CHAPTER I
INTRODUCTION

1.1 Background

Size reduction (comminution) is an operation to reduce the size into a smaller size according to the desired size. Size reduction operation can be done by grinding or pounding. The operation of size reduction is needed in the chemical and mineral industry to match materials with tool specifications or adjust product specifications to be marketed. This is due to the physical nature of the various loads. Another factor affecting size reduction is the energy demand on the tool in an attempt to form a new surface of the reduced material. Empirical equations useful for predicting tool performance have been developed from existing theory. Kick and Rittinger's law states that the amount of work required in a size reduction operation is proportional to the logarithmic reduction ratio and the area of the new surface formed. Based on this description, it is necessary to conduct an experiment to examine Kick's and Rittinger's Law.

1.2 Problem Statement

In this practicum, a size reduction operation was carried out using a hammer mill. The response of this experiment is the effect of feed size on the amount of energy required for grinding. The calculation of the amount of energy required is done through the application of the size reduction equation, namely Kick's Law and Rittinger's Law, which will be compared between theoretical and practical calculations.

1.3 Practicum Objectives

The objectives of the size reduction practicum are:

1. Examine Kick and Rittinger's Law by comparing the energy required for size reduction operations theoretically and experimentally.
2. Calculate the power transmission factor (scouring energy).

1.4 Practicum Benefits

1. Understand and know how to calculate the reduction ratio and scouring energy with different particle sizes.
2. Understand the application of Kick and Rittinger's Law in size reduction operations.

CHAPTER II
LITERATURE REVIEW

The size reduction unit operation is one of the operations used to reduce the size of a particle by refining the shape of the product or simply making it smaller to the desired size. Size reduction operations can be carried out by crushing or grinding (Agrawal, 2007). The size reduction unit operation is usually used to adjust the size of raw materials to suit the processing equipment or to adjust the product to market requirements.

2.1 Classification of Size Reduction Based on Feed Size

Classification of grinding tools is grouped based on the type of machine in the operation of each stage of product size. There are three stages in size reduction operations and the types of grinding tools as shown in Table 2.1.

1. Coarse size reduction : feed size of 2 – 96 inch or more.
2. Intermediate size reduction : feed size of 1 – 3 inch.
3. Fine size reduction : feed size of 0.25 – 0.5 inch.

(Brown, 1979)

Table 2.1 Type of grinding tools based on operation classification

Coarse crushers	Intermediate crushers	Fine crushers
Stag jaw crusher	Crushing rolls	Buhrstone mill
Dodge jaw crusher	Disc crusher	Roller mill
Gyratory crusher	Edge runner mill	NEI pendulum mill
Other coarse crusher	Hammer mill	Griffin mill
	Single roll crusher	Ring roller mill (Lopulco)
	Pin mill	Ball mill
	Symons disc crusher	Tube mill
		Harginge mill
		Babcock mill

(Coulson, 2002)

Size reduction tools include:

1. Crusher

Size reduction equipment that breaks large solid chunks into smaller pieces until they reach a size of a few inches. Crushers are commonly classified as follows:

a. Primary crusher

It can operate with all feed sizes. The resulting product measures 8–10 inches.

b. *Secondary crusher*

It can operate with feed sizes of up to 4 inches, such as those from a primary crusher.

2. *Grinder*

This tool breaks down the chunks produced by the crusher into powder. For intermediate grinders, the resulting product is 40 mesh. Meanwhile, ultrafine grinders can produce products ranging from 250 to 2.500 mesh, if the feed is no larger than 20 mm.

3. *Cutter*

This tool operates differently from previous size reduction tools. A cutter operates by cutting. This tool is used for products that cannot be easily broken or reduced in size using previous methods. Product size: 2–10 mesh.

Size reduction operations are often used in industries that require raw and finished products of specific sizes, such as cement, coal, mining, fertilizer, ceramics, and other industries. The type of equipment used is usually selected based on the feed size of the product, the properties of the material, the hardness of the material, and its capacity.

2.2 Size Reduction Operations

2.2.1 Grinding Operations

Grinding, also known as comminution, is a term commonly used in size reduction operations that typically involve crushers, grinders, and other grinding tools. An ideal grinding tool meets the following requirements:

a. It has a large operating capacity.
b. It requires low power input per unit of product.
c. The products produced are uniform or able to meet the desired size distribution.

Achieving ideal grinding operations is difficult because the resulting product will never be uniform due to variations in feed size. The product always consists of a mixture of particles ranging from the largest desired size to the smallest (McCabe, 1993).

2.2.2 Factors Affecting Size Reduction Operations Based on the Natural Properties of Materials

The type of machine used for grinding operations depends on the natural properties of the material being processed. These properties include:

a. Hardness

It affects the power requirements of the machine. The hardness of a material is determined using the Mohs scale.

b. Structure

The structure of granular materials is easier than fibrous materials.

c. Moisture Content

A moisture content between 5% and 50% will cause caking and inhibit flow.

d. Crushing Strength

The power required by a machine is proportional to the crushing strength of the material.

e. Friability

Brittle materials break easily before grinding, which affects the size distribution of the product.

f. Stickiness

Sticky materials clog the operating unit.

g. Soapiness

Measurement based on the surface friction coefficient of the material. A low friction coefficient makes the grinding operation difficult.

h. Explosive Material

Materials that must be operated in an inert atmosphere..

i. Material Dusts

Materials that produce harmful dust must be operated in a safe location.

(Coulson, 2002)

2.3 Screening

Screening is an operational unit for separating a mixture of various sizes of solid particles into two or more smaller parts by passing them over a screen (Fellows, 2022). The principle of the screening process for solid particles is based on particle size. Materials smaller than the mesh diameter will pass through, while materials larger than the mesh diameter will be retained on the surface of the sieve wire. The results of the screening process are twofold:

particles larger than the sieve openings (oversize) and particles smaller than the sieve openings (undersize). The objectives of the screening process include:

a. To improve the specifications of a material as a final product.
b. To prepare the appropriate feed size for the next process.
c. To prevent undersized material from entering the surface.

Screening is typically performed in dry conditions for coarse materials and can be optimized for sizes up to 10 inches (10 mesh). Wet screening is usually used for fine materials ranging from 20 to 35 inches.

(Taggart, 1927)

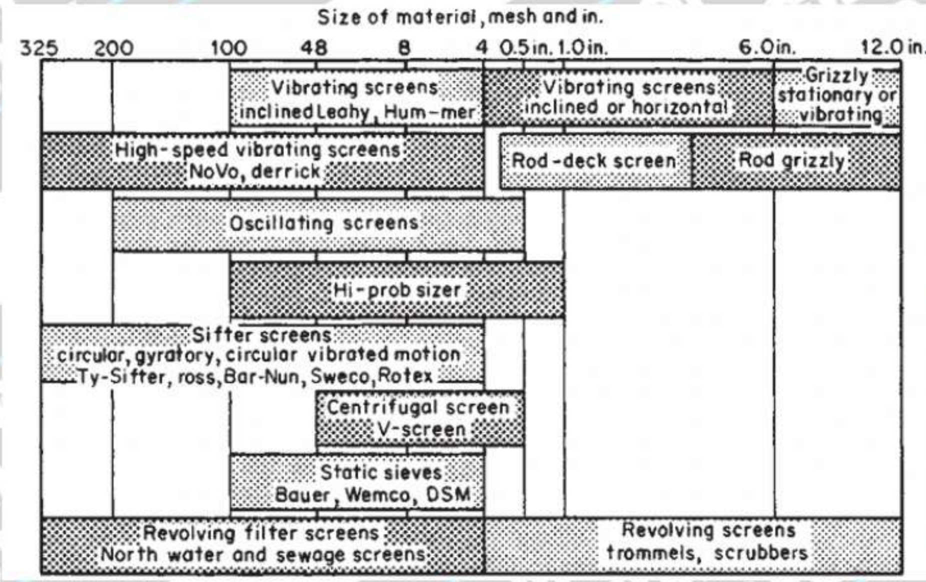

Figure 2.1 Screen selection based on size (Perry, 1997)

2.4 Law of Energy Size Reduction

The amount of energy required for size reduction operations depends heavily on the size of the resulting particles.

2.4.1 Rittinger's Law

Rittinger believes that the amount of energy required for size reduction is directly proportional to the new surface area produced. The specific surface area produced will be proportional to the particle size, so the equation is formulated as follows:

$$E = k\left(\frac{1}{d_i} - \frac{1}{D_i}\right) \tag{2.1}$$

Description:

E	: grinding energy
k	: Rittinger constant
d_i	: average product diameter
D_i	: average feed diameter

2.4.2 Kick's Law

Kick believes that the energy required to break down solid particles is directly proportional to the feed-to-product ratio. Mathematically, this relationship can be expressed as follows:

$$E = K \log\left(\frac{D_i}{d_i}\right) \tag{2.2}$$

Description:

E : energy required to break down solid particles or feed

K : Kick constant

d_i : average product diameter

D_i : average feed diameter

Breaking down cube particles larger than ½ inch requires the same amount of energy as breaking down ½ inch particles into ¼ inch particles.

2.5 Definition of Diameter

a. Trade Arithmetic Average Diameter (TAAD)

TAAD is defined as the average diameter based on the number of particles.

$$\text{TAAD} = \frac{\sum(\text{particles} \times \text{diameter})}{\sum(\text{total particle})} \tag{2.3}$$

$$= \frac{N_1D_1+N_2D_2+ \dots +N_nD_n}{N_1+N_2+ \dots + N_n}$$

$$\sum_{i=1}^{n} \frac{N_iD_i}{N_i} \tag{2.4}$$

$$N_i = \frac{V_t}{v_t} = \frac{M \cdot X_i}{v_t \cdot \rho} = \frac{M \cdot X_i}{\rho \cdot C_i \cdot {D_i}^3} \tag{2.5}$$

$$\text{TAAD} = \frac{\sum_{i=1}^{n} \frac{X_i}{C_i {D_i}^2}}{\sum_{i=1}^{n} \frac{X_i}{C_i {D_i}^3}} \tag{2.6}$$

Description:

D_i : particles diameter (cm)

N_i : number of particles with diameter D_i

M : total mass of particles with diameter D_i (grams)

m : mass of particles with diameter D_i (grams)

V_t : total volume of particles with diameter D_i (cm^3)

C : constant whose value depends on the shape of the particle so that for spherical particles = π/6; cube = 1

v_t : volume of particles with diameter D_i (cm^3)

b. Mean Surface Diameter

It is defined as the average diameter based on the surface area of the number of particles x area.

$$= N_i B_i D_i^{\,2} \times \sum_{i=1}^{n}(\text{number of particles} \times \text{total area}) \quad (2.7)$$

$$= N_1 B_1 D_1^{\,2} + N_2 B_2 D_2^{\,2} + \ldots + N_n B_n D_n^{\,2} = B(Dsur)^2 N_t \quad (2.8)$$

$$(Dsur)^2 = \frac{N_1 B_1 D_1^{\,2} + N_2 B_2 D_2^{\,2} + \ldots + N_n B_n D_n^{\,2}}{N_1 + N_2 + \ldots + N_n} \quad (2.9)$$

$$= \sum_{i=1}^{n} \frac{N_i B_i D_i^{\,2}}{B.\sum_{i=1}^{n} N_i} \quad (2.10)$$

$$= \sum_{i=1}^{n} \frac{\frac{M}{\rho} \cdot \frac{X_t}{C.D_i^{\,3}} \cdot B_i D_i^{\,2}}{B.\sum_{i=1}^{n} \frac{M}{\rho} \cdot \frac{X_i}{C.D_i^{\,3}}} \quad (2.11)$$

$$Dsur = \sqrt{\frac{\sum_{i=1}^{n} \frac{B_i X_i}{C_i D_i}}{B \cdot \sum_{i=1}^{n} \frac{X_i}{C_i D_i^{\,3}}}} \quad (2.12)$$

Description:

B : a constant whose value depends on the shape of the particle, for a sphere B = 2 and for a cube B = 6.

c. Mean Volume Diameter

Defines as the average diameter based on volume.

$$\text{Total} = N_i V_i = N_i C_i D_i^{\,3} n = C(Dvol)^3 \sum_{i=1}^{n} N_i \quad (2.13)$$

$$\sum_{i=1}^{n} \frac{M}{\rho} \cdot \frac{X_i}{C_i D_i^{\,3}} \cdot C_i D_i^{\,3} = C(Dvol)^3 \sum_{i=1}^{n} N_i \quad (2.14)$$

$$Dvol = \sqrt[3]{\frac{\sum_{i=1}^{n} X_i}{C \cdot \sum_{i=1}^{n} \frac{X_i}{C_i D_i^{\,3}}}} \quad (2.15)$$

(Brown, 1979 pp. 20 – 22)

2.6 Hammer Mill

Hammer mill is a grinding tool used to crush or grind materials into smaller pieces. A hammer mill is made of a steel drum containing a vertical or horizontal rotating shaft with hammers attached. The rotor rotates at high speeds, causing the hammers to strike along their path. The feed material is struck by the rotating hammers and collides with the drum walls. As a result, the feed material breaks down. This process continues until the product can pass through the screen at the bottom of the machine (Salahu, 2023).

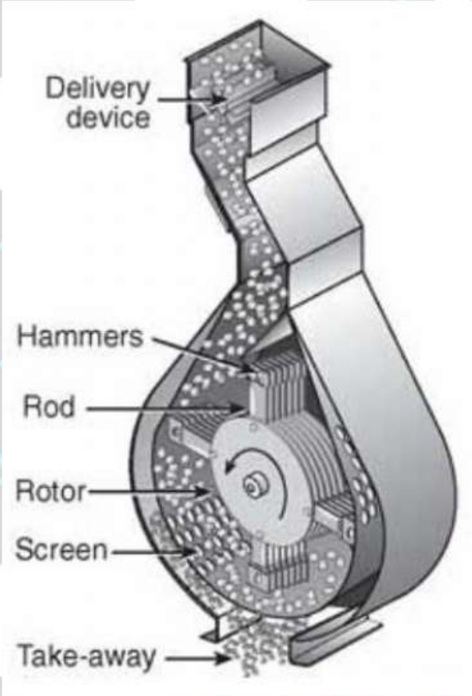

Figure 2.2 Hammer mill components

The components of a hammer mill are as follows:

1. Hopper : a place to put feed before the grinding process.
2. Hammer : a tool for striking feed that is attached to the rotor.
3. Rotor : a rotating shaft to which the hammer is attached.
4. Screen : used to filter ground material.
5. Take away : the outlet for the ground material.
6. Drive motor : the power source for the hammer mill.

CHAPTER III
METHODOLOGY

3.1 Experimental Design

3.1.1 Practicum Framework

To achieve the objective, the practicum was carried out in several stages, including material preparation, size reduction operation, screening operation, and particle size analysis using the TAAD method. In the material preparation stage, data containing the average feed diameter (D_i) was obtained. In the size reduction stage, a hammer mill was used as the grinding equipment. During its operation, the power consumption for each variable was also measured. The ground material was then sieved in the screening operation. In this stage, data containing the average product diameter (D_{avg}) and the weight of the product on each tray was obtained. The values obtained from the screening operation were then analyzed using the TAAD method to determine the reduction ratio for each different variable.

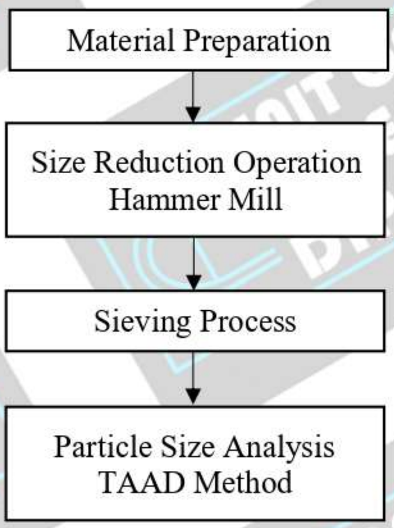

Figure 3.1 Experimental schematic diagram

3.1.2 Variable Determination

1. Controlled Variable

   Sieving Time :

2. Independent

   Solid Dimension Size(cm) :

   Solid Weight (grams) :

3.2 Materials and Equipment Used

In the implementation of the size reduction practicum, there were materials and equipment used to support the activity. The material used in this practicum was charcoal. The supporting equipment included a hammer mill, sieving equipment, an amperemeter, and a stopwatch. An illustration of the hammer mill to be used is shown in Figure 3.2, and the model of the sieving equipment is shown in Figure 3.3.

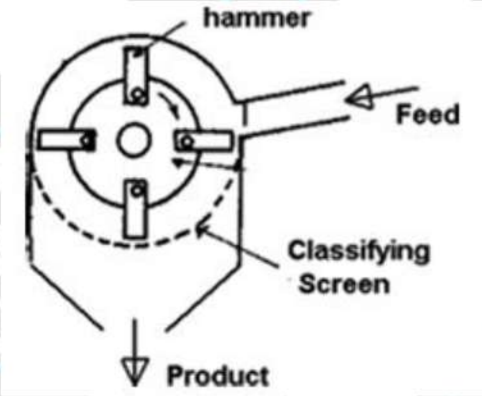

Figure 3.2 Hammer mill-crusher

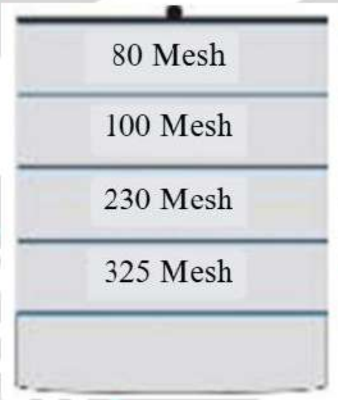

Figure 3.3 Set of sieves
(Shashidhar *et al*., 2013)

3.3 Practicum Procedure

The size reduction practical is conducted in several systematic stages. The practical begins by preparing the materials to be used according to the predetermined variables. Next, the material (feed) is measured before being fed into the hammer mill. Set the feeder cover opening according to the desired capacity, ensuring it is not too wide so that the material entering is not too large. Then, feed the material into the hammer mill in a certain amount according to the variables. During the size reduction process using the hammer mill, measure the current or power consumption with an amperemeter. After completing the size reduction operation, collect and weigh the results for each variable and then perform a sieving analysis. The sieving analysis is carried out by arranging the screens from the bottom position with 325 mesh, followed by 230 mesh, 100 mesh, and the top position with 80 mesh. Place the weighed sample on the arranged screens and shake for 5 minutes until the particle mass stabilizes, using an amplitude of 1.8. Afterward, weigh the particles on each screen and record the results. The sieving analysis is performed once for each variable.

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