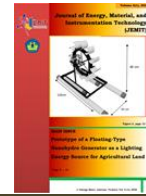




## JOURNAL OF ENERGY, MATERIALS, AND INSTRUMENTATION TECHNOLOGY

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# Differential and Cumulative Particle Size Distribution Analysis using Home Made Sieving Equipment

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### Abstract

Particulate solids remain the most commonly used materials in the industry due to their characteristics, such as stability, purity, and ease of transportation. Particle size is one of the physical characteristics of a particulate solid that may affect its chemical characteristics. Hence, understanding particle size will give a better insight into a solid material's physical and chemical properties. The oldest method to determine particle size is using a sieve to separate particles in bulk based on their size, more commonly called Particle Size Distribution (PSD). This research aimed to design home-made sieving equipment for particle size analysis. The sieving equipment was made out of acrylic and four different mesh sizes to help separate particles based on the opening of each mesh. In addition, an agitator table was also built to help the particle flow smoothly along the sieve based on its particle size. Six different materials were chosen to be tested using the newly built equipment: table salt, whey powder, wheat flour, coarse coffee ground, cement, and chalk dust. Based on the sieve analysis, cement and chalk dust showed consistent particle size uniformity compared to other materials. With limitations such as broad mesh sizes, it is recommended to have more mesh sizes to get better particle size distribution of the sample.

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### Abstrak

Partikel padatan merupakan material yang paling sering digunakan di industri, hal ini dikarenakan beberapa sifat seperti kestabilan, kemurnian, dan kemudahan dalam transportasi. Ukuran partikel adalah salah satu karakteristik fisik yang dapat memberikan efek kepada karakteristik kimia. Maka dari itu, ukuran partikel akan memberikan pemahaman mengenai karakteristik kimia dan fisika dari suatu zat padatan. Salah satu cara penentuan ukuran partikel adalah dengan menggunakan ayakan, pada dasarnya memisahkan partikel berdasarkan ukuran atau lebih dikenal sebagai Particle Size Distribution (PSD). Penelitian ini bertujuan untuk mendesain alat rumahan yang dapat digunakan untuk melakukan analisa ukuran partikel. Alat ukur ini dibuat menggunakan akrilik dengan 4 ukuran mesh yang berbeda. Sebagai tambahan, meja agitator juga dibuat untuk membantu partikel melewati mesh dengan lebih mulus. Enam material yang berbeda dipilih untuk mencoba alat tersebut, yaitu: garam, bubuk whey, tepung terigu, bubuk kopi, semen, dan kapur. Berdasarkan analisis yang dilakukan, semen dan kapur menunjukkan ukuran partikel yang konsisten dibandingkan dengan material yang lain. Limitasi yang dihadapi adalah ukurnya mesh yang terlalu jauh, untuk itu direkomendasikan untuk menambahkan ukurnya mesh lainnya guna mendapatkan particle size distribution yang lebih baik.

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## 1. Introduction

Solid is a common material used in the industry due to its stability, ease of control, ease of transportation, and high purity. It doesn't easily reach with other materials. The particle sizes of solid material showed different characteristics, both physical and chemical properties, from chunky solids. Hence, a new discipline was created to specifically study behavior and how to handle particulate solids (Ortega-Rivas, 2012). Different terms are used to express different particle sizes, as seen in **Table 1**.

**Table 1.** Particle size terms (McCabe, Smith, & Harriott, 2005)

|                     |                                                |
|---------------------|------------------------------------------------|
| Coarse Particles    | Inches or millimeters                          |
| Fine Particles      | Screen size                                    |
| Very fine Particles | Micrometers or nanometers                      |
| Ultrafine Particles | Surface area per unit mass (m <sup>2</sup> /g) |

Monosized bulk is very rarely found in the industry, the common practice is to use Particle Size Distribution (PSD) to show range of particle size (Zhang & Guo, 2014). There are two types of PSD: normal and abnormal distribution, a normal distribution has close particle size ranges within a bulk and wide for abnormal distribution. There are various methods to determine PSD, however the most popular and widely used method is still the sieving method (Polakowski, et al., 2021) (Vaezi, Pandey, Kumar, & Bhattacharayya, 2013) (Igathinathane, et al., 2009).

A sieve mesh, often called a sieve or a mesh, is a device or material used to separate particles or substances based on size. It consists of a mesh or perforated surface with uniform-sized openings or holes through which particles can pass. The mesh is typically made of metal, plastic, or other materials, and the size of the openings can vary depending on the specific application.

Sieves separate particles based on their mesh openings, allowing particles with diameters smaller than the mesh opening to pass through to the next mesh while larger particles remain trapped. This separation process analyzes the result using cumulative and differential analysis methods to get the particle size distribution (Chaloupkova, Ivanova, & Havrland, 2016).

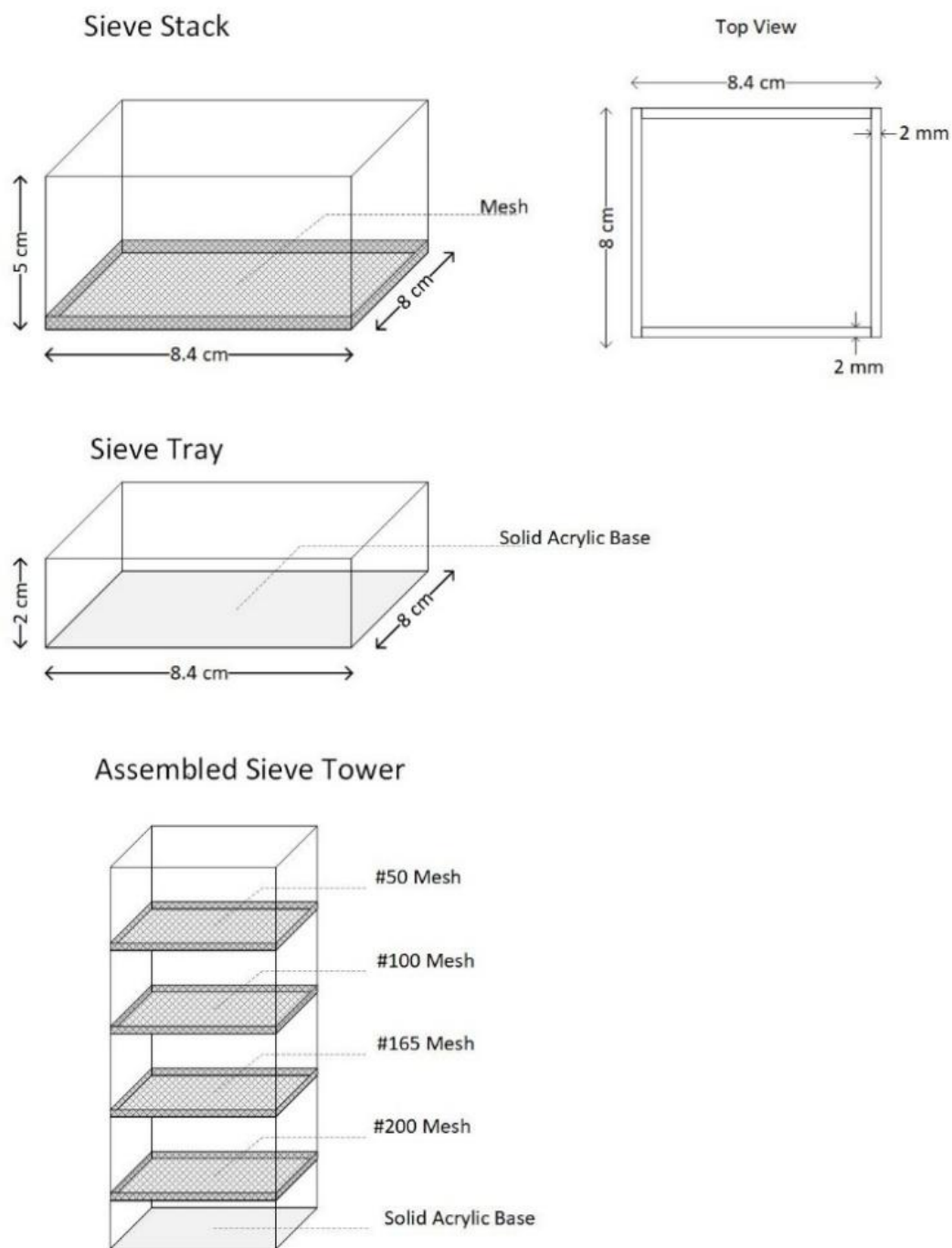
The number of sieves influences the accuracy of the PSD; more layers would mean a smoother curve of the PSD. The amplitude of the agitation also influences how the particles move through the sieves. High amplitude would move the particles too much to pass through the apertures of the sieve, whilst low amplitude wouldn't allow the particles to orient themselves to pass through the sieve. (Mike & Hanke, 2016) One method to provide the required agitation is using electromagnets to impart vertical movement. Adjustment of the voltage enables accurate control of the agitation. (Ujam & Enebe, 2013) Another method employed by Ro-Tap machines is using a "tapper" to dislodge any stuck particles between the apertures of the sieve whilst simultaneously being shaken. (Carpenter & Deitz, 1950)

This research aimed to design and build rudimentary sieving equipment using cheap and readily available household materials that are capable of providing accurate results. Five stacks (four meshes and one tray) with different mesh screens were used to determine the PSD. A weighted fan imparted rotational movement and acted as an agitator to ensure the particles could pass through the screen.

## 2. Research Methods

This research is divided into two categories: designing the sieving equipment and analyzing six different powders using the built equipment through cumulative and differential analysis. The equipment's design basically consists of two main parts. The first part is the sieve meshes made out of acrylic, and the second part is the agitator table. A more detailed design is shown below in **Figures 1** and **2**.

Once the fixed design is approved, the next step is to build the equipment. Acrylic was chosen as the main material for building the sieving equipment, and four different mesh numbers were chosen (mesh #200, mesh #165, mesh #100, mesh #50). A tray was used for the bottom stack to collect the smallest particles that pass through the last mesh opening. The complete materials and equipment used to build the equipment can be seen in **Table 2**.



**Figure 1.** Silver Design

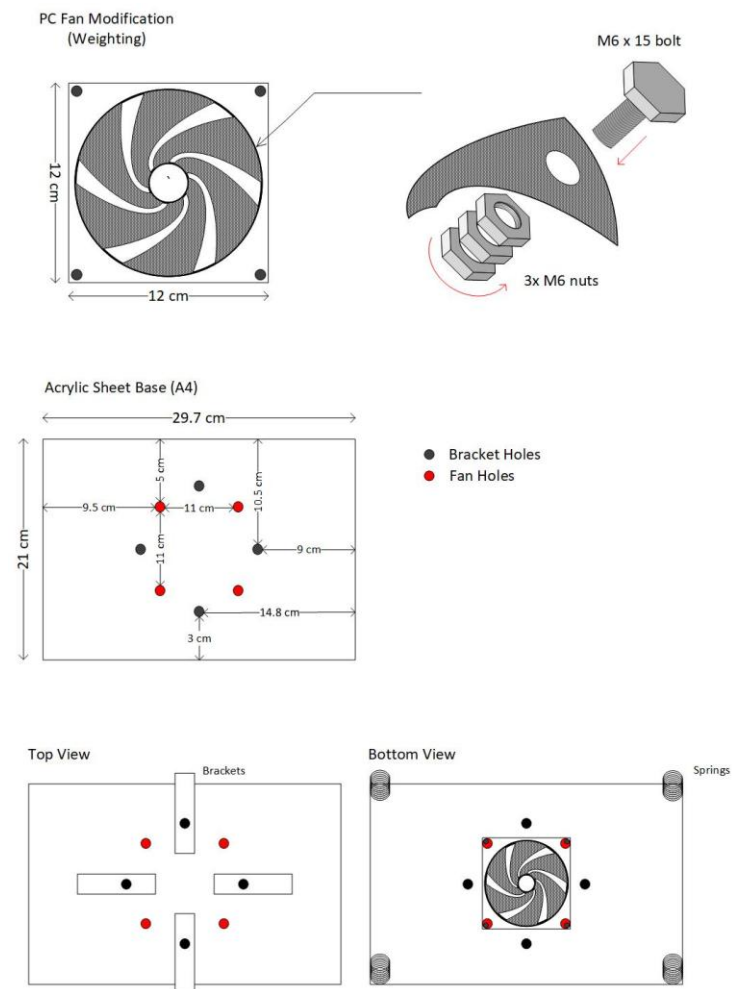


Figure 2. Agitator table design

Table 2. Materials and Equipment

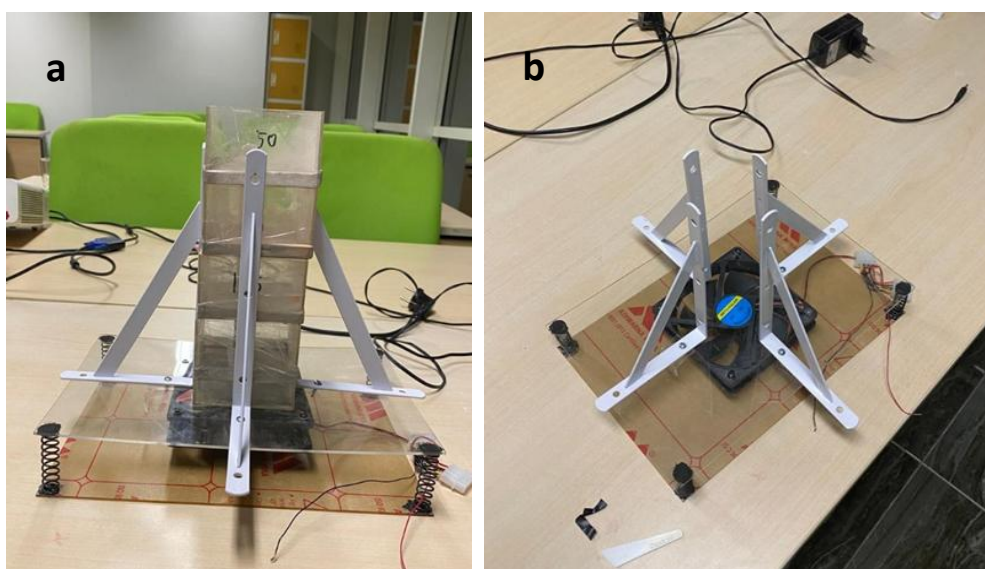
| Materials                                                                | Equipment                   |
|--------------------------------------------------------------------------|-----------------------------|
| 8 Acrylic A4 Sheets (21cm x 29.7 cm)                                     | Acrylic cutter              |
| Acrylic glue                                                             | Syringe needle (for gluing) |
| 4 Steel spring (Thick = 1.5mm, outside diameter = 13 mm, length = 50 mm) | Ruler                       |
| 4 Steel brackets (length 16 cm, height = 20 cm)                          | Scale                       |
| Wire Screen Mesh 200                                                     |                             |
| Wire Screen Mesh 165                                                     |                             |
| Wire Screen Mesh 100                                                     |                             |
| Wire Screen Mesh 50                                                      |                             |
| Approximately 10g of various samples                                     |                             |
| Tape                                                                     |                             |
| 1 Computer cooling fan                                                   |                             |
| 1 DC adaptor                                                             |                             |
| 1 M6x15 Bolt                                                             |                             |
| 3 Nuts                                                                   |                             |
| Electric Tape                                                            |                             |

Acrylic sheets were cut into several different pieces, as shown in Table 3 below. A cube without a top and a bottom was created with 8 cm x 8.4 cm x 5 cm dimensions. This process was repeated four times to create four topless and bottomless cubes. The 4 pieces of 8 cm x 2 cm acrylic were then glued onto the 8 cm x 8.4 cm acrylic piece to make the walls of the tray. Sieve meshes were cut into 10 cm x 10 cm size and stuck into the bottom of the acrylic using acrylic glue.

**Table 3.** Acrylic size

| Size          | Amount |
|---------------|--------|
| 8 cm x 5 cm   | 16     |
| 8 cm x 8.4 cm | 1      |
| 8 cm x 2 cm   | 4      |

An agitator table is a device used to facilitate the sieving process. It typically consists of a flat, vibrating surface on which the sieves are placed. The purpose of the agitator table is to agitate or shake the sieves, which helps the particles to pass through the mesh more efficiently. A computer cooling fan is modified to function as a vibrator. One of the fan's blades is drilled to form a hole, where an M6x15 bolt is threaded through it, and three nuts are used to secure the bolt to the fan. Two A4 acrylic sheets are used to function as the 'workbench' of the equipment. On one of the A4 sheets, eight holes are drilled. 4 holes were used to secure the 4 brackets, which would act as the holder for the mesh screens. The other 4 holes were used to secure the fan to the base of the A4 sheet. The four brackets are attached to the top side of the A4 sheet, securing the short side of the bracket to the acrylic sheet with screws. The long side of the bracket points upwards, and on the bottom of the acrylic sheets, the modified fan is secured to the acrylic sheet with four screws. Four springs are attached to the bottom side of the acrylic at the four corners of the sheet using a two-part epoxy glue. These springs are then attached to another A4 acrylic sheet, allowing the top sheet to wobble when the bottom acrylic sheet is secured. A 12 DC adaptor was used to power the fan when in use.



**Figure 3.** a. Siever equipment; b. Agitator table

The finished sieving equipment can be seen in Figure 3 above, with five different mesh openings, the biggest opening at the top and the pan at the bottom. Six different materials were then used to test the equipment: salt, whey powder, wheat powder, coarse-ground coffee, cement, and chalk dust. First, all trays were measured using a scale and put into brackets to test the equipment. The agitator table was turned on before the experiment started, and 10 grams of each sample material was poured into the top mesh. Each trial runs for about 5 minutes or until no more samples fall from the upper mesh to the lower mesh. Once the agitator table was turned off, each stack was measured using a scale, and the data was recorded.

### 3. Results and Discussions

The experiment was conducted on a variety of samples. The six samples analyzed with this apparatus are salt (table salt), whey powder, wheat flour (refined flour), coarse ground coffee, cement, and chalk dust. Each of these powders was analyzed three times with duplication, and their averages were taken. Ten grams of each of the substances were weighed out and then placed into the sieve and allowed to separate according to the various mesh sizes. Since only 4 meshes were used in this apparatus, the data provided is coarse and has a relatively poor resolution. Using the opening of each mesh number, the average particle size was then determined, and the mass fraction of each sample retained in each stack was calculated; using this data, the cumulative result of each sample can also be determined, as can be seen from **Tables 4** and **5**.

**Table 4.** Mass fraction and cumulative result for Salt, Whey powder, and Wheat powder

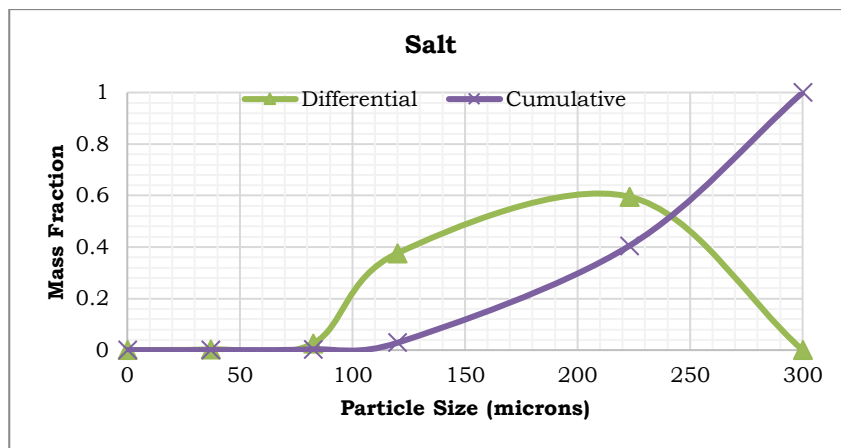
| Average<br>Particle Size<br>( $\mu$ ) | Salt             |             | Whey Powder      |             | Wheat Flour      |             |
|---------------------------------------|------------------|-------------|------------------|-------------|------------------|-------------|
|                                       | Mass<br>fraction | Cummulative | Mass<br>fraction | Cummulative | Mass<br>fraction | Cummulative |
| <b>300.0</b>                          | 0.0000           | 1.0000      | 0.0000           | 1.0000      | 0.0000           | 1.0000      |
| <b>223.0</b>                          | 0.5955           | 0.4045      | 0.2993           | 0.7007      | 0.0780           | 0.9220      |
| <b>120.0</b>                          | 0.3761           | 0.0284      | 0.6739           | 0.0268      | 0.4484           | 0.4736      |
| <b>82.5</b>                           | 0.0254           | 0.0030      | 0.0255           | 0.0013      | 0.4000           | 0.0736      |
| <b>37.0</b>                           | 0.0030           | 0.0000      | 0.0013           | 0.0000      | 0.0705           | 0.0031      |
| <b>0.0</b>                            | 0.0000           | 0.0000      | 0.0000           | 0.0000      | 0.0031           | 0.0000      |

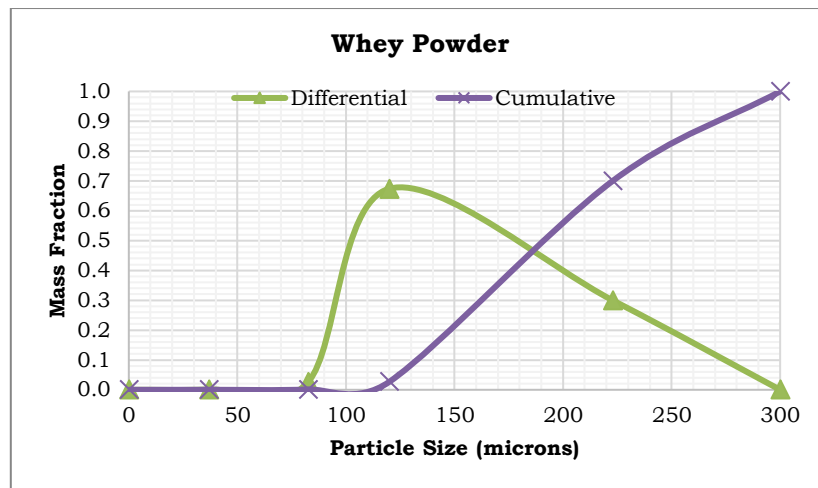
**Table 5.** Mass fraction and cumulative result for Coarse coffee ground, Cement, and Chalkdust

| Average<br>Particle Size<br>( $\mu$ ) | Coarse coffee ground |             | Cement           |             | Chalk dust       |             |
|---------------------------------------|----------------------|-------------|------------------|-------------|------------------|-------------|
|                                       | Mass<br>fraction     | Cummulative | Mass<br>fraction | Cummulative | Mass<br>fraction | Cummulative |
| <b>300</b>                            | 0.0000               | 1.0000      | 0.0000           | 1.0000      | 0.0000           | 1.0000      |
| <b>223</b>                            | 0.8240               | 0.1760      | 0.2809           | 0.7191      | 0.2942           | 0.7058      |
| <b>120</b>                            | 0.1724               | 0.0036      | 0.3973           | 0.3219      | 0.4849           | 0.2209      |
| <b>82.5</b>                           | 0.0036               | 0.0000      | 0.2468           | 0.0751      | 0.1888           | 0.0321      |
| <b>37</b>                             | 0.0000               | 0.0000      | 0.0517           | 0.0233      | 0.0222           | 0.0100      |
| <b>0</b>                              | 0.0000               | 0.0000      | 0.0233           | 0.0000      | 0.0100           | 0.0000      |

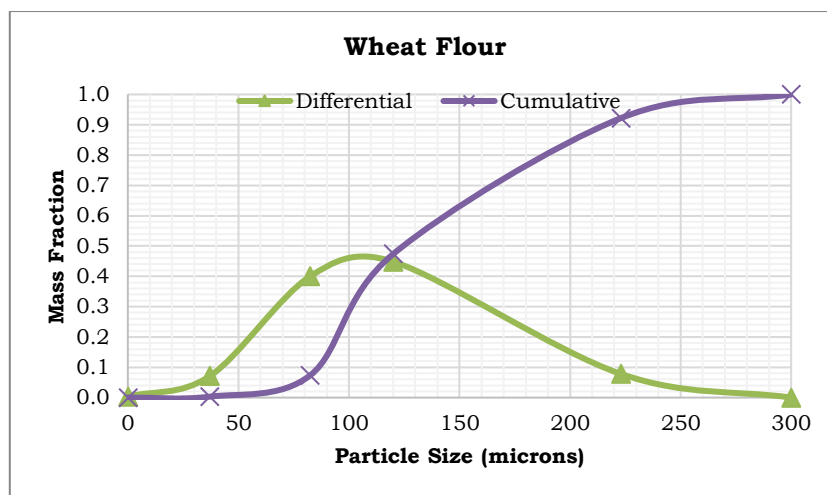
These data are being used to show both cumulative and differential analyses. Both are useful to know the particle size distribution of each sample. Cumulative analysis is the analysis of mass fraction accumulating in the ranges of the average particle size of the sieve (McCabe, Smith, & Harriott, 2005). The accumulated mass fraction is based on the mass of the sample from the bottom up. This analysis shows the range of each singular particle size around the average particle size of each sieve, providing an overall picture of distribution.

Differential analysis is the analysis of mass fraction from each average particle size of the sieve (McCabe, Smith, & Harriott, 2005). This analysis focuses on the mass fraction retained in each sieve. This analysis assumes that every particle size retained in a sieve, has the same size as the average particle size of the sieve. Each scatter graph is constructed from the data for each of the samples. Two lines indicate the differential and continuous graphs in each graph, as seen below in Figures 4, 5, 6, 7, 8, and 9.

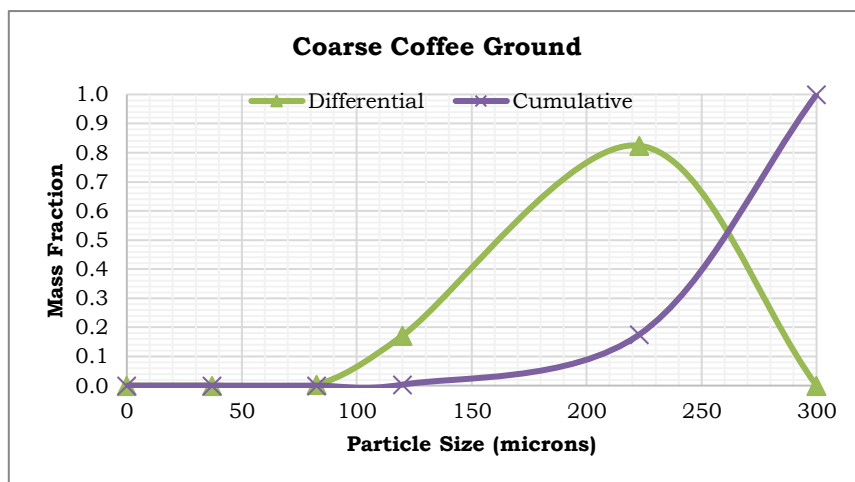
**Figure 4.** Differential and Cumulative analysis for table salt



**Figure 5.** Differential and Cumulative analysis for whey powder

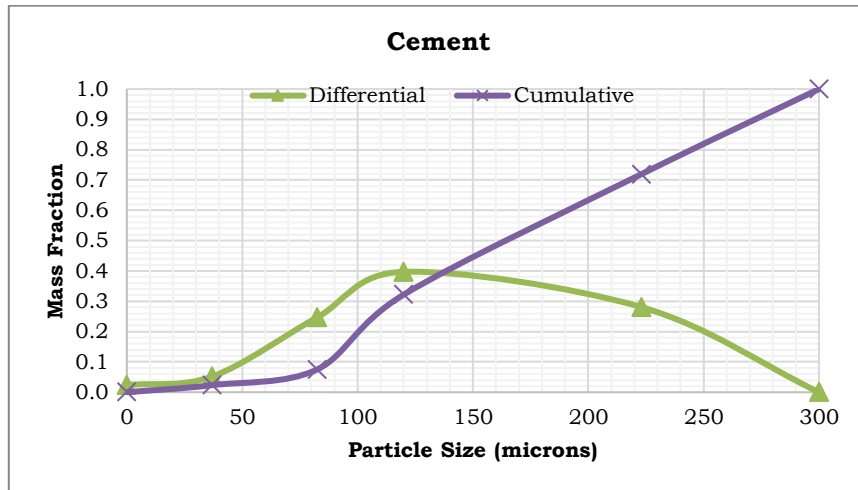


**Figure 6.** Differential and Cumulative analysis for wheat flour

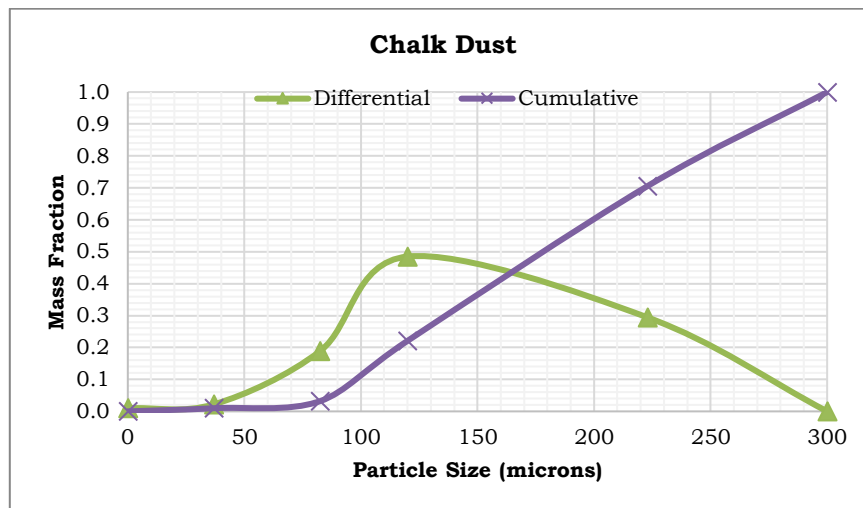


**Figure 7.** Differential and Cumulative analysis for coarse coffee ground





**Figure 8.** Differential and Cumulative analysis for cement



**Figure 9.** Differential and Cumulative analysis for chalk dust

The cumulative distribution curve can be analyzed to determine the sample's uniformity or non-uniformity. A steeper curve suggests a more uniform distribution of particle sizes, while a flatter curve indicates a wide range of particle sizes. *Cement* and *Chalk Dust* show uniformity compared to other samples, especially *Wheat Flour* and *Coarse Coffee Ground*.

On the other hand, differential analysis is important for understanding the presence of dominant size fractions and their changes. Peaks in the differential analysis graph pinpoint the specific size fractions. This can be seen in the *Salt*, *Whey Powder*, and *Coarse Coffee Ground* graphs. These graphs show visible peaks, meaning there is no normal distribution of sizes in these samples. *Cement* and *Chalk Dust* show smoother slopes, suggesting smaller differences in size fractions.

From the cumulative curves, the values of  $D_{10}$ ,  $D_{50}$ , and  $D_{90}$  can be estimated to provide an estimation of the distribution. The arithmetic mean of the particle sizes can also be calculated.

**Table 6.** Mean,  $D_{10}$ ,  $D_{50}$ , and  $D_{90}$  values of the various materials

| Material             | Particle Size ( $\mu\text{m}$ ) |          |          |          |
|----------------------|---------------------------------|----------|----------|----------|
|                      | Mean                            | $D_{10}$ | $D_{50}$ | $D_{90}$ |
| Salt                 | 180.14                          | 144      | 238      | 288      |
| Whey Powder          | 149.76                          | 133      | 192      | 272      |
| Wheat Flour          | 106.81                          | 86       | 124      | 215      |
| Coarse Ground Coffee | 204.74                          | 204      | 259      | 291      |
| Cement               | 132.59                          | 89       | 164      | 273      |
| Chalk Dust           | 140.19                          | 98       | 178      | 273      |



According to (Kang, Lee, Kim, Yun, & Chun, 2012), the mean particle size of *Wheat Flour* is 78.42 $\mu\text{m}$ ,  $D_{10}$  of 10 $\mu\text{m}$ ,  $D_{50}$  of 72.8 $\mu\text{m}$  and  $D_{90}$  of 145 $\mu\text{m}$ . And according to (Ferraris, Hackley, & Aviles, 2004), *Cement* has a  $D_{10}$  of 1.5-2 $\mu\text{m}$ ,  $D_{50}$  of 12-16 $\mu\text{m}$  and  $D_{90}$  of 32-48 $\mu\text{m}$ . Lastly, according to (Majumdar & William, 2008), the mean particle size of *Chalk Dust* is 12.25 $\mu\text{m}$ ,  $D_{10}$  is 1.39 $\mu\text{m}$ ,  $D_{50}$  is 5.13 $\mu\text{m}$ , and  $D_{90}$  is 25.83 $\mu\text{m}$ . These reference values are significantly lower compared to the results of this experiment.

The results shown above are affected by several factors, as this sieve analysis experiment also has some limitations that must be acknowledged. One concern is the mesh of the instrument itself. The size gap of the screen opening is too large in the first two of the mesh. The first two mesh (#50 and #100) have 148  $\mu\text{m}$  in screen opening size difference, followed by the next two mesh sizes (#100 and #165) with a 58  $\mu\text{m}$  gap. This causes an unequal gap in average particle size and may affect the particle size distribution results and reading.

The mesh number range may not be suitable for the sample due to the unequal opening size difference. Based on the result, the tray or the bottom of the sieve and the mesh #200 have the mass fraction of less than 0.1. It means that mesh #200 is not exactly suitable for this experiment as it shows a tendency for the distribution curve to be not in the center. Recreating the sieve with lower and closer number of mesh may solve these two problems, for example using mesh #50, #70, #100, and #120 to close the big size gap of the screen opening and the compatibility with the sample.

Another limitation is the efficient vibrating mechanism; while it works, additional force is needed to maximize the sieving process. The holders are lengthy and less stable, so the vibrations are not fully utilized. Other ways to secure and firmly shake the sieve are the potential solution to this design challenge. There is also possibility to add more detail to ensure that the results are as accurate as the mass retained in the sieve. An additional securing element to maintain the sample from being spilled or loss as it is weighed on the balance to have a higher accuracy.

#### 4. Conclusions

The sieve analysis experiment provided insights into the particle size distribution of various samples. The cumulative distribution curve assessed the uniformity of these materials, with steeper curves indicating a more consistent distribution of particle sizes. The results revealed that *cement* and *chalk dust* exhibited a higher level of uniformity than *wheat flour* and *coarse coffee ground*, which displayed broader particle size distributions.

Additionally, the differential analysis proved vital in identifying specific size fractions and variations within the samples. Peaks in the differential analysis graph precisely highlighted these fractions. Notably, the *Salt*, *Whey Powder*, and *Coarse Coffee Ground* samples exhibited pronounced peaks, indicating non-uniform size distributions. In contrast, *Cement* and *Chalk Dust* displayed smoother slopes, suggesting a more uniform distribution of sizes.

However, the experiment had its limitations, including the mesh size of the sieves, which affected the accuracy of the results, as they are significantly different from the referenced results. A redesign of the sieves with closer mesh numbers may address the issue. The efficiency of the vibrating mechanism and sample securing during the weighing process could also be improved for more precise results.

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