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Optimum Design of Hammer Mill for Grinding Leonardite

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ABSTRACT

The objective of this research is to design and construct a hammer mill for grinding leonardite charcoal (Lignite, class J). The conditions for the design and construction of the grinder are hammer thickness, 3, 6, and 9 mm, a number, hammer 20, 24, and 28. The size of the ground leonardite should range between 250 µm to 30 µm (less than 0.066 mm). The hammer thickness and number of hammers were chosen alternatingly in order to see the effect of these two parameters. By manipulating these two parameters, it was found that the optimum operation can be achieved by using 28 hammers having a thickness of 3 mm. It results in the highest grinding efficiency of 96.2 percent. Percentages of the grate (retained) and passed of the ground mineral are found for each sieve size by means of weight. The approximations of the retained and passed were calculated and found to intersect at 225 µm. At the intersection, the percentage by weight passed through the sieve is 50 percent and the percentage by weight retained sieve is 50 percent, respectively.

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1. Introduction

Mineral size reduction is a preliminary method before separating or dressing. Because it is already known that natural minerals coexist with rocks or other impurities. In order to obtain clean minerals, it is necessary to reduce the size or to break minerals into tiny pieces. This process lets mineral- free from stigma.

Once the ore is mined or exploded, it is taken from the mine. Generally, the ore that is mined or exploded from the mining site can be as large as 1.5 meters cube. In this initial coarse grinding, the mineral cube is reduced to 10-20 centimeters cubes. There are 2 steps in reducing the size of ore. The first is to crush, usually using a dry system. This step results in a small ratio of mineral reduction. After the crushing process, the second step is to grind. In mining works, wet grinding is preferred. Then, the ground mineral is transferred to the mineral processing system [1, 2].

The first step of grinding is to reduce the mineral size so that the ore is separated from impurities. After that, it will be fed into the second step, the coarse grinding process. In this second grinding process, the size will be reduced to 2-0.5 cm. Sometimes the ground ore exhibits a sticky mineral texture which may need to be crushed in the third step or so on. The grinding process will repeat until getting the desired size. In this process, in practice, a vibrating sieve can be used in combination with grinding, for which may be connected to an open circuit or closed circuit as appropriate [3, 4].

Vibratory Mill, in comparison to the vibrations of ordinary circles, the vibration profile of the grinding pot in this machine can be in the form of elliptical, circular, or linear. Springs at the base of the machine are a key factor in producing vibration in a circular motion. However, the vibration is much more powerful and can be increased. The speed of the motor affects the rotation of unbalanced mass and that results in amplitude of vibration. Also designs of the unbalance mass influence different results and show the effectiveness of the grinder. So, the grinder strength depends on these factors. The force within the grinding pot consists of impact or pressure, shear, and abrasive force [5-7].

In the past, a number of studies on working principles and efficiency of hammers mill are as follows. The perforated metal screen covering the discharge opening of the mill retains coarse material for further grinding while allowing properly sized materials to pass as finished product. Screen size is determined by the size of the opening in the screen. This size can be given in inches or microns (one-millionth of a meter). The US mesh uses three number of wires running east/west and north/south in one square inch of a screen [8].

Based on the results obtained, the following conclusion was drawn. The existing literature shows that the efficiency of the hammer mill was found to be 54% [9]. The following objectives can be said to be achieved. This includes redesigning the hammer mill, redesigning the hammer mall chamber shape, directly incorporating the variable speed engine to the hammer mill shaft, improving cereal grinding operation for both humans, birds, and animal feed, alleviating the physical sufferings associated with the conventional grinding machine and improving the economic condition of the rural populace [10]. In the big mining industry, four processes are adopted for continuous size reduction; there are primary, secondary, tertiary, and quaternary crushing operations [11]. Mentioned that a hammer mill with 16 hammers, a 4.58 mm screen, and an operating speed of 3600 rpm was more effective at grinding a mixture of 1.24 mm (miner diameter) cheat seed, chaff, and straw than a roller mill set with a roller gap force for alfalfa than 0.1 mm [12]. Mentioned that particle size reduction is an important procedure for utilizing biomass to use it in energy production and animal feedstock. Particle size and their densification are important for harvesting, and drying [13]. Indicted that the power requirements for grinding biomass are related to biomass selection, initial and final particle size (geometric mean diameter), moisture content, and feed rate of the material [14]. Mentioned that hammer mills have achieved merit because of their ability to finely grind a greater variety of materials than any other machine [15]. Mentioned that there is an interaction between hammer tip speed and hammer thickness affected energy efficiency of the hammer mill [16]. The sieve analysis to ascertain the crushability and predict the energy consumption rate of the machine was satisfactory. As a sequel to this fact, the machine appears to be capable of crushing other minerals such as limestone and talc with a powerful crushing capacity and reasonable energy consumption [17]. The designed machine showed that the maximum crushing efficiency was 94.4 %. The study indicated the relationship between cumulative passed and retained materials. The results showed that the pass cumulative weights were 60 % and 65% for maize and broad bean respectively [18]. The crushing capacity and efficiency of the improved machine are seen as satisfactory, despite the slight loss obtained was due to the sticking of the powdery material to the wall of the crushing hammer known as the hammering chamber and some strains that pass through the screen due to size [19].

According to previous studies, no one has done any studies on the design of hammer mills for grinding leonardite, therefore the purpose of this article is to find the optimum design of hammer mill for grinding leonardite.

2. Material and method

The general design was based on the process of allowing a strong and durable metallic object inform of hammers to beat any material that obstructs its way during operation. In other words, it results in the breakage of the material. This braking process can be referred to as size reduction. This usually occurs in an enclosed chamber called the crushing chamber. The physical and mechanical properties of the mineral to be crushed were studied as this would help immensely in the design of various components of the rotor. The engineering properties and some other parameters are the main factors considered before designing the machine.

2.1. Theoretical Design Consideration

Determination of shaft speed, to calculate the shaft speed the following parameters are used.

$$\frac{D_1}{D_2} = \frac{N_1}{N_2} \quad (1)$$

Determination of nominal length of the belt, the nominal length of the belt was calculated by using the following formula.

$$L = 2C + \frac{\pi}{2}(D_1 + D_2)\left(\frac{D_1 + D_2}{4C}\right)^2 \quad (2)$$

Minimum center distance is determined from

$$C_{min} = 0.55(D_1 + D_2) + T \quad (3)$$

and maximum center distance is determined from

$$C_{max} = 2(D_1 + D_2) \quad (4)$$

Determination of belt contact angle, the belt contact angle is given by equation.

$$Sin^{-1}\beta = \frac{(R-r)}{C} \quad (5)$$

Determination of the belt tension, the driven belt tension is determined using the following formula.

$$T_2 = \frac{(T_1 - MV_2)}{exp\left[\frac{\mu\alpha}{Sin\frac{1}{2}\theta}\right]} \quad (6)$$

Determination of the torque and power transmitted for the shaft, the torque and power transmitted for the shaft are determined using the following formula.

$$P = T_r(\omega_a), T_r = (T_1 - T_2)R, \text{ N} \quad (7)$$

Determination of hammer weight. Hammer weight is determined using the following formula.

$$W_h = m_n g \quad (8)$$

$$Density = \frac{\text{Mass}}{\text{Volume}}, \text{kg/m}^3 \quad (9)$$

Determination of the centrifugal force exerted by the Hammer, the centrifugal force exerted by the hammer is calculated using the following formula.

$$F = \omega r\sqrt{ms} \quad (10)$$

Determination of hammer shaft dimeter, hammer shaft diameter is calculated using the following formula.

$$\frac{I}{Y_{max}} = Z = \sigma_S = \frac{M_b}{Z} \quad (11)$$

$$\sigma_S(allowable) = \frac{M_b Y_{max}}{I}$$

$$M_{b\,max} = \frac{\text{L}^2\text{W}}{8} \quad (12)$$

For solid round bar

$$I = \frac{\pi d^4}{64} \quad (13)$$

$$Z = \frac{\pi d^3}{32}$$

Determination of the shaft diameter, the ASME code equation for a solid shaft having little or no axial loading is the following formula.

$$d^3 = \frac{16}{\pi\sigma_S}\sqrt{(K_b M_b)^2 + (K_t M_t)^2} \quad (14)$$

Grinding efficiency, the following formula is used for calculating the grinding efficiency

$$GrindingEfficiency = \frac{Mass\,of\,output\,material}{Mass\,of\,input\,material} x100 \quad (15)$$

2.2 Designed and Construction of the Hammer Mill

The design process started by applying the design theory equations in Section II(A), Equations (1) to (14), to calculate the various translations involved in the design. Hammer mill, as shown in Table 1, the results of the translator calculations used in the hammer mill design. After that, these calculated results were used for designing the forging shaft.

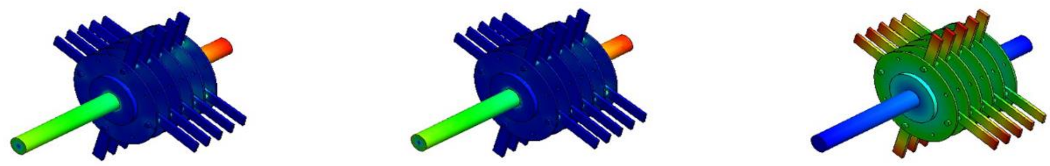
Force was analyzed by simulating torque that would occur on each shaft set. This simulation estimates damages in actual use. The parameters for the force analyzer are defined as follows. A number of 20, 24, and 28 hammers are made with a thickness of 3, 6, and 9 mm. Hammer width and length are 50 mm and 200 mm, respectively. As shown in Figures 1 to 3, the engineering force analysis of hammers 20, 24, and 28 are shown respectively in Tables 2 to 4 for stress-strain displacement and safety of factor at hammer thickness 3, 6, and 9 mm. of the hammer set of numbers 20, 24 and 28, respectively.

Table 1. *Results of calculated parameters.*

Parameters	Symbol	Value	Unit
Speed	N	2380	*rpm*
Length of belt	L	1842	*mm*
Tension in the slack side of belt	T_2	11.2	*N*
Tension in the tight side of belt	T_1	82.7	*N*
Torque transmitted to the shaft	T	73.5	*N.m*
Power transmitted to the shaft	P	18.3	*kW*
Weight of hammer	W_h	142.8	*kN*
Weight of hammer shaft	Ws	276.6	*N*
Diameter of main shaft	d	62	*mm*

Table 2. *Simulation of the 20 hammers.*

Number of hammers		Simulation	
		Min	Max
3	stress	$1.10x10^{1}$	$6.08x10^{7}$
	strain	$5.68x10^{-12}$	$2.28x10^{-4}$
	displacement	$1.00x10^{-30}$	$1.02x10^{1}$
	safety factor	4.13	
6	stress	$0.00x10^{1}$	$6.01x10^{7}$
	strain	$3.59x10^{-12}$	$2.30x10^{-4}$
	displacement	$1.00x10^{-30}$	$9.93x10^{-1}$
	safety factor	4.10	
9	stress	$1.53x10^{1}$	$6.04x10^{7}$
	strain	$5.58x10^{-12}$	$2.28x10^{-4}$
	displacement	$1.00x10^{-30}$	$9.73x10^{-1}$
	safety factor	4.09	

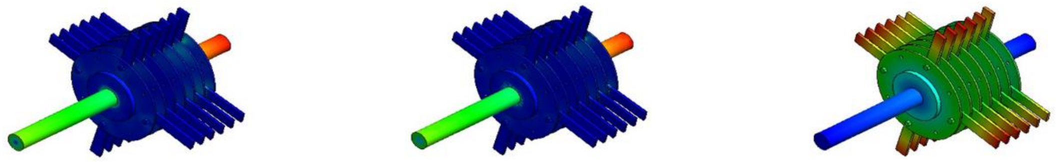


(a) Stress (b) Strain (c) Displacement

Fig.1. *Simulation of the 20 hammers.*

Table 3. *Simulation of the 24 hammers.*

Number of hammers		Simulation Min	Max
3	stress	9.82×10^{-1}	7.21×10^{7}
	strain	7.39×10^{-12}	2.74×10^{-4}
	displacement	1.00×10^{-30}	1.20×10^{1}
	safety factor	3.59	
6	stress	1.90×10^{-1}	9.00×10^{7}
	strain	5.62×10^{-12}	2.78×10^{-4}
	displacement	1.00×10^{-30}	1.19×10^{1}
	safety factor	3.46	
9	stress	1.22×10^{-1}	6.94×10^{7}
	strain	3.45×10^{-12}	2.63×10^{-4}
	displacement	1.00×10^{-30}	1.13×10^{1}
	safety factor	2.77	

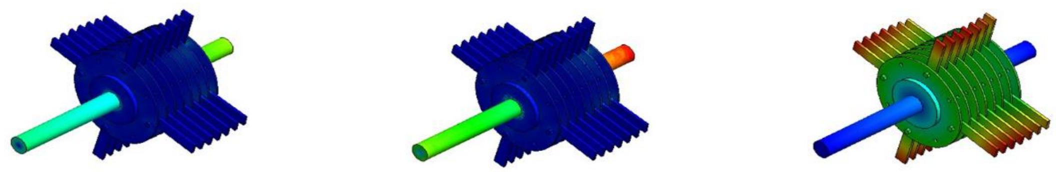


(a) Stress (b) Strain (c) Displacement

Fig.2. *Simulation of the 24 hammers.*

Table 4. *Simulation of the 28 hammers.*

Number of hammers		Simulation Min	Max
3	stress	1.68×10^{-1}	8.32×10^{7}
	strain	3.96×10^{-12}	3.04×10^{-4}
	displacement	1.00×10^{-30}	1.39×10^{1}
	safety factor	3.11	
6	stress	1.73×10^{-1}	8.02×10^{7}
	strain	8.65×10^{-12}	2.96×10^{-4}
	displacement	1.00×10^{-30}	1.33×10^{1}
	safety factor	2.54	
9	stress	1.86×10^{-1}	1.64×10^{8}
	strain	6.93×10^{-12}	3.66×10^{-4}
	displacement	1.00×10^{-30}	1.31×10^{1}
	safety factor	1.52	



(a) Stress (b) Strain (c) Displacement

Fig. 3. *Simulation of the 28 hammers.*

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After analyzing the force of the shaft assembly, the values are found within the standard design range. Therefore, the values obtained from the calculation as shown in Table 1, are used in designing the Hammermill as shown in Figure 4. A drawing aid program was employed to help in the design as calculated according to the equation mentioned in section II(A). After that, the Hammer mill will be constructed for testing. As shown in Figure 5, the dimensions of the hammer mill constructed for this study are 60 centimeters in stride, 150 centimeters in length, and 160 centimeters in height. The mineral feeder has a capacity of 10 kilograms and is powered by a 25-horsepower three-phase electric induction motor. The diameter of the driveshaft, blade set, is 62 mm.

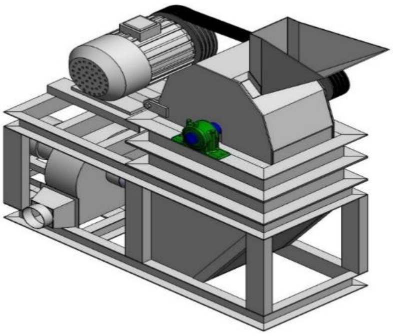


Fig.4. *Designed of the Hammer Mill.*

The dimensions of the crushing chamber are 35 x 65 x 30 cm. A circular sieve with a diameter of 2 mm is employed. This size of sieve hole gives the fineness within the desired range of 250 μm. A 2-horsepower motor drives a blower with a flow rate of 2,500 CMH. The blower is employed for suctioning the mineral that passes through the sieve into the bottom of the crushing chamber. Later it is ready to be transported to the silo to collect dust from the system.

(a) (b) (c)

Fig.6. Test 20 hammers, at thickness (a) 3 mm. (b) 6 mm. And (c) 9 mm.

Fig.5. *Construction of the Hammer Mill.*

In the test, the study conditions were the number of 3 sets of blades (hammers) and the thickness of 3 sets of blades, consisting of

1) A set of 20 hammer with thicknesses of 3, 6, and 9 mm. The width of 50 mm, and a length of 200 mm as shown in Figure 6.

2) A set of 24 hammer with thicknesses of 3, 6, and 9 mm. The width of 50 mm, and a length of 200 mm as shown in Figure 7.

3) A set of 28 hammer with thicknesses of 3, 6, and 9 mm. The width of 50 mm, and a length of 200 mm as shown in Figure 8.

2.3. Testing Procedures

Figure 9 shows the procedure for testing the designed hammer mill grinder. The test began with the process of preparing 25 kg of leonardite sample for each test. The prepared sample was to be ground with a hammer mill to the specified size with a fineness of -80 to 250 µm. The tests were subjected to the test conditions for 20, 24, and 28 hammers along with the thickness of 3, 6, and 9 mm, alternatingly. After that, a blower sucked the ground leonardite coal obtained from the crushing process and sent it to silo for storage and grading. The silo set of this size is equipped with a water spray system to trap small dust particles to avoid dispersing during grinding.

(a) (b) (c)

Fig.7. *Test 24 hammers, at thickness (a) 3 mm. (b) 6 mm. And (c) 9 mm.*

(a) (b) (c)

Fig.8. *Test 28 hammers, at thickness (a) 3 mm. (b) 6 mm. And (c) 9 mm.*

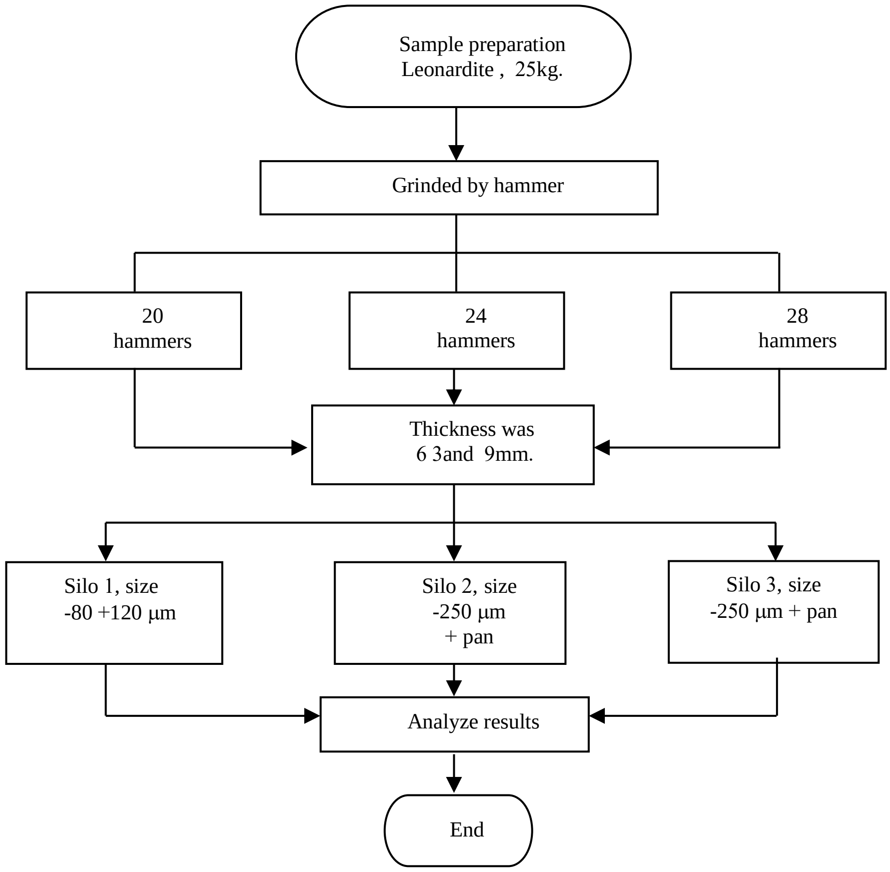


Fig.**9**. *Flowchart of the testing procedures.*

3. Results and Discussion

This section shows the results of grinding tests of hammer mill alternatively having 20, 24, and 28 hammers, and thickness of 3, 6, and 9 mm. To determine the optimum design of a hammer mill for grinding leonardite, three key conditions must meet. The first condition to meet is a sieve analysis. The cumulative weight percentage passed at 250 μm size must be greater than 50 percent. The second condition is that the percentage of passed weight must be in the range of 50–65 percent for the grinder to be implied effective with the highest working conditions [1-2]. If the percentage of accumulated weight passed is less than 50 percent, the test condition is not optimum. The percentage of the passed weight can be obtained from intersection of the estimate curves. The curves are calculated and constructed using percentages of weight retained and weight passed. The last condition to meet is the value of grinding efficiency is used to analyze the value of optimum design. The efficiency should be the highest value in case more than one set of parameters meets the first and the second conditions.

3.1. Effects of the Number of 20 Hammers

From the test with a set of 20 hammers, effects of the thickness by means of the ability to crush leonardite can be seen. Then accumulated weight passed through the 250 μm sieve was examined, for which is the desired size from the test of the hammer at 3, 6, and 9 mm thickness. The percentage of accumulated weight passed through the sieve increased from 40.5 to 49.4 and 56.4 percent, respectively, as shown in Figure 10.

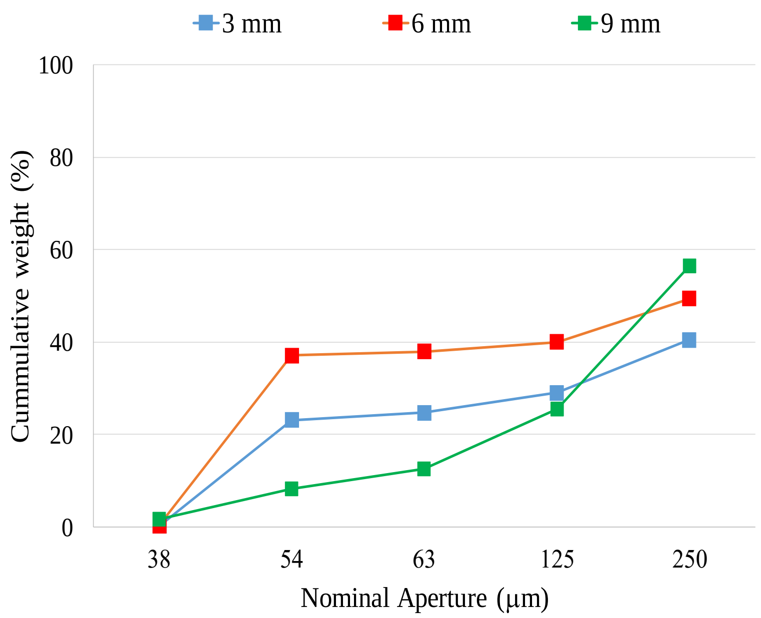
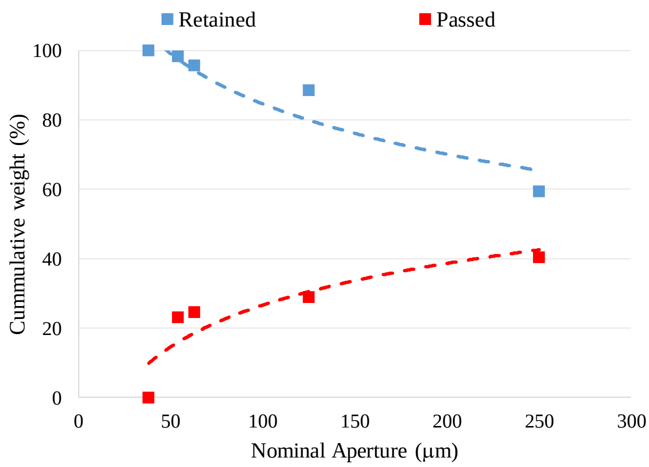


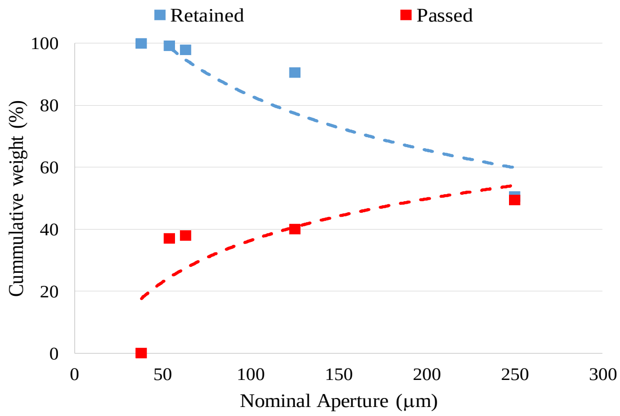
Fig.10. *Sieve analysis of cumulative weight percentage passed, 20 hammers*.

As one can see from Fig. 11(a) and Fig. 11(b), there is no intersection of the curves between the percentage by retained weight and the percentage bypass weight (passed). Therefore, having 20 hammers with a thickness of 3 mm and 6 mm, resulting in poor grinding efficiency. Whereas that shown in Fig. 11(c) appears intersection of curves when applying 20 hammer test kit with a thickness of 9 mm. The intersection is at the point of around 225 μm. The ratio of the percentage of passing through the sieve and the percentage by weight retained in the sieve is 48% : 52%, and the result is in accordance with the previous studies [18,20]. The ratio shows that having 20 hammers with a thickness of 9 mm does not meet the optimum design.

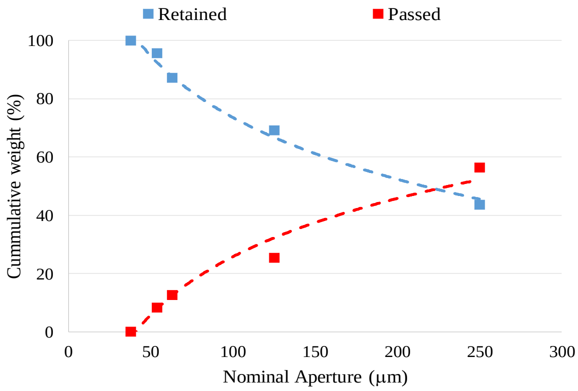
However, as shown in Table 5, increasing the hammer thickness from 3, 6, and 9 mm, the grinding efficiency increased from 90.4 to 92.6 and 93.3 percent, respectively. The effect difference is due to different thickness of the hammer. The thicker hammer comes with the larger the area of the forging. So that, the smaller the leonardite particle can be obtained. This allows the bower to easier suck up the crushed ore and transfer it to the silo for storage.



(a) thicknesses 3 mm.



(b) thicknesses 6 mm.



(c) thicknesses 9 mm.

Fig.11. *Sieve analysis of cumulative weight percentage passed and retained, 20 hammers.*

Table 5. *Effects of the Number of 20 Hammer*

Thickness (mm.)	**Silo 1 (kg)**	**2 (kg)**	**3 (kg)**	**Total (kg)**	**Percentage (%) Retained**	**Passed**	**Grinding Efficiency (%)**
3	22.34	0.16	0.09	22.59	N/A	N/A	90.4
6	22.75	0.29	0.11	23.15	N/A	N/A	92.6
9	22.87	0.32	0.14	23.33	52	48	93.3

When analyzing the results of sieve analysis, the percentage of passed weight and grinding efficiency of a set of 20 hammers, the thickness of hammer from 3, 6, and 9 mm. It was found that the values of the cumulative weight percentage passed at 250 µm and the percentage of accumulated weight passed for all three thicknesses was less than 50 percent, the test condition is not optimum.

3.2. Effects of the Number of 24 Hammer

From the test with a set of 24 hammers, effects of the thickness by means of the ability to crush leonardite can be seen. Then accumulated weight passed through the 250 µm sieve was examined, for which is the desired size from the test of the hammer at 3, 6, and 9 mm thickness. The percentage of accumulated weight passed through the sieve increased from 41.5 to 49.4 and 56.4 percent, respectively, as shown in Figure 12.

As one can see from Fig. 13(a) and Fig. 13(b), there is no intersection of the curves between the percentage by retained weight and the percentage bypass weight (passed). Therefore, having 24 hammers with a thickness of 3 mm and 6 mm, resulting in poor grinding efficiency. Whereas that shown in Fig. 13(c) appears intersection of curves when applying 24 hammer test kit with a thickness of 9 mm. The intersection is at the point of around 225 µm. The ratio of the percentage of passing through the sieve and the percentage by weight retained in the sieve is 50% : 50%. This ratio meets the second condition by means of the optimum design.

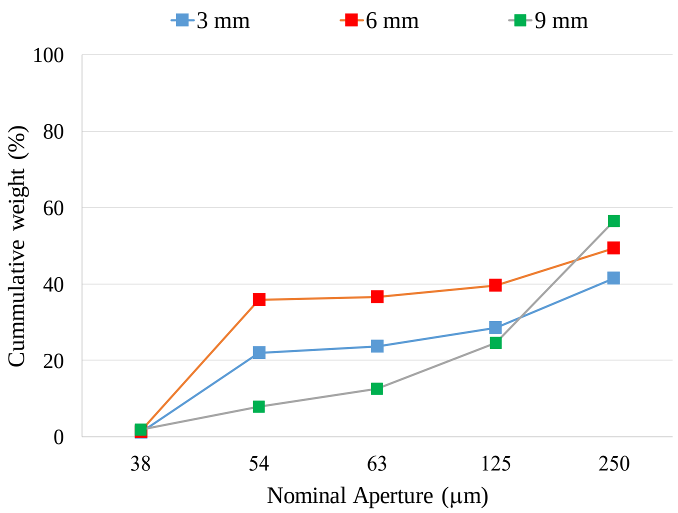


Fig.12. *Sieve analysis of cumulative weight percentage passed, 24 hammers.*

Figure 13: Sieve analysis of cumulative weight percentage passed and retained, 24 hammers.

The test results for a set of 24 hammers are shown in Table 6. It shows accordingly that increasing the thickness of the hammer from 3, 6, and 9 mm, increases the grinding efficiency from 94.8 to 95.1 and 95.8 percent, respectively. The differentiating effect is due to the increase in the thickness of the hammer, the larger the area of the forging results in the smaller the leonardite particles. This allows the bower to suck up the crushed ore and transfer it to the silo much easier.

Table 6. *Effects of the Number of 24 Hammer*

Thickness (mm.)	Silo 1 (kg)	Silo 2 (kg)	Silo 3 (kg)	Total (kg)	Percentage (%) Retained	Percentage (%) Passed	Grinding Efficiency (%)
3	23.41	0.20	0.09	23.70	N/A	N/A	94.8
6	23.24	0.35	0.18	23.77	N/A	N/A	95.1
9	23.48	0.32	0.16	23.96	50	50	95.8

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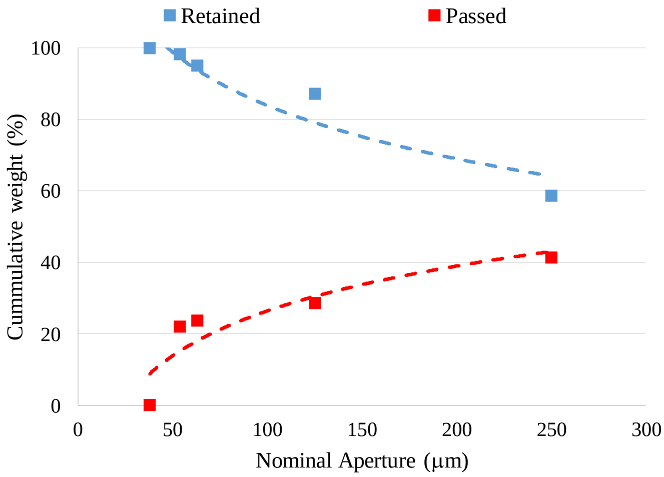
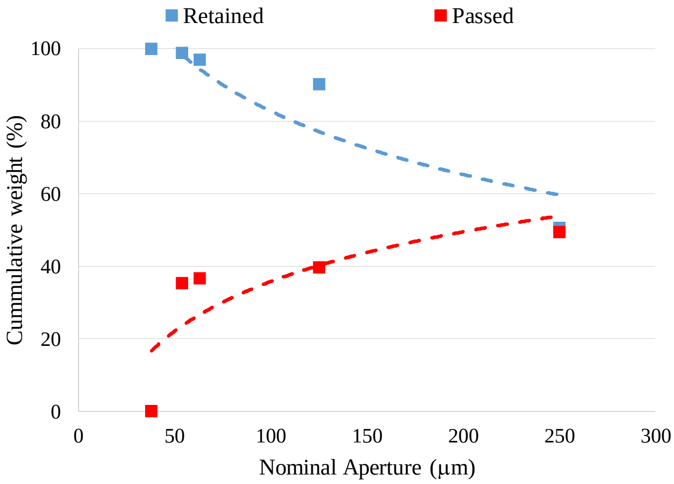
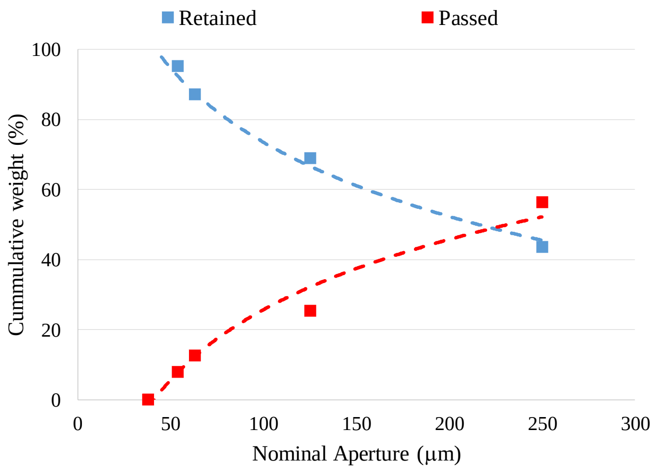


(a) thicknesses 3 mm.



(b) thicknesses 6 mm.



(c) thicknesses 9 mm.

When analyzing the results of sieve analysis, the percentage of passed weight and grinding efficiency of a set of 20 hammers. It was found that the values of the cumulative weight percentage passed at 250 µm and the percentage of accumulated weight passed for the thickness 3, and 6 mm are less than 50 percent. This implies that the test conditions are not optimum. For the thickness of 9 mm, the values of the cumulative weight percentage passed and the percentage of accumulated weight passed are 50 percent, and the Grinding Efficiency was 95.83 percent. These results are consistent with previous studies [18,20].

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3.3. Effects of the Number of 28 Hammer

From the test with a set of 28 hammers, effects of the thickness by means of the ability to crush leonardite can be seen. The passed through the 250 μm sieve is examined for the hammer at 3, 6, and 9 mm thickness. The percentage of accumulated weight passed through the sieve increased from 57.3 to 61.3 and 63.0 percent, respectively, as shown in Figure 14.

Plots of percentages correlation between retained and passed weight to the sieve size of the 28 hammers with a thickness of 3 mm are shown in Figure 15(a). The intersection of the percentage by retained weight retained (retained) and the percentage by retained weight passed through the sieve (passed) is seen at a point of 225 μm. Percentage by retained weight through the sieve is of around 50% and a percentage by accumulated weight the sieve freeze is around 50%.

For percentage analysis by retained and passed weight, it is compared with the sieve size of the 28 hammers, the beater thickness of 6 mm, as shown in Fig. 15(b). Intersection of curves is found at 200 μm. At this point, the retained weight passed through the sieve is found to be 48% percent, and the percent by weight retained sieve is 52%.

Similar results appear for the 28 hammers with thickness of 9 mm. The results are shown in Figure 15(c). Intersection of the curves is seen at 190 μm, which had the percentage by retained weight passed through the sieve of 45%, and the percentage by weight retained sieve was 55%, respectively.

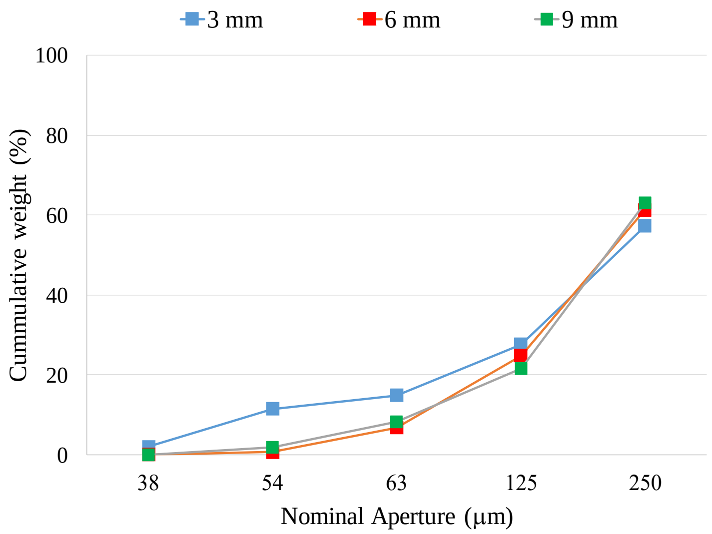

Fig.14. *Sieve analysis of cumulative weight percentage passed, 28 hammers.*

Testing results for the set of 28 hammers are shown in Table 7. As aforementioned, a thicker blade results in the finer ground particle. Ranging thickness from 3, 6, to 9 mm increases grinding efficiency from 96.2, 98.2 to 99.4 percent, respectively. The different effect is due to the increase in the thickness of the hammer, the larger the area of the forging, the smaller the leonardite particles. This also allows the bower to suck up the crushed ore and transfer it to the silo easier.

Table 7. *Effects of the Number of 28 Hammer*

Thickness (mm.)	Silo 1 (kg)	Silo 2 (kg)	Silo 3 (kg)	Total (kg)	Percentage (%) Retained	Percentage (%) Passed	Grinding Efficiency (%)
3	23.36	0.51	0.19	24.05	50	50	96.2
6	23.82	0.52	0.20	24.54	52	48	98.2
9	23.55	0.75	0.40	24.87	55	45	99.4

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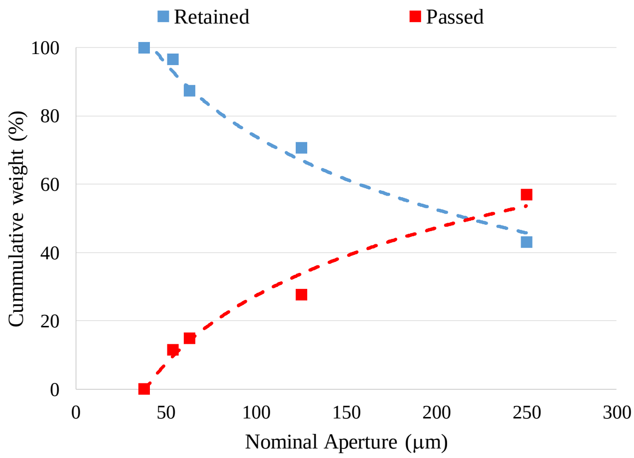
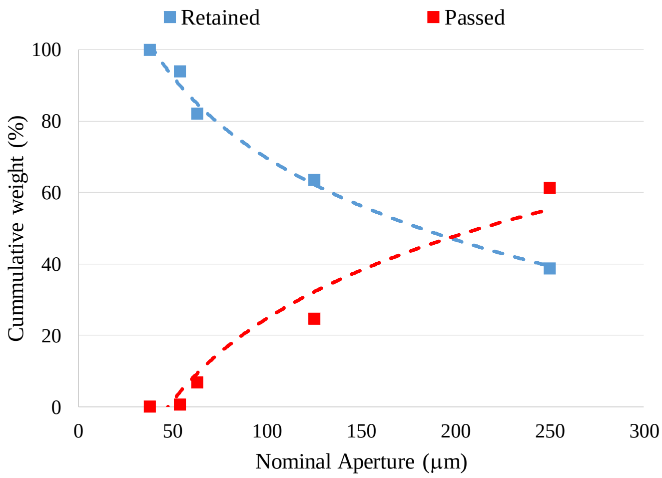
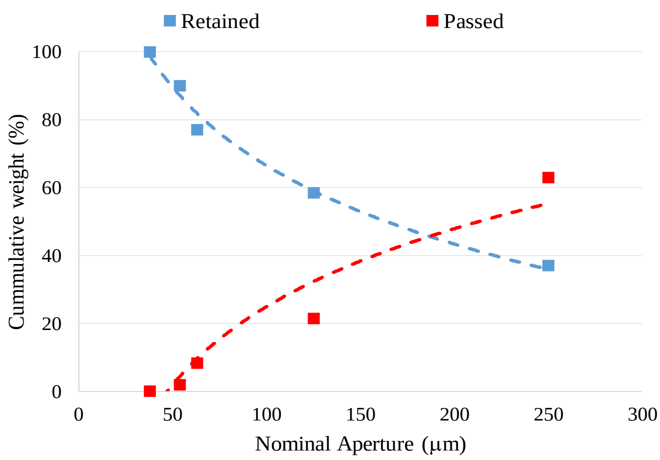
When analyzing the results of sieve analysis, the percentage of passed weight and grinding efficiency of a set of 28 hammers. It is found that the values of the cumulative weight percentage passed at 250 µm for the thickness 3, 6, and 9 mm are 50 percent, and the percentages of accumulated weight passed for the thickness 6, and 9 mm are less than 50 percent, the test condition is not optimum. For the thickness of 3 mm, the values of the cumulative weight percentage passed and the percentage of accumulated weight passed were 50 percent, and the Grinding Efficiency was 96.2 percent. These results are consistent with previous studies [18,20].



(a) thicknesses 3 mm.



(b) thicknesses 6 mm.



(c) thicknesses 9 mm.

Fig.15. *Sieve analysis of cumulative weight percentage passed and retained, 28 hammers.*

Table 8. *The ratio of percentages between the retained and passed weight and Grinding efficiency*

Thickness (mm)	Number of Hammers Retained % : Passed % (Grinding Efficiency,%)		
	20	24	28
3	N/A (90.4)	N/A (94.8)	50:50 (96.2)
6	N/A (92.6)	N/A (95.1)	52:48 (98.2)
9	52:48 (93.3)	50:50 (95.8)	55:45 (99.4)

As the results, it is seen from Table 8 that the sets of 24 hammers with 9 mm thickness and 28 hammers with 3 mm thickness provide the same ratio of percentage between retained and passed weight, i.e., 50% : 50%. The values of efficiency are 95.83 and 96.2 percent, respectively. Thus, a hammer set at the optimum design of a hammer mill for grinding leonardite is a test set of 28 hammers with a thickness of 3 mm.

4. Conclusions

The results of the tests on the effects of the number and thickness of the hammer on leonardite grinding ability are examined. Using the 28 hammers with thickness of 3 mm is found to result in the highest grinding efficiency of 96.2 percent. By analyzing the relationship of the projection intersection between percent by the accumulated weight of the grate (retained) and the percentage by weight passed (passed) at 225 μm. At this point, the percentage by weight retained through the sieve is 50 percent and the percentage by weight retained sieve is 50 percent, respectively.

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