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Effect of Slope Chute Angle of HAP Magnetic Separator to the Acquisition of Nickel Matte from Undersized Product Resulted by Pierce Smith Converter Machine

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Abstract: The prototype of a magnetic separator was initiated and manufactured for handling undersized products of Pierce Smith Converter which has been channeled to a temporary shelter called a matte pond. It was dredged three to four times a year and it's costly. This expenditure can be minimized by the manufacture of magnetic separators that used to attract undersized nickel products. The manufacture of this prototype uses a scale of 1:20.000 for the volume of water and nickel matte, while for chute and magnetic drums with a scale of 1:4 from the conditions in the field. The purpose of this research is to find out whether magnetic separators are relevant for installation in the nickel processing industry, with the slope angle of the chute and magnetic power as the main parameters. Thus the matte pond can be minimized and undersized products can be directly processed and distributed to consumers. The material used in the manufacture of this prototype is aluminum sheet 1/16 in which is rolled for magnetic drums, aluminum sheet 1/8 in for chute, copper wire 0.5 mm and mild steel, lathe for rods and axis, and bending for magnetic holders. The result of this magnetic separator prototype is 24.48% nickel can be attracted.

Keywords: Magnetic Separator; Nickel Matte; Undersized Product; Pierce Smith

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1. Introduction

Nickel is one of the abundant minerals in Indonesia, especially on the island of Sulawesi, which has made many nickel mining processing plant [1]. Metallic nickel and nickel compounds are used in manifold industrial and commercial applications such as batteries, coinage, catalysts, electronics, pigments, stainless steel and other nickel alloys, electroplating, foundries, and ceramics [2]. Nickel is produced from two main sources: sulfide ore and laterite ore. While 70% of land-based nickel resources are contained in laterite deposits, the majority of the world's nickel production currently still comes from sulfide sources. The dominant nickel mineral in these deposits is pentlandite (NiFe)9S8 this is because the main mineral of nickel sulfide ore is pentlandite [3], [4].

Previous researchers have tried to increase nickel concentration through a reduction process [5]–[8], using either coal [9], [10] or natural reducing agents such as palm kernel shell [11]–[15], rice husk [16], [17], coconut [18], [19], and bagasse [20]. In one of the mining industries in Sulawesi, there was a problem in the process of handling undersized products from the nickel matte granulation process from the refining process in the Pierce-Smith Converter. In general, the process that occurs from Pierce-Smith Converter to produce products that are ready to be packaged is illustrated in Figure 1.

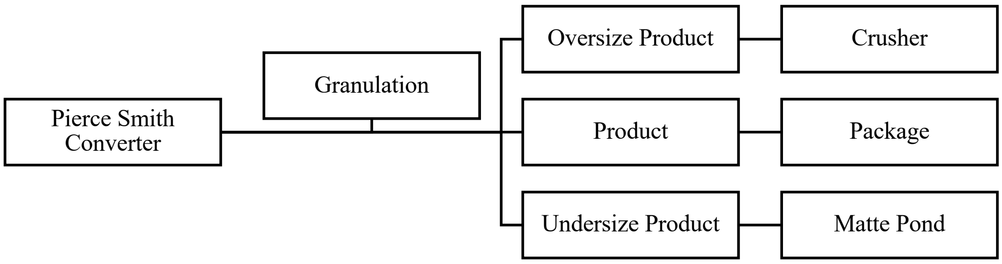

Figure 1. General Process Flow Diagram in Converter [4].

From Figure 1, it can be seen that from the granulation process or casting converter matte to matte granule, three product sizes were produced can be categorized as :

1. Oversize products or products with a size larger than consumer demand which will later be processed with a crusher to obtain products according to qualifications and returned to the granulation process
2. Products in accordance with consumer demand
3. Undersize products or products smaller than 100 mesh that has been channeled into temporary storage ponds called matte ponds that are reclaimed three to four times a year, and sump pits are clamping once a month to take small nickel grains that are accommodated in that area.

The pouring on the granulation system is a very important part where the poured matte liquid will become a matte granule [4], [21]. There are no parameters used to determine the size of the granulation product, only a visual observation and requires sufficient experience, therefore three types of products are formed as shown in Figure 1. Responding to this, the idea arose for handling undersize products more effectively and efficiently. The idea is illustrated in the scheme in Figure 2.

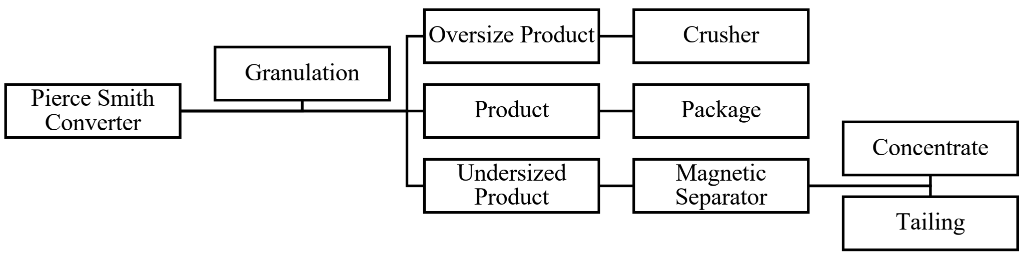

Figure 2. New Flow Chart Offer in Pierce-Smith Converter.

The innovation in this research is to replace the matte pond with a magnetic separator for handling undersized products from the granulation process. With the magnetic separator, it is expected that the undersized product from the granulation process can be handled more effectively, efficiently, and increase the productivity of nickel.

2. Materials And Methods

This research was conducted with a HAP magnetic separator by flowing a mixture of nickel matte with water, hereinafter referred to as slurry from slurry drum to the magnetic drum by passing through the chute with a certain slope. In this research, we will find the optimum slope chute angle to get the maximum efficiency. The tools and materials in this research are adjusted to the industrial scale because it is hoped that the results of this study can be scaled up to industrial scale. The nickel matte used in this study is the undersized product of granulation from Pierce Smith Converter whose sizes range from 100 - 400 mesh. In addition, the research will also find out the size distribution of nickel matte so that later it can be seen on the size of how dominant the particles are magnetized and on how many particles are lost or loss. In addition, to find out the composition of the sample that will be examined in advance the sample will be tested with XRF and the final product too. To calculate the efficiency of nickel matte in this study were calculated with a dry-based product. The final goal of this research is that the magnetic separator can be developed from a prototype scale into an industrial-scale tool to help nickel industries to be able to increase its productivity.

Materials :

1. Undersized product of nickel matte from granulation process of the Pierce Smith Converter with sizes ranging from 100 - 400 mesh
2. Mild steel st. 37 solid cylindrical shape which is turned to become a magnetic drum, magnetic rod, and sheet supporting shaft for magnetic rod mounting applications.
3. Aluminum Alloy 6061, sheet-thickness 0.063 in (1/16 in) for magnetic drum blankets and sheet-thickness 0.125 in (1/8 in) for chute, product storage containers, and disposal systems.
4. 0.5mm copper wire for electrical conductor winding wire on each magnetic rod.
5. Water to be mixed with nickel matte to make it slurry like the conditions in the field.

Parameters: Effect of slope chute, variation at an angle of 15, 20, and 25 deg to the efficiency of undersized nickel matte.

This experiment is limited by assuming the fluid flow is considered constant and laminar, there is no friction between the slurry and the chute where the slurry flows, the process of agitation is considered constant, magnetic drum rotation is considered constant, and the study was conducted on a prototype scale with a certain scale.

3. Results And Discussion

Previous research with HAP magnetic separator obtained 2.4% recovery using product-based calculations. Further research on HAP Magnetic separator was carried out because the efficiency of previous research was still very low, with the hope of getting efficiency of undersized nickel product in the nickel industry in Sulawesi which is higher. The evaluation of the previous HAP magnetic separator was that there were no product storage containers, the slope chute angle was not set and changed every trial, the tailings disposal system was not organized so that it polluted the surrounding environment, and the magnetic drum blanket was still thick due to using aluminum alloys 6061 sheet-thickness 1/8 inch or 0.125 inch. This evaluation tool is used as a benchmark to make HAP magnetic separators more efficient in terms of process and efficiency.

The following will describe the data and operational conditions collected through literature, direct experiments, and also field observations used to support this research. The operational data used is sourced from the Metal Accounting division one of the nickel industry in Sulawesi which includes undersized matte pond reclaim data and matte pond sieve analysis data. Table 1 summarizes the reclaimed matte pond data from May 2018 to February 2019 obtained from the Metal Accounting division :

Table 1. Data Reclaim Undersized Product (Matte Pond)

No.	Period	Ni Weight (Ton)	Unit
1.	May–August	104.55	DMT
2.	August–November	124.30	DMT
3.	November–February	123.92	DMT
	Total	**352.77**	

From the data in Table 1, it can be seen that the reclaim for nine months, from May 2018 to February 2019 is 352.77 Dry Metric Ton (DMT) and if averaged per month there are 39.19 DMT of undersized nickel products entering into the matte pond, if multiplied by a year, there are 470 DMT of undersized products that are accommodated in the matte pond and must wait for their turn to be reclaimed so that later they can produce value which is further diminished by reclaiming operational costs to pay labor and heavy equipment to become profit.

To find out the sample size distribution that will be used for the research process, sieve analysis is carried out using a sieve shaker with sieves of 100 mesh, 200 mesh, 230 mesh, 325 mesh, and 400 mesh respectively.

Table 2. Sieve Distribution Data of Matte Pond Feed.

Particle Size (mesh)	Weight (gr)	Persentage (%)
- 100	3.8	0.76
+ 100 – 140	14.6	2.92
+ 140 – 200	76.8	15.36
+ 200 – 230	88.2	17.64
+ 230 – 325	103.4	20.68
+ 325 – 400	160.2	32.04
- 400	49.6	9.92
loss	3.4	0.68

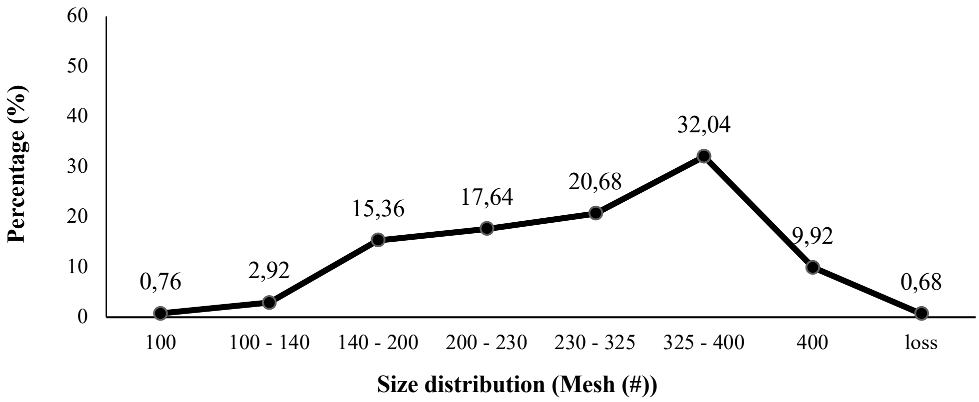

Figure 3. Distribution of Matte Pond Feed Particles.

The operational data sieve analysis of the undersized product sample in Figure 3 shows the distribution of particles in the matte pond or temporary storage pond for undersized products. Based on Table 2 and the illustration in the graph in Figure 3, the sample tendency to be tested is at most 325-400 mesh or around 44-37 micron (μm) 32.04%, and at least at 100 mesh or 149 micron (μm)) the amount is 0.76%. These particles will be used as sample experiments in this study.

Table 3. Composition of mineral elements in the product and the tailings.

No	Sample	Slope of the chute	Electric Current (A)	Composition			
				Ni (%)	Fe (%)	Co (%)	S (%)
1.	Product *Matte Pond*	25 deg	3.75	78.81	0.594	1.098	19.4
2.	*Tailing Matte Pond*	25 deg	3.75	79.24	0.666	1.094	18.9
3.	Product *Matte Pond*	20 deg	3.75	79.19	0.651	1.052	19.1
4.	*Tailing Matte Pond*	20 deg	3.75	79.14	0.671	1.094	19.0
5.	Product *Matte Pond*	15 deg	3.75	79.24	0.617	1.075	19.06
6.	*Tailing Matte Pond*	15 deg	3.75	78.82	0.698	1.085	19.2
7.	Product *Matte Pond*	15 deg	3.0	78.97	0.533	1.101	19.3
8.	*Tailing Matte Pond*	15 deg	3.0	78.92	0.681	1.101	19.2
9.	Product *Matte Pond*	15 deg	2.25	79.04	0.578	1.087	19.2
10.	*Tailing Matte Pond*	15 deg	2.25	78.92	0.691	1.094	19.2

The XRF data from the laboratory is shown in Table 3, it can be seen the composition of mineral elements in the product and the tailings of the experimental results shown are the elements Ni, Fe, Co, and S, it is possible there are still other elements. However, the data in Table 3 only shows the most dominant elements contained in the product and tailings in this experiment. The data in Table 3 is also still influenced by the variable slope of the chute and the magnetic strength.

To optimize the process, the slope of the chute at a certain point is needed to get an efficient process. The slope of the chute will affect the flow rate, productivity, and of course the effect on efficiency in this study. Therefore, determining the optimum point of the slope chute angle in this experiment is very important because it supports almost all lines. In this research, the chute serves as a slurry distribution medium from the slurry drum to the magnetic drum. Chute referred to here is an artificial channel made of aluminum with a length of 157cm and width of 37.4cm. The reason for choosing aluminum as the materials of the chute is because aluminum is easily fabricated and strong enough to accept low fluid flows [22]. In addition, if the material used is iron, iron tends to have ferromagnetic properties and can be attracted strongly by magnets, it is feared that when using iron, magnets will also attract the chute so that the magnet does not focus on attracting the slurry being flowed. Calculation of the length and width of the chute has been adjusted to the magnetic drum holder, besides that there is also a chute holder that functions as a supporting chute. With the chute holder, the slope angle of the chute can be adjusted according to the desired slope and this slope variation will be examined in this study to later obtain the optimum angle that supports maximum efficiency

Actually not only limited to the slope chute angle to get the optimum efficiency, however, the design process and also fabrication must be made and thought out into separate parts and can become a single unit so that the links between these parts can be drawn [23]. However, the focus in this study will look at the influence of the slope chute angle which is a very influential thing in terms of the productivity of devices such as magnetic separators. The following will describe the results of experiments that have been carried out by using a variation of slope chute at an angle of 15, 20, and 25 deg to the efficiency of matte nickel, with the condition of the HAP magnetic separator, made standard using 112.5W electrical power, 3.75A input current, and 30V voltage using a sample of nickel undersized products that have been prepared.

Experiment with the sloping chute at an angle of 15 deg

Table 4 shows the experimental results with the sloping chute at an angle of 15 deg.

Table 4. Experiment results with the sloping chute at an angle of 15 deg.

Current (A)	Feed (kg)	Product (kg)	Tailing (kg)	efficiency (Product Base) (%)	efficiency (Tailing base) (%)
3.75	16	4.678	9.100	29.23	56,87
3.75	16	3.032	8.180	18.95	51,12
3.75	16	4.046	10.468	25.28	65,42
Average		3.918	9.25	24.48	57.80

From the data in Table 4 it can be seen that from the 16kg samples tested an average of 3.91kg became products and calculated as efficiency product base, if calculated in percent counts there was an average of 24.48% of samples that could be attract by HAP magnetic separator. While for tailings from samples weighing an average of 9.25 kg which is calculated as efficiency of tailing base, if calculated in percent counts there is an average of 57.80% of samples that become tailings in this experiment. This tailing rate is quite high because of the limited power that can be provided by the power supply and also the agitation system which is still made manually, thus making many samples left at the bottom of the slurry drum. To find out the distribution of particles that can be attract into products and tailings, a sieve analysis is conducted for the results of this experiment, the distribution data is shown in Table 5.

Table 5. Matte Pond Sieve Analysis Results, sloping chute at an angle of 15 deg.

Size (mesh)	Product (514 gr)		Tailing (500 gr)	
	Weight (gr)	Percentage (%)	Weight (gr)	Percentage (%)
- 100	1.6	0.31	1.9	0.3
+ 100 – 140	7.7	1.50	6.9	1.38
+ 140 – 200	50.8	9.88	43.2	8.64
+ 200 – 230	80.1	15.58	99.6	19.92
+ 230 – 325	182.9	35.58	240.4	48.08
+ 325 – 400	61.3	11.93	2.5	0.5
- 400	127.1	24.73	103.2	20.6
Loss	2.5	0.49	2.3	0.46

The sample used to carry out this sieve analysis is a sample that has been homogenized and taken approximately 500gr to be further tested on a sieve shaker machine to determine its size distribution. It can be seen that the most particles into a product are +230 - 325 mesh particles which are 182.9gr or 35.58% for products and particles +230 - 325 mesh which are 240.4gr or 48.08% for tailings, this is influenced because the second largest number of particles in the sample makes it possible to recover more and become tailings simultaneously.

Experiment with the sloping chute at an angle of 20 deg

Table 6 shows the experimental results with the sloping chute at an angle of 20 deg.

Table 6. Experiment results with the sloping chute at an angle of 20 deg.

Current (A)	Feed (kg)	Product (kg)	Tailing (kg)	efficiency (Product Base) (%)	efficiency (Tailing base)(%)
3.75	16	2.854	9.588	17.83	59,92
3.75	16	2.302	12.846	14.38	80,28
3.75	16	3.890	12.566	24.31	78,53
Average		3.015	11.667	18.84	72.91

In Table 6 it can be seen that from the 16 kg samples tested, an average of 3.01 kg became a product and was calculated as efficiency product base. While for tailings from samples weighing an average of 11.66 kg which is calculated as the efficiency of tailing base, if calculated in percent counts there is an average of 72.91% of samples that become tailings in this experiment. This tailing rate is quite high because there is an increase in the angle of 5o, the limited power that can be provided by the power supply and also the agitation system which is still made manually, thus making many samples left at the bottom of the slurry drum and the slope of the chute high enough to make the slurry flow with very fast and makes the magnetic drum time to attract samples so short that many samples become tailings. To find out the distribution of particles that can be attract into products and tailings, a sieve analysis is conducted for the results of this experiment, the distribution is shown in Table 7.

It is known that the particles which are the most widely produced are particles of +230 - 325 mesh in the amount of 155.5gr or 31.1% and for tailings the same thing is obtained, where the particles most attracted by magnets are particles sized +230 - 325 mesh as many as 219.6gr or 43.92% of the total particles that become tailings. This is influenced because the number of particles measuring +230 - 325 mesh is the most in the sample so that it is possible to recover more and become tailings simultaneously.

Table 7. Matte Pond Sieve Analysis Results, sloping chute at an angle of 20 deg.

Size (mesh)	Product (504 gr)		Tailing (500 gr)	
	Weight (gr)	Percentage (%)	Weight (gr)	Percentage (%)
- 100	1.9	0.38	2.2	0.44
+ 100 – 140	8.0	1.60	8.4	1.68
+ 140 – 200	57.9	11.58	61	12.20
+ 200 – 230	95.7	19.14	122.7	24.54
+ 230 – 325	155.5	31.10	219.6	43.92
+ 325 – 400	37	7.40	28.5	5.70
- 400	146.8	29.36	57.6	11.52
Loss	2	0.24	0	0

Experiment with the sloping chute at an angle of 25 deg

Table 8 shows the experimental results with the sloping chute at an angle of 25o.

Table 8. Experiment results with the sloping chute at an angle of 25 deg.

Current (A)	Feed (kg)	Product (kg)	Tailing (kg)	efficiency (Product Base) (%)	efficiency (Tailing base) (%)
3.75	16	2.534	10.214	15.83	63.83%
3.75	16	2.338	9.878	14.61	61.73%
3.75	16	2.376	10.360	14.85	64.75%
Average		2.416	10.159	15.09	63.43%

Table 8 shows that out of the 16 kg samples tested. an average of 2.416 kg became a product and was calculated as efficiency product base. if calculated in percent counts there was an average of 15.09% of samples that could be attract by HAP magnetic separator. While for tailings from samples weighing an average of 10.15 kg which is calculated as the efficiency of tailing base. if calculated in percent counts there is an average of 63.43% of the samples that become tailings in this experiment. This tailing rate is the highest when compared to the other slope. Same as the situation in the two previous experiments this was due to the limited power that could be provided by the power supply and also the agitation system which was still made manually. One important point of the low efficiency in experiments with the sloping chute at an angle of 25o is due to the increase in slope which is quite far compared to other variables and variables recommended by some of the literature. As a result. experiments with sloping chute at an angle of 25o make the slurry flow very quickly and make the magnetic drum time to attract the sample very short so that many samples become tailings. To find out the distribution of particles that can be attract into products and tailings. a sieve analysis is conducted for the results of this experiment. the distribution is shown in Table 9.

Table 9. Matte Pond Sieve Analysis Results. sloping chute at an angle of 25 deg.

Size (mesh)	Product (500 gr)		Tailing (500 gr)	
	Weight (gr)	Percentage (%)	Weight (gr)	Percentage (%)
- 100	2.3	0.46	2.1	0.42
+ 100 – 140	13.1	2.62	9.6	1.92
+ 140 – 200	79.6	15.92	51.1	10.22
+ 200 – 230	92	18.4	76	15.20
+ 230 – 325	185.7	37.14	225.7	45.14
+ 325 – 400	29.5	5.90	95.3	19.06
- 400	78.2	15.64	35.6	7.12
Loss	19.6	3.92	4.6	0.92

It is known that the particles which are the most widely produced are particles of +230 - 325 mesh in the amount of 185.7gr or 37.14% and for tailings the same thing is obtained. where the particles most attracted by magnets are particles sized +230 - 325 mesh as many as 225.7gr or 45.14% of the total particles that become tailings. this is influenced because the number of particles of that size is the most in the sample so it is possible to recover more and become tailings simultaneously

4. Conclusions

The most optimum slope of the chute results of this study is 15o. The greater the slope angle. the higher the flow rate. high productivity. but will reduce efficiency. so the efficiency is low. If the chute angle is low. the efficiency is high. but the production capacity is low and the optimum value of the slope of the chute is 15°. The biggest average of efficiency obtained from this study was 24.48%. far greater than the previous research results of 2.4%. In this study. the most dominant particle size of the sieve analysis results in size +230 - 325 mesh. Particles of this size are the most products or tailings in this experiment. With the presence of HAP Magnetic Separator for handling undersized products. with 24.48% efficiency.

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