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Study on the Utilization of Low Grade Tin Ore Results Washing (SHP) with a Shaking Table to Improve Recovery and Grade of Tin Ore: Case Study in Toboali Washing Plant PT Timah Tbk Bangka

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Abstract: Shaking table is a technology that is still used in processing of tin ore using water as a medium. In the application at PT Timah Tbk, the shaking table is still used to process low grade tin ore into tin ore with a standard smelting grade of PT Timah (72%-74% Sn). In processing tin ore using a shaking table, valuable minerals and impurity minerals are separated based on differences in specific gravity, size and shape of the mineral. To get the recovery of valuable minerals (recovery) and optimal grades, it is strongly influenced by the separation variables of tin ore minerals. These variables include riffle, slope of deck, washing water rate, stroke length, and deck movement speed. This study aims to vary the number of riffles, table slope and time in a laboratory scale to obtain optimal recovery and grade of tin ore. Tin ore samples were obtained from the washing residue of the Toboali Washing Plant tin ore. In the experiment, the numbers of riffles set were 16 (R1), 24 (R2) and 34 (R3). The table slopes were 2° (S1), 3° (S2), and 4° (S3). Time variations were 15 (T1), 20 (T2) and 25 min (T3). The relationship between the number of riffles and the grade can be determined through quadratic polynomial regression analysis with the function $\hat{Y} = -20.60 + 2.26X + (-0.04X^2)$, while the relationship between the number of riffles and recovery is determined by the function $\hat{Y} = -173.33 + 17.376X + (-9.315X^2)$. Optimal levels are obtained at variations in the number of riffle 26 by 66.43%, with levels of 8.45% Sn. Optimal recovery is obtained on the variation of the number of riffle 28 with a recovery of 66.43%.

Key words: Tin ore, shaking table, riffle, content, recovery.

1. Introduction

Shaking table is included in the wet process metal mineral separation tool which is still used to separate tin ore based on differences in the specific gravity of the minerals. In the process of separating valuable minerals (concentrates) and unvalued minerals (tailings) based on differences in mineral density through a thin fluid flow. [1]. In the separation of metallic minerals, especially tin ore on the shaking table, the media used is water, which serves to create a driving force for the minerals to be separated. In addition to the difference in specific gravity, separation using a shaking table is also influenced by the size and shape of the mineral grains [2]. In the separation of tin ore at PT Timah Tbk, shaking table technology is an effective tool for separating valuable minerals (concentrate) and impurity minerals with relatively high recovery in accordance with the company's target. High ore content (70% Sn) is the main requirement in the smelting process to obtain quality tin [3]. In addition to specific gravity, mineral grain size also affects the speed of mineral movement in the separating medium. This relates to the value of the terminal velocity of the mineral in the separating

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medium. The grain size of the sample feed for the gravity concentration process was prepared by sieving analysis using a sieve shaker [4].

In its application at PT Timah Tbk, the shaking table is used to process low grade tin ore (29%-50% Sn) with fine grains (50-200 mesh), into high grade to meet the technical criteria for smelting raw materials [5]. Currently, tin is still one of Indonesia's mainstay export commodities in the mining sector. Indonesia's tin production, which reached 82,460 metric tons in 2019, is one of the world's main tin producers with a contribution of around 24% of the total estimated world tin production according to the ITA (International Tin Association) of 334,400 tons [6]. Research on shaker tables for tin ore processing has been carried out previously. The research focused on the variables of deck slope, feed rate, and stride length. But research was not conducted on the variable number of rifles [7]. Tin (tin) is a silvery-white metal, with low hardness, specific gravity of 7.3 g/cm^3, and has high thermal and electrical conductivity with the chemical element with the symbol Sn (Latin: stannum) [8]. The rocking table tool is a metal mineral concentration technology that utilizes fluid motion and the impact of the table to separate valuable minerals from impurities [9]. The results of previous studies showed that the greater the slope of the deck, the higher the recovery but at a lower level. The slope of the deck also affects the speed of water flow, a large slope causes fast water flow and carries fine grained ore so that recovery is small [10]. Tin mineral (cassiterite) is the main product of the washing process. Advances in science have made it possible to separate cassiterite and related minerals and use them. By knowing these properties, each type of mineral can be recognized, and its chemical composition is known within certain limits [11].

In an effort to increase the recovery of tin ore, it is necessary to conduct a technical study of the important variables that affect the separation of metallic minerals using a shaking table. These variables include the number of riffles, slope of deck, water discharge, feed rate, and stride length. Based on this, in this study a technical study will be conducted that focuses on variations in the number of riffles and slope of table by using a shaking table to improve recovery and grade of tin ore.

2. Research Methods

The research was carried out for 2 months from March 4, 2022 to June 5, 2022 at the Mineral Processing Laboratory and Paleontology Laboratory, Department of Mining Engineering and Geology, Faculty of Engineering, Sriwijaya University, which is located on Jalan Palembang-Prabumulih kilometers 32 Indralaya, Ogan Ilir Regency.

The initial stage in this research is to conduct field observations and sampling at PT Timah Tbk. The sampling location for tin ore is tin ore/washed residual material (SHP) from the Washing Plant (PPBT Toboali). Sampling was carried out by manual drilling using an auger drill at 4 angles/sampling points on the tin ore stockpile, so that 50 kg of tin ore was obtained (Fig. 1).

Fig. 1 Tin ore sampling location.

In this research, the stages of activities carried out include 2 major stages, including the following:

2.1 Physical Analysis and Characteristics

After taking the tin ore sample, drying and cleaning of the sample is carried out for the sieving analysis process with a digital sieve shaker. The sieving analysis process is for sifting and preparing the particle size of tin ore so that it is in accordance with the needs of the next process. The results will be tested and analyzed for grain counting the distribution of sample sizes and material content of each size using a SEM (Scanning Electron Microscope). From the stages above, the physical and characteristics of the tin ore sample can be analyzed. This activity was carried out at the Geology and Exploration Laboratory of PT Timah Tbk Bangka.

2.2 Analysis of Sample Experimentation

The study was conducted using a shaking table measuring 85 cm × 155 cm with the variables determined, including the number of riffles 16 (R1), 24 (R2) and 34 pieces (R3), slope of deck 2° (S1), 3° (S2), 4° (S3), separation time 15 min (T1), 20 min (T2) and 25 min (T3). Other variables such as stroke length of 2.5 mm, washing water discharge 20 L/min, and feeding speed of 5 min were not varied.

The sample used in this study was tin ore left over from the Toboali Washing Plant. Sampling was carried out by manual drilling using an auger drill at many points to obtain 50 kg of material. The samples were then dried and analyzed for their physical and chemical content before being processed using a shaking table. After all the above samples have been prepared, they will be sieved using a sieve shaker to obtain a sample size distribution.

The experimental products in the form of concentrate and dried tailings were weighed and grain counting was analyzed in the laboratory to obtain the levels and recovery of Sn from each experiment.

The data obtained were calculated using regression analysis to obtain variations in the number of riffles for optimal grade and recovery results.

2.3 Evaluation

After all the samples were tested, the concentrate and taillings were dried and weighed and grain counting was analyzed in the laboratory to obtain the levels and recovery of Sn from each experiment.

The data obtained were calculated using regression analysis to obtain variations in the number of riffles for optimal grade and recovery results. Fig. 2 shows a research flow chart for the study of the utilization of refined tin ore using a shaking table.

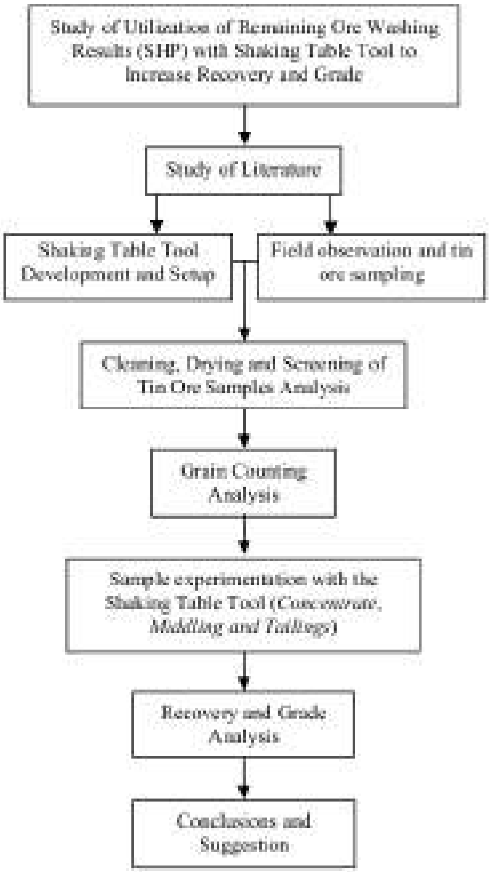

Fig. 2 Research flowchart.

3. Discussion

From the results of the study of testing and experimentation to increase the recovery of tin ore from the washing residue, it is obtained as follows:

3.1 Tin Ore Characterization Analysis

The physical characteristics of tin ore as a result of washing the remaining tin ore washing in Toboali PT Timah Tbk after sieving with ASTM (American Standard Testing and Material) standards show that the distribution of ore sizes varies from 30 mesh to 200 mesh. The results of the measurement of the weight of tin ore retained on each sieve are shown in Table 1.

From the results of characteristic testing on samples of tin ore from the Washing Plant Toboali PT Timah, the size ranges from 30 mesh to 200 mesh, where the size of 50 mesh is larger than other sizes.

From the results of grain counting analysis, quartz mineral has a transparent color and glass luster with an irregular crystal shape with a specific gravity of 2-2.5. The mineral cassiterite as a tin-bearing mineral (Sn) has a dominantly angular shape of angular-rounded grains with brownish black and reddish colors, with a specific gravity of 7-7.5.

The results of grain counting analysis using a SEM showed that the tin ore sample contained the minerals cassiterite, ilmenite, xenotime, quartz and zircon (Fig. 3).

From the analysis of Sn content in the sample tin ore of 3.05% Sn, from the analysis of mineral content, ilmenite dominates this tin ore sample with its black or gray color and angular metallic luster with a specific gravity of 4.5.

The mineral zircon has a grayish yellow to purple color with a waxy luster and a round to angular grain shape. The mineral monazite, which is a carrier of rare earth metals, has a round, brownish-yellow color.

3.2 Experimental Analysis

The experiment of separating tin ore using a shaking table was carried out with a sample feed of 700 g. The results of all experiments are shown in Tables 2-4.

Table 1 Sample characteristics test results.

No.	Sieve size (mesh)	Oversize (gram)	Undersize (%)	Weight (gram)
1	30 #	13.11	86.89	13.11
2	50 #	77.96	8.93	77.96
3	100 #	3.16	3.16	3.16
4	200 #	0.69	0.69	0.16
5	-200 #	5.08	0.37	5.08

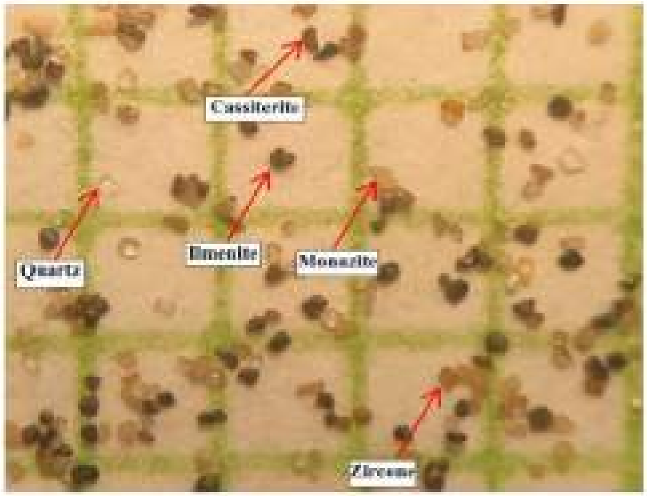

Fig. 3 Tin ore minerals.

Table 2 Experimental results of the effect of the number of riffles 16 (R1) and the slope of deck (2°, 3° and 4°).

Combination variation	Weight concentrate (kg)	Grade concentrate (%)	Weight tailing (kg)	Grade tailing (%)	Time process (menit) (T)	Slope of deck (°) (S)	Recovery (%)
R1S1T1	0.13	3.46	0.54	0.29		2.00	20.75
R1S2T1	0.10	3.98	0.56	0.25	10	3.00	19.4
R1S3T1	0.09	4.00	0.60	0.22		4.00	16.53
R1S1T2	0.14	3.89	0.53	0.33		2.00	26.26
R1S2T2	0.12	4.48	0.55	0.28	15	3.00	24.56
R1S3T2	0.10	4.51	0.59	0.24		4.00	20.92
R1S1T3	0.16	4.32	0.51	0.36		2.00	32.42
R1S2T3	0.13	4.97	0.53	0.31	20	3.00	30.32
R1S3T3	0.11	5.01	0.57	0.27		4.00	25.83

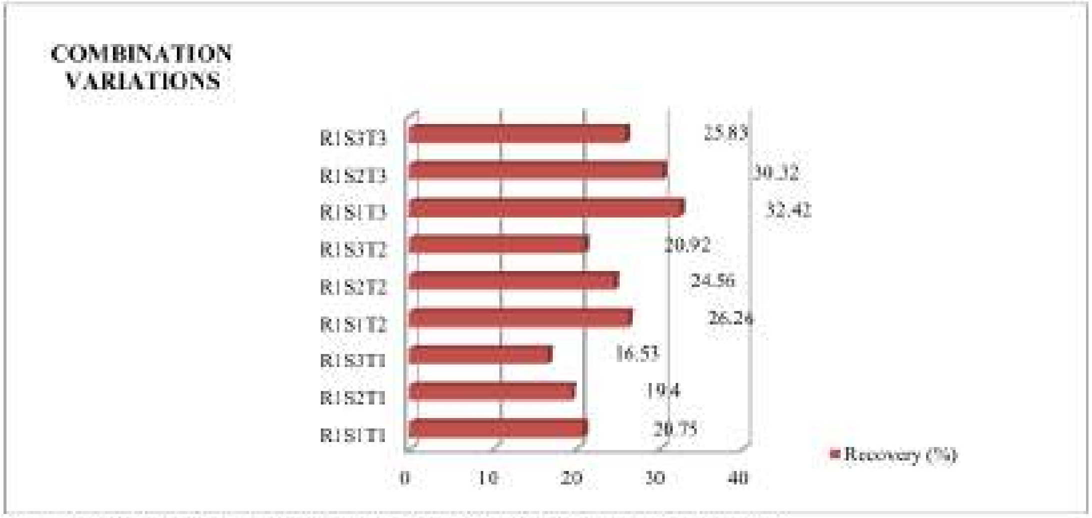

Fig. 4 Graph of the effect of the number of riffles 16 (4 cm) on the recovery of tin ore (%).

Table 3 Experimental results of the effect of the number of riffles 24 (R2) and the slope of deck (2°, 3° and 4°).

Combination variation	Weight concentrate (kg)	Grade concentrate (%)	Weight tailing (kg)	Grade tailing (%)	Time process (menit) (T)	Slope of deck (°) (S)	Recovery (%)
R2S1T1	0.18	6.14	0.48	0.34		2.00	50.65
R2S2T1	0.14	7.53	0.51	0.28	10	3.00	49.4
R2S3T1	0.12	8.52	0.54	0.40		4.00	46.65
R2S1T2	0.20	6.91	0.47	0.38		2.00	64.1
R2S2T2	0.16	8.47	0.50	0.32	15	3.00	62.52
R2S3T2	0.13	9.58	0.53	0.46		4.00	59.04
R2S1T3	0.22	7.67	0.46	0.43		2.00	79.14
R2S2T3	0.18	9.41	0.49	0.35	20	3.00	77.18
R2S3T3	0.15	10.65	0.51	0.51		4.00	72.89

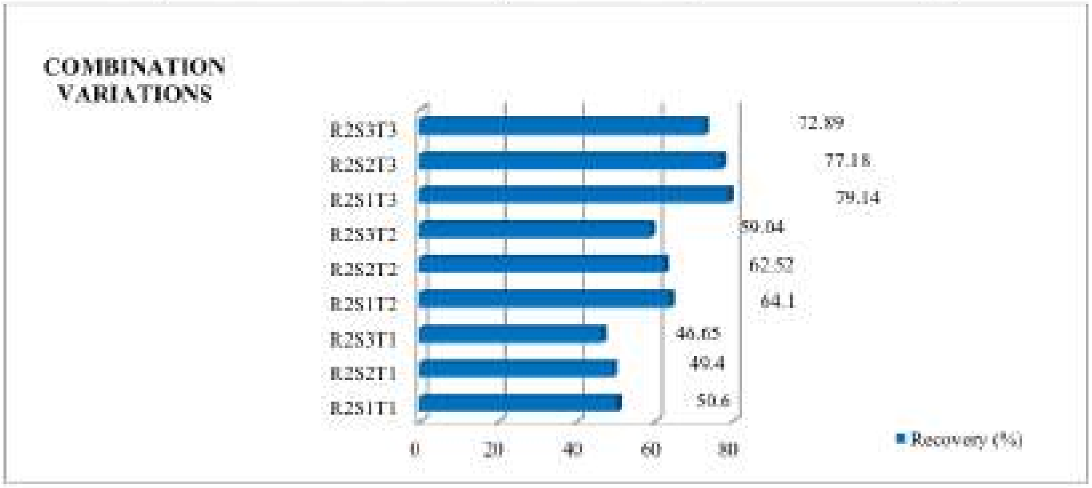

Fig. 5 Graph of the effect of riffle number 24 (2.5 cm) on the recovery of tin ore Sn (%).

Table 4 Experimental results of the effect of the number of riffles 34 (R3) and the slope of deck (2°, 3° and 4°).

Combination variation	Weight concentrate (kg)	Grade concentrate (%)	Weight tailing (kg)	Grade tailing (%)	Time process (menit) (T)	Slope of deck (°) (S)	Recovery (%)
R3S1T1	0.22	4.27	0.39	0.23	10	2.00	54.66
R3S2T1	0.18	4.88	0.44	0.23		3.00	53.25
R3S3T1	0.16	5.43	0.47	0.20		4.00	51.57
R3S1T2	0.27	5.33	0.37	0.29	15	2.00	54.66
R3S2T2	0.23	6.10	0.42	0.28		3.00	53.25
R3S3T2	0.20	6.79	0.45	0.25		4.00	51.57
R3S1T3	0.27	5.33	0.37	0.29	20	2.00	67.49
R3S2T3	0.23	6.10	0.42	0.28		3.00	65.74
R3S3T3	0.20	6.79	0.45	0.25		4.00	63.67

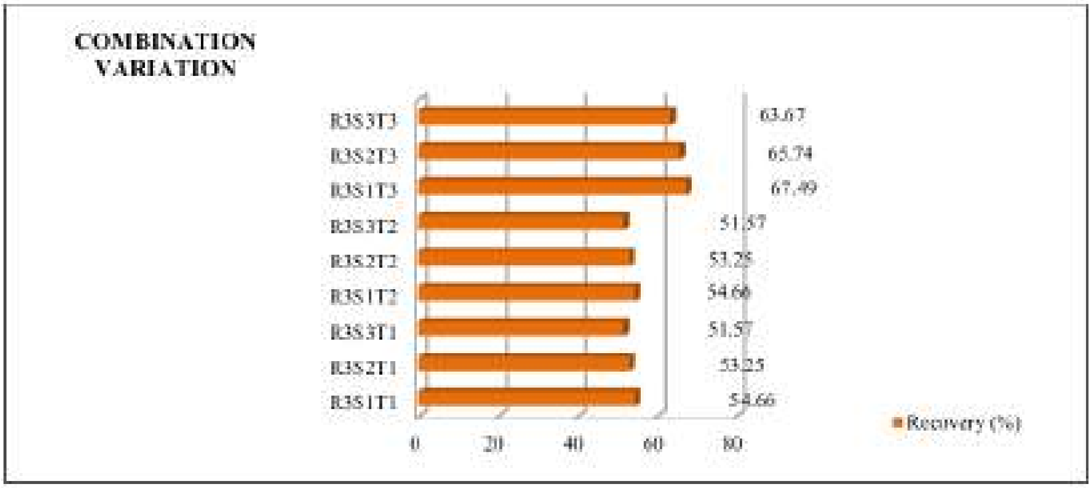

Fig. 5 Graph of the effect of riffle number 34 (1.5 cm) on the recovery of tin ore Sn (%).

3.3 Analysis Evaluation and Optimization

Fig. 7 shows the arrangement of the riffles installed on the surface of the deck on the shaking table that was designed and has been installed in the Mineral Processing Laboratory. Riffles will be installed according to the experimental plan, namely the number of riffles 34 (1.5 cm), 24 (2.5 cm) and the number of riffles 16 (4 cm).

From the experimental results on samples of tin ore using shaking table technology (Fig. 7) shown in Table 2, Table 3 and Table 4 with various combinations, including: the number of riffles is set into 3 variables, namely the number of riffles 16, 24 and 34, deck slope 2°, 3° and 4° and operating times of 10, 15 and 20 minutes.

The results obtained from experimental experiments on the number of riffles 16 (4 cm) showed very low yields ranging from only 16 - 32, 42% (Fig. 4), while for the number of riffles 34 (1.5 cm) tin ore recovery ranged from 51.57 - 63.67% (Fig. 6).

Fig. 5 shows that the combination of variations in the number of riffles 24 (2.5 cm) tends to be more optimal for heavy/valuable minerals, where the recovery of tin ore ranges from 46.65-79.14%.

The patterns of mineral movement above the riffle at variations in the number of riffles are 34, 24 and 16. Fig. 8 shows the effect of the number of riffles 34, 24 and the number of riffles 16 on the pattern of mineral movement on the surface of the shaking table deck.

In variations in the number of riffles 34 (distance 1.5 cm), the distance of the riffles is too close resulting in the washing water not being able to form eddy/turbulence currents to stir the mineral layers that have accumulated. At this distance, with the same grain weight, water is only able to separate fine-grained light minerals while the minerals retained in the riffle still contain large-grained light minerals. The speed of grain movement horizontally is greater than the speed of vertical motion so that there is no turbulence and the mineral grains will only settle. The retained minerals will move towards the concentrated reservoir due to the movement of pounding the table.

Fig. 7 Riffle arrangement on the deck shaking table.

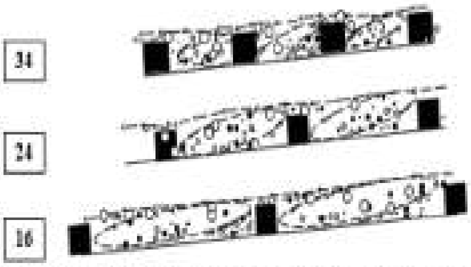

Fig. 8 The pattern of mineral movement above the riffle at variations in the number of riffles 34, 24 and 34.

The variation in the number of riffles 24 (distance 2.5 cm) shows the suitability of the riffle distance where the washing water is able to stir the accumulated minerals. Light minerals can be carried away by water currents while heavy minerals are trapped in the riffle. Grain velocity vertically and horizontally has the most suitable composition in this variation, so the separation goes quite well.

As for the variation in the number of riffles 16 (distance 4 cm) it indicates the distance of the riffle is too far so that the ability to hold minerals is not optimal. Washing water mixes well, but the heavy, fine-grained minerals are also removed along with the lighter minerals.

The speed of grain movement vertically is greater than the speed of horizontal motion, causing too much turbulence flow. Minerals carried by water currents will enter the tailings storage container.

Other factors that affect the separation capability of a shaking table include:

(1) The effect of the slope of the deck in a tight variation in the number of riffles, must be accompanied by a slightly extreme slope setting. Based on the gravity equation, proving the Gaudin effect equation: $F1 = 4/3\ r^3\ g\ (Dp - Df)\ \sin \alpha$, proving that the greater the slope of the deck indicates the greater the sine value, the greater the mineral thrust force (fluid thrust) capable of through the riffles. Based on the equation of friction between the particles and the surface of the plane, it shows that increasing the cosine value will decrease the frictional resistance of minerals on the deck surface. Gaudin effect equation: $F2 = -4/3\ r^3\ g\ (Dp - Df)\ \cos\alpha$

In every movement of particles and fluids there is a particle resistance in the fluid which is a function of the relatively slow settling velocity of the particles and the laminar flow of the fluid. The thrust of a fluid in the presence of fluid resistance is the sum of all the forces acting on the particles themselves.

(2) The influence of the size, weight and shape of the ore particles from the separated mineral particles affects the effectiveness of what concentration tools will be used. The weight of the particles affects the increase in the ability of the grains to slide due to the gravitational force according to the gravitational force equation. Particle shape also affects the shear ability of mineral grains. The rounded grain shape makes the mineral easier to slide due to the small frictional force.

(3) The speed of water flow over the deck surface plays an important role in the process of separating the transverse or vertical motion of mineral grains (perpendicular to the table axis). This vertical movement is hindered by the height and number of riffles. The level of water washout must be adjusted to the deck slope and the number of riffles. Wash water is also used as a means of transporting particles from the feed box to the product reservoir.

3.4 Recovery and Level Improvement Evaluation Analysis

3.4.1 The Effect of Riffle Number on Recovery

The experimental data in Tables 2-4 were calculated using a quadratic non-linear regression analysis with data recovery as a fixed variable and the number of riffles as independent variables. The result of the calculation is that the quadratic regression function is

$$\hat{Y} = -173.33 + 17.376\,X + (-0.315X^2)$$

The relationship between the variable number of rifles and recovery can be seen in Fig. 9.

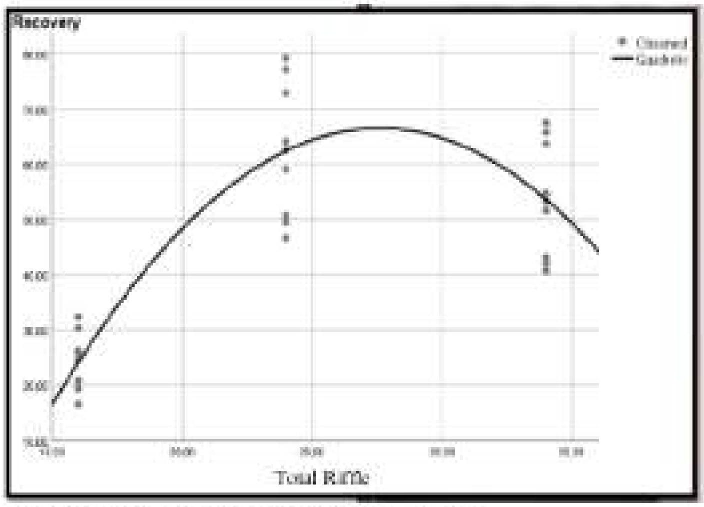

Fig. 9 Graph of the relationship between the number of riffles and recovery.

The coefficient of determination obtained an R^2 value of 0.763, meaning that the number of riffles on the shaking table had an effect of 76.3% on Sn recovery while 23.7% was influenced by other factors.

3.4.2 The Effect of Riffle Amount on Level

The experimental data in Table 2 are calculated using a non-linear regression analysis using the quadratic method with content data as a fixed variable and the number of riffles as an independent variable. The result of the calculation is that the quadratic regression function is

$$\hat{Y} = -20.60 + 2.26X + (-0.04X^2)$$

The relationship between the variable number of riffles and levels can be seen in Fig. 10.

Calculation of the coefficient of determination obtained an R^2 value of 0.771, meaning that the number of riffles on the shaking table has an effect of 77.1% on Sn levels while 22.9% is influenced by other factors.

3.4.3 Recovery Optimization Analysis

The results of the regression analysis using the quadratic polynomial method yielded the equation function $\hat{Y} = -173.33 + 17.376X + (-0.315X^2)$. To get the largest recovery that can be obtained, a trial is carried out by changing the value of X as shown in Table 2.

Table 5 shows that the optimal recovery was obtained in the variation of the number of riffles 28 with a recovery of 66.43%. The intersection point between the riffle variation and the highest recovery is shown in Fig. 11.

3.5 Optimization Analysis Grade of Sn

The results of the regression analysis of the quadratic polynomial method produce the equation function $\hat{Y} = -20.60 + 2.26X + (-0.04X^2)$. To get the largest level that can be obtained, a trial is carried out by replacing the X value as shown in Table 6.

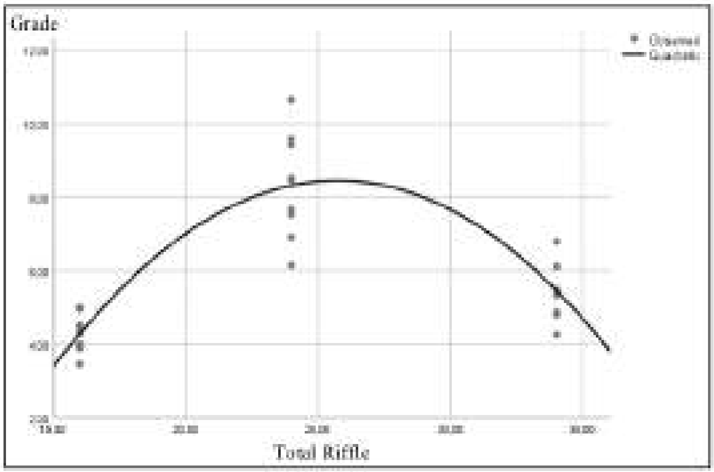

Fig. 10 Graph of relationship between riffle amount and Sn content.

Table 5 Recovery optimization.

	Total riffle	Recovery Sn (%)
	24	62.40
	25	64.35
	26	65.67
	27	66.37
Peak →	28	66.43
	29	65.86
	30	64.67

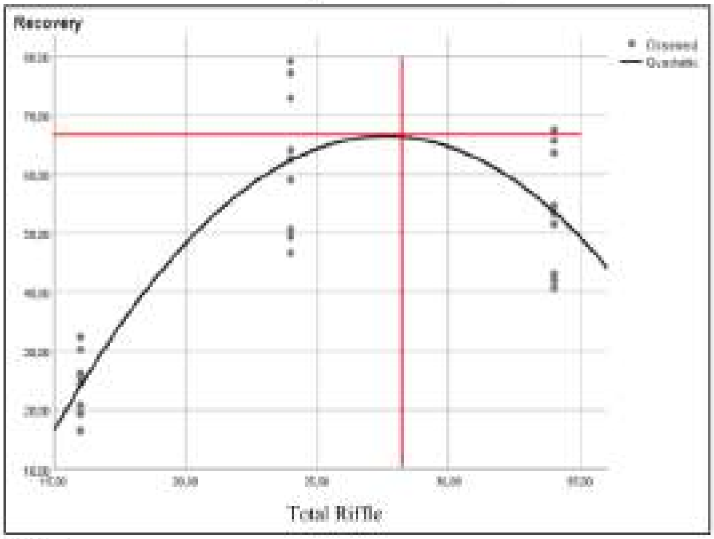

Fig. 11 Optimal recovery.

Table 6 Optimization of grade of Sn.

	Total riffle	Grade Sn (%)
	24	8.32
	25	8.43
Peak →	26	8.45
	27	8.38
	28	8.23
	29	7.99
	30	7.66

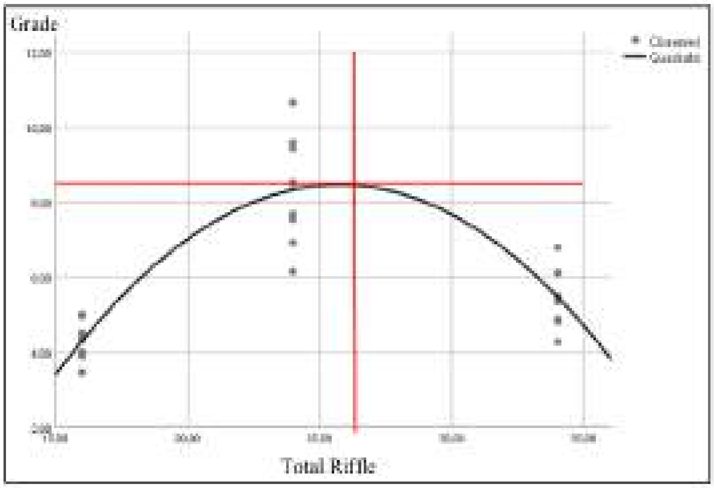

Fig. 12 Optimal level.

Table 6 shows that the optimal grade was obtained in the variation of the number of riffles 26 with a level of 8.45%. The intersection point between the riffle variation and the highest grade is shown in Fig. 12.

4. Conclusions and Suggestions

4.1 Conclusion

Based on the results and discussion of research that has been done, it can be concluded as follows:

From the results of the characteristic test of Toboali tin ore left over from washing (SHP) in terms of grain size, it shows that the distribution of ore size varies widely but is dominant in fine size. The highest percentage was found in size -30# +50# with 77.96%, while the smallest percentage was at -100 +200 with 0.69%.

The number of riffles on the shaking table has a major effect on the equipment's ability to hold minerals. The more riffles with the same slope angle experiment, the more concentrate obtained, while the grade and recovery increased and decreased. The highest recovery was obtained by 79.14% for variations in the number of riffles 24, slope deck 2°, and time of 20 min. Meanwhile, the lowest recovery was obtained by 16.53% in the variation of the number of riffles 16, slope deck 4°, and a time of 10 min. The highest level was obtained by 10.65% in the variation of the number of riffles 24, slope deck 4°, and time of 20 min, while the lowest level was obtained by 3.46% in the variation of the number of riffles 16, slope deck 2°, and time of 10 min.

Based on the results of non-linear quadratic polynomial regression, the optimal level was obtained at the number of riffles 26 with a level of 8.45%, while the optimal recovery is obtained at the number of riffles 28 with 66.43%.

4.2 Suggestions

From the results of the study on the improvement of tin ore recovery in refined tin ore using the Shaking Table tool, the authors suggest the following: (1) The performance of the shaking table has not yet reached optimal, but it is functioning well because it can process fine tin ore left over from washing tin ore with sizes above 50 mesh; (2) With variations in the number of riffles 16, 24 and 34 and slopes of deck 2°, 3°, and 4°, resulting in optimal recovery and grades; (3) In the future, it is necessary to carry out further research studies that can be done by changing the length of the stroke and the number of strokes and the amount of weight of the feed more.

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