FM 306: SIZE REDUCTION AND SIEVING

OBJECTIVE

• To grind the given limestone material to a smaller size using a ball mill and to obtain the size distribution of the initial and the final mixture by sieving.
• To estimate the energy required for the grinding operation.
• To analyze the results using the available theories.

INTRODUCTION

Size reduction is major unit operation in industries handling particulate solid. The industries like mineral dressing, paint, cement, bauxite, pharmaceutical as well as black powder handles large amount solid materials which need to be grinded to fine size. The equipments usually used for size reduction are,

1. Cutting machines like knife cutters, slitters, dicers
2. Crushers like jaw crushers, gyratory crushers, etc. Crushers are used for coarse and fine size reduction.
3. Grinders like hammer mills, rolling-compression mills, tumbling mills, etc. Grinders are used for intermediate and fine size reduction.
4. Ultrafine grinders like hammer mills, agitated mills, fluid-energy mills, etc.

The basic motive behind performing the size-reduction is to make too large to be used solid materials usable. It leads to an increase in surface area per unit volume which enhances the rate of the reaction by allowing more sites for the reaction to take place. Moreover handling of smaller size particles is much easier as compared to that of bigger particles.

Ball Mill:
The equipment to be used for size reduction is ball mill. The ball mill is kind of grinder used for intermediate or fine grinding. Ball mill is a metal cylinder which rotates about its horizontal axis. The coarse material charged along with the metal balls breaks to fine powder by impact of metal balls.
THEORY AND ANALYSIS

Significance of the Experiment

Size reduction of particle is very important and useful in many chemical and other industries. This is because:

• Handling of small particles is easier as compared to that of big particles
• There is an increase in surface area per unit volume, higher surface area will enhance the rate of reaction involving solids
• Entrapped components are separated and may be available for further reaction

Why do we classify particles?

We classify particles to remove contaminants and unlike particles (wheat from chaff or metal particles from polymers). We classify to remove unwanted parts of a size distribution. Figure 1 shows the tailing and oversize particles that may be removed from a material for a particular purpose.

Sieve Analysis

Probably, the most common method of particle-sized analysis used is sieve analysis. Standardized sieves are available to cover a wide range of sizes. These sieves are generally round and designed to sit in a stack so that material fall through smaller and smaller meshes until it reaches a mesh, which is too fine for it to pass through. The stack of sieves is mechanically shaken or tapped to promote the passage of the solids. The finest material is caught in a pan at bottom of the stack.
When carrying out the sieve analysis it is important to maintain a standard method. The result achieved will depend on the duration of agitation and the manner of the agitation. Care needed when collecting the fractions from the sieves that the meshes are not damaged by rough handling.

The minimum energy required for crushing is the energy required for creating fresh surface. In addition, energy is absorbed by the particulate material due to deformation, friction, etc., which results in an increase of the material temperature. Defining the crushing efficiency as

$$\eta_c = \frac{\text{surface energy created}}{\text{energy absorbed by material}} = \epsilon_s \frac{A_w - A_{w_d}}{W_n}$$

Where,

$\epsilon_s$ is the surface energy per unit area

Wn is the energy absorbed by the material.

We can experimentally find $\eta_c$. The range of $\eta_c$ is between 0.06 – 1.00%. If $\eta_m$ is the mechanical efficiency, the energy input is

$$W = \epsilon_s \frac{A_w - A_{w_d}}{\eta_c \eta_m}$$

Since $W_n = \eta_m W$

Finally, the grinding energy used per unit mass is

$$\frac{W}{m} = \frac{6 \epsilon_s}{\eta_c \eta_m \rho_p} \left( \frac{1}{\phi_b D_{z_b}} - \frac{1}{\phi_a D_{z_a}} \right)$$

Where

m is mass of material being ground,

$\phi$ is the sphericity,
$D_s$ is the surface volume diameter,

Subscripts $a$ & $b$ refer to the initial and final states respectively.

And, \[ Sphericity = \frac{\text{Surface area of a sphere of same volume as the given particle}}{\text{Surface area of the given particle}} \]

Experiments show that above equation is difficult to use for analysis. Instead a number of empirical laws have been proposed for calculation the energy requirements for crushing. The laws can be unified in a differential form as follows:

\[ d\left(\frac{W}{m}\right) = -K \frac{dD_s}{D_s^n} \]

Theories depend upon the basic assumption that the energy required to produce a change in $D_s$ in a particle of a typical size dimension $D_s$, is a simple power function of $D_s$.

The different laws for the different values of the exponent are

$n = 1$, \textbf{Kick’s Law}:

Assumes that the energy required to reduce a material in size was directly proportional to the size reduction ratio $dD_s/D_s$.

\[ \frac{W}{m} = K_K \ln \left( \frac{D_{s_b}}{D_{s_a}} \right) \]

$n = 2$, \textbf{Rittinger’s Law}:

Assume that the energy required for size reduction is directly proportional to the change in surface area.

\[ \frac{W}{m} = K_r \left( \frac{1}{D_{s_b}} - \frac{1}{D_{s_a}} \right) \]

$n = 3/2$, \textbf{Bond’s Law}:

\[ \frac{W}{m} = K_b \left( \frac{1}{\sqrt{D_{s_b}^{80}}} - \frac{1}{\sqrt{D_{s_a}^{80}}} \right) \]
Note that the definition of particle size in Bonds law is different: \( D_{80} \) = Particle size such that 80% by weight of the sample is smaller than it.

Bonds law is often written in terms of the work index \( (W_i) \) as,

\[
\frac{W}{m} = 0.3162W_i \left( \frac{1}{D_{80b}} - \frac{1}{D_{80a}} \right)
\]

Where the work index is defined as the energy required per unit mass in kWh/ton to reduce an infinitely large particles to \( D_{80} = 100 \) μm. In the above equation, unit of \( D_{80} \) is in mm, of ‘W’ is kWh and of ‘m’ is in ton.

Work index for common materials is

<table>
<thead>
<tr>
<th>Material</th>
<th>( W_i ) (kWh/ton)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Basalt</td>
<td>20.41</td>
</tr>
<tr>
<td>Coke</td>
<td>73.8</td>
</tr>
<tr>
<td>Limestone</td>
<td>11.6</td>
</tr>
<tr>
<td>Mica</td>
<td>134.5</td>
</tr>
<tr>
<td>Glass</td>
<td>3.08</td>
</tr>
<tr>
<td>Calcined clay</td>
<td>1.43</td>
</tr>
</tbody>
</table>

**PROCEDURE**

1. Take 5.0 kg lime stone and charge it to the series of sieves to get pre-grinding size distribution.

2. Continue sieving for 10 minutes.

3. Weigh the mass of lime stone retained on each sieve.

4. Load lime stone to the ball mill along with metal balls.

5. Run the ball mill for 40 minutes at the speed 1 rpm.

6. After 40 minutes take out lime stone powder from the ball mill.

7. Fill the lime stone powder to new set of sieves of small sizes. Keep the sieves on the vibrator for 20 minutes.
8. Weigh the mass of lime stone powder retained on each sieve.  

Questions:

1. Plot the initial distribution and distributions obtained after sieving.  
2. Calculate the surface volume diameter in each case.  
3. Obtain the diameter D80 for all three distributions.  
4. Obtain the coefficients KK, KR and the work index, Wi for all the runs. Are there any variations in coefficients / working indices in the runs?  
5. Assuming reasonable values of ηc and ηm estimate es.  
6. Do you have any suggestions to improve the experiments?  

REFERENCES

1. Unit Operations of Chemical Engineering by McCabe, Smith, and Harriott.  