at 2.5°. Although the feed grade at 2.5° was slightly higher than those at the other inclination settings, the concentrate grade at this inclination also showed the highest value among the tested conditions. The increase from 4.77% Sn at 1.5° to 11.58% Sn at 2.0° indicates a clear rise in concentrate grade between the lower and middle inclination settings. A further increase was observed at 2.5°, where the mean concentrate grade reached 13.02% Sn.

The mean concentrate Sn grade for each deck inclination is shown in Figure 5. The graph provides a visual comparison of the concentrate grade trend across the three inclination settings and supports the pattern presented in Table 1.

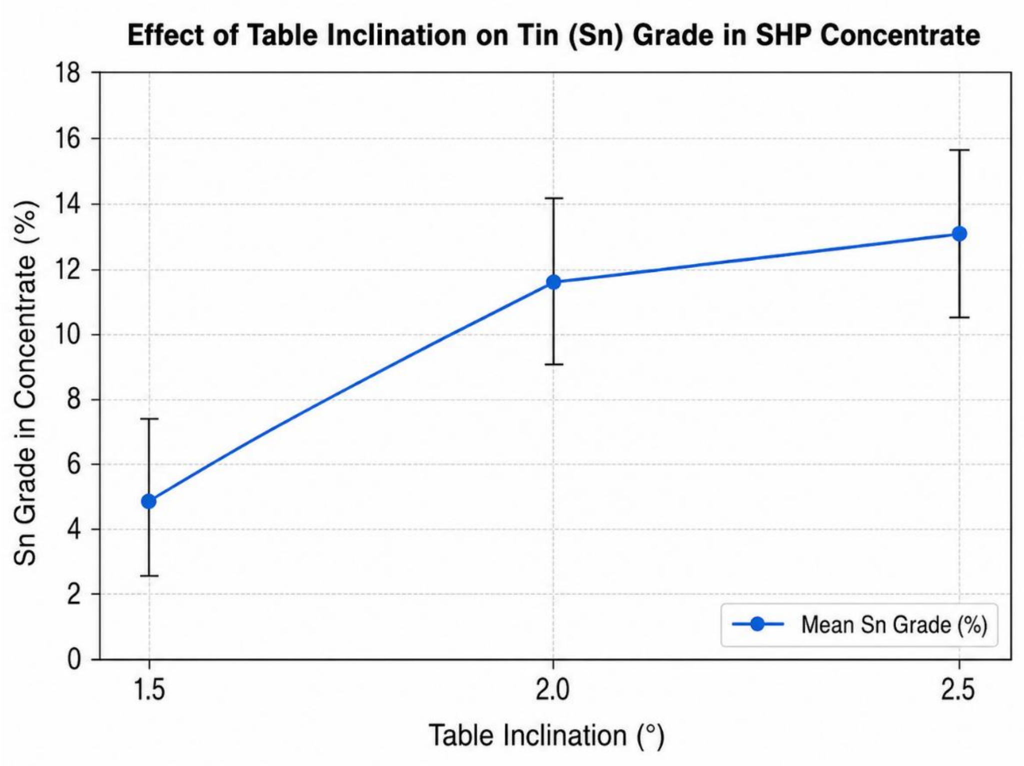

Figure 5. Mean concentrate Sn grades at different shaking table deck inclinations

Figure 5 shows that the concentrate Sn grade increased from 1.5° to 2.5° under the tested operating conditions. The largest increase occurred between 1.5° and 2.0°, followed by a smaller increase from 2.0° to 2.5°. This pattern indicates that higher deck inclination within the tested range corresponded to higher concentrate Sn grade. However, the results describe concentrate grade only and do not represent overall shaking table performance because recovery, tailings grade, concentration ratio, and mass balance were not evaluated in this study.

Discussion

The results presented in Table 1 and Figure 5 show that the mean Sn grade of the concentrate increased with increasing shaking table deck inclination under a constant water flow rate of 0.43 L/s. The mean concentrate grade increased from 4.77 ± 1.59% Sn at 1.5° to 11.58 ± 0.19% Sn at 2.0° and reached 13.02 ± 0.54% Sn at 2.5°. This trend indicates that, within the tested operating range, higher deck inclination corresponded to higher concentrate Sn grade. However, this finding should be interpreted as a descriptive grade trend rather than as evidence of an optimum operating condition because recovery, tailings grade, concentration ratio, mass balance, and inferential statistical testing were not included in this study.

The observed increase in concentrate grade can be explained through the basic principle of gravity concentration, in which particles are separated based on differences in specific gravity, particle movement, and interaction with the flowing water film on the table surface [1], [4]. Cassiterite has a higher specific gravity than most associated gangue minerals, allowing it to settle more readily and move toward the concentrate stream when the operating conditions support particle stratification [2], [3]. In this study, increasing the deck inclination may have changed the balance between particle residence time and material transport across the table surface. At a lower inclination, particle movement may be slower and the separation pathway may become less distinct. In contrast, a moderate increase in inclination may help reduce excessive material accumulation and support clearer separation between heavier cassiterite particles and lighter gangue minerals.

This interpretation is aligned with previous studies showing that shaking table performance is sensitive to operating parameters such as deck inclination, water flow rate, stroke length, and feed particle characteristics. You and Liu [5] reported that shaking table control parameters influence particle stratification and separation performance. In the context of tin processing, Panjaitan et al. [6] showed that deck inclination and stroke length were associated with changes in Sn grade and recovery during SHP reprocessing at PT Timah Tbk. Similarly, Mirahati et al. [7] demonstrated that water flow rate affected tin recovery and concentrate quality in tailings reprocessing using a shaking table. Recent work on intelligent shaking table beneficiation also emphasizes that concentrate grade and recovery are affected by interacting operating parameters, including bed slope, water flow, stroke, and concentrate-zone behavior [16]. Compared with these studies, the present work provides additional field-based support for the importance of operating-parameter control in tin reprocessing, particularly because it evaluates deck inclination variation under actual plant operating conditions and uses XRF-based Sn grade as the primary response variable.

The highest mean concentrate grade was obtained at 2.5°, but this result should not be interpreted as definitive evidence that 2.5° is the optimum deck inclination. The feed grade at 2.5° was also slightly higher than those at 1.5° and 2.0°, which may have contributed to the higher concentrate grade obtained under this condition. In addition, tailings were not sampled; therefore, the amount of cassiterite lost to the tailings stream could not be evaluated. This limitation is important because a higher concentrate grade does not always represent better overall separation performance. In mineral processing, grade should ideally be assessed together with recovery, mass balance, and concentration ratio to determine whether an operating condition is technically favorable [1], [14]. Therefore, the present findings are best interpreted as evidence of concentrate-grade improvement within the tested range, not as a complete evaluation of shaking table efficiency.

The role of feed characteristics should also be considered when interpreting the results. The SHP material used in this study represents secondary processing residue that may contain unrecovered cassiterite with variable particle size, liberation degree, and gangue association. Previous work has shown that fine cassiterite particles and tailings-derived materials can be difficult to recover because they are more easily affected by water flow, entrainment, and incomplete stratification [8], [17]. This means that the increase in concentrate grade observed in Table 1 may not be controlled by deck inclination alone. It may also be influenced by feed heterogeneity and the proportion of liberated cassiterite particles entering each experimental run. This reinforces the need for future studies to include particle size distribution and mineral liberation analysis.

The use of X-ray fluorescence analysis provided a practical basis for comparing Sn grade across the tested deck inclination conditions. XRF is widely used for elemental analysis of mineral and geological materials because it allows rapid, relatively non-destructive measurement with simple sample preparation [14], [15]. Recent methodological studies also support the applicability of portable XRF and combined XRF-based approaches for rapid geochemical and geological sample characterization [18], [19]. In this study, drying, homogenization, grinding, and standardized sample preparation were used to support measurement consistency before XRF analysis. However, XRF provides elemental grade data and does not directly describe the physical movement or stratification behavior of particles on the shaking table. Therefore, the mechanism proposed in this discussion should be understood as an interpretation based on gravity separation principles and observed grade patterns, rather than direct visual or dynamic measurement of particle trajectories.

The pattern shown in Figure 5 also indicates that the largest increase in concentrate grade occurred between 1.5° and 2.0°, whereas the increase from 2.0° to 2.5° was smaller. This suggests that the response of concentrate grade to deck inclination may not be linear across a wider operating range. Studies on wet shaking table operation also show that product grade and recovery can be affected by interacting operating parameters, so deck inclination should not be evaluated independently from other operating conditions [20]. From this perspective, deck inclination should not be optimized independently. Instead, it should be evaluated together with other operating variables to avoid producing high-grade concentrate at the expense of recovery or process stability.

From an operational perspective, the findings indicate that deck inclination is an important parameter to monitor during SHP reprocessing because moderate changes in inclination were associated with clear changes in concentrate Sn grade. The field-based nature of this study provides practical relevance for plant conditions at PT Timah Tbk, especially because the experiment was conducted using an existing shaking table and routine operating practices. Nevertheless, the interpretation remains limited to grade variation. Future work should include recovery calculation, tailings grade analysis, mass balance, concentration ratio, particle size distribution, mineral liberation analysis, and the combined effects of water flow rate and stroke length. For fine or tailings-derived cassiterite, complementary routes such as combined gravity-flotation separation may also be considered when single-stage gravity concentration is insufficient [21]. In addition, feed characterization and gravity separability evaluation are needed because particle size, liberation degree, and mineral association can influence the response of gravity concentration systems [22]. Such additional data would allow a more complete assessment of whether the higher concentrate grade observed at 2.5° also corresponds to better overall separation performance.

Overall, this study contributes preliminary field-based evidence on the variation of Sn concentrate grade under different shaking table deck inclination settings in SHP reprocessing. The results extend previous findings on shaking table operating-parameter control by focusing on actual industrial conditions and XRF-based grade analysis. However, the findings should be applied cautiously because the study does not establish statistical significance, process optimization, or complete separation efficiency. The most defensible conclusion is that, within the tested range, a deck inclination of 2.5° produced the highest mean Sn concentrate grade, while further evaluation is required to determine the most technically favorable operating condition.

CONCLUSION

This study shows that shaking table deck inclination was associated with changes in the Sn grade of concentrate produced from SHP reprocessing at PT Timah Tbk. Within the tested inclination range of 1.5°–2.5°, the highest mean concentrate grade was obtained at 2.5°, reaching approximately 13.02% Sn, while lower inclination settings produced lower concentrate grades. These findings indicate that deck inclination is an important operating parameter for controlling concentrate grade under the studied conditions. However, the conclusion is limited to descriptive grade variation because recovery, tailings grade, mass balance, and inferential statistical testing were not included. Further studies should incorporate these additional performance indicators to provide a more comprehensive evaluation of shaking table operation in SHP reprocessing.

REFERENCES

[1] B. A. Wills and J. A. Finch, Wills' Mineral Processing Technology, 8th ed. Boston, MA, USA: Butterworth-Heinemann, 2016, doi: 10.1016/B978-0-08-097053-0.00002-9.

[2] B. Lehmann, "Formation of tin ore deposits: A reassessment," Lithos, vol. 402–403, p. 105756, 2021, doi: 10.1016/j.lithos.2020.105756.

[3] A. Y. Fosu and N. Kanari, "Insight into the extractive metallurgy of tin from cassiterite," Materials, vol. 17, no. 13, p. 3312, 2024, doi: 10.3390/ma17133312.
[4] Y. Tsunazawa and Y. Kon, "Numerical investigation of density segregation on a shaking table using the discrete element method," Materials Transactions, vol. 62, no. 6, pp. 892–898, 2021, doi: 10.2320/matertrans.M-M2021809.
[5] K. You and H. Liu, "Research on optimization of control parameters of gravity shaking table," Scientific Reports, vol. 13, p. 1133, 2023, doi: 10.1038/s41598-023-28171-5.
[6] K. D. Panjaitan, J. Pitulima, and D. E. Andini, "Kajian teknis pengolahan SHP menggunakan shaking table untuk mengoptimalkan kadar dan recovery Sn di TB Batu Besi PT Timah Tbk," Mineral, vol. 8, no. 1, pp. 31–38, 2023, doi: 10.33019/mineral.v8i1.4096.
[7] R. Z. Mirahati, N. Wulandari, F. A. Mardhatila, U. Sukamto, F. Y. Putri, H. H. Labib, and M. H. Faturrahman, "Studi eksperimental recovery timah (Sn) dari tailing high tension roll separation menggunakan shaking table: Pengaruh laju aliran air," Jurnal Teknologi Pertambangan, vol. 11, no. 1, pp. 69–73, 2025, doi: 10.31315/jtp.v11i1.14957.
[8] Y. Amalia and F. E. Oktanugraha, "Analysis of tin processing retreatment tailings using a shaking table based on the effect of deck slope and water flow velocity on tin grade and recovery at PT Timah TBK," AIP Conference Proceedings, vol. 3337, no. 1, Art. no. 040056, 2026, doi: 10.1063/5.0303016.
[9] A. O. Oyelola, B. J. Olatunde, A. O. Ebenezer, and G. Y. Elizabeth, "Investigating the gravity beneficiation consequence on Farin-Lamba (Plateau State) cassiterite towards tin oxide production," Saudi Journal of Engineering and Technology, vol. 9, no. 2, pp. 121–127, 2024, doi: 10.36348/sjet.2024.v09i02.011.
[10] Subandrio, R. Kurniawati, W. Dahani, and S. P. Adji, "Optimization of tin ore concentration using gravity method," AIP Conference Proceedings, vol. 2598, no. 1, Art. no. 040010, 2023, doi: 10.1063/5.0146309.
[11] T. Arief, "Design and experimentation shaking table tool for gravity concentration metal mineral separation," International Journal of Mineral Processing and Extractive Metallurgy, vol. 7, no. 1, pp. 1–7, 2022, doi: 10.11648/j.ijmpem.20220701.11.
[12] R. O. Burt, Gravity Concentration Technology. Amsterdam, Netherlands: Elsevier, 1984.
[13] L. Pulungan, D. N. Usman, S. Widayati, and S. Maulida, "Improvement of cassiterite levels with variation of feed roll and separation roll speed in high tension roll separator (HTRS)," Journal of Engineering Science and Technology, vol. 16, no. 1, pp. 427–437, 2021.
[14] R. Ribeiro, D. Capela, M. Ferreira, R. Martins, P. Jorge, D. Guimarães, and A. Lima, "X-ray fluorescence and laser-induced breakdown spectroscopy analysis of Li-rich minerals in veins from Argemela Tin Mine, central Portugal," Minerals, vol. 11, no. 11, p. 1169, 2021, doi: 10.3390/min11111169.
[15] H. Zhang, J. Antonangelo, and C. Penn, "Development of a rapid field testing method for metals in horizontal directional drilling residuals with XRF sensor," Scientific Reports, vol. 11, p. 3901, 2021, doi: 10.1038/s41598-021-83584-4.
[16] K. You, C. Wen, and H. Liu, "Research on intelligent implementation of the beneficiation process of shaking table," Minerals Engineering, vol. 199, Art. no. 108108, 2023, doi: 10.1016/j.mineng.2023.108108.
[17] M. E. Amosah, M. Yvon, J. Zhou, and K. P. Galvin, "The role of enhanced desliming and gravity separation as a precursor to flotation in the upgrading of cassiterite from tailings," Minerals Engineering, vol. 208, Art. no. 108581, 2024, doi: 10.1016/j.mineng.2024.108581.
[18] S. Zhou, J. Wang, W. Wang, and S. Liao, "Evaluation of portable X-ray fluorescence analysis and its applicability as a tool in geochemical exploration," Minerals, vol. 13, no. 2, Art. no. 166, 2023, doi: 10.3390/min13020166.
[19] B. Maestracci, S. Delchini, D. Chateigner, and E. Borovin, "Simultaneous combined XRF-XRD analysis of geological samples: New methodological approach for on-site analysis on New-

Caledonian Ni-rich harzburgite," Journal of Geochemical Exploration, vol. 252, Art. no. 107250, 2023, doi: 10.1016/j.gexplo.2023.107250.
[20] H. M. Sierra, M. Šyc, and E. Korotenko, "Wet shaking table operating parameters optimization for maximizing metal recovery from incineration bottom ash fine fraction," Waste Management, vol. 174, pp. 539–548, 2024, doi: 10.1016/j.wasman.2023.12.030.
[21] L. Zhang, S. A. Khoso, M. Tian, and W. Sun, "Cassiterite recovery from a sulfide ore flotation tailing by combined gravity and flotation separations," Physicochemical Problems of Mineral Processing, vol. 57, no. 1, pp. 206–215, 2021, doi: 10.37190/ppmp/131006.
[22] T. Kundu, S. K. Das, N. Dash, P. K. Parhi, P. Sangurmath, and S. I. Angadi, "Characterization and gravity concentration studies on spodumene-bearing pegmatites of India," Separation Science and Technology, vol. 58, no. 13, pp. 2331–2343, 2023, doi: 10.1080/01496395.2023.2258273.