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Comparison of Sieving Techniques in Size Distribution and Estimation of Particle Size of a Bulk Sample

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Abstract: **The Sizing of minerals is important in pricing and designing the cause of the mineral industry. Particle size distribution is a difficult task for bulk samples and sieving is one of the most used methods. In the present study, particle size distribution was done with four different sieving techniques to compare the accuracy. The iron ore sample was collected from a mine in Joda-Barbil region of India for this purpose. All four methods were used for the estimation of the mean size, standard deviation, and R square of the duplicate samples. It was found that the estimated mean particle size of the sample is more for dry mechanical sieving than wet mechanical sieving than dry mechanical sieving than wet mechanical sieving. There is a decrease in R^2 value from dry manual to wet mechanical indicating an increase in non-uniformity of particle size distribution. Each pair of method were analyzed with T-test for comparison. The two differentiating factors among the methods are slope in the column chart and variance in the T-test. The result shows the effectiveness of screening increases with the addition of moisture and also using a mechanical system.**

Index Terms: **iron ore, mineral, sieving, size distribution, T-test**

I. Introduction

Many industries related to particle processing like mineral, pharmaceutical, food processing, etc. increasingly emphasize on particle characteristics to improve productivity and process control. Size analysis is an important part of mineral processing operation which is used for the estimation of approximate size for feed, concentrate, and intermediate samples at different stages of operation. Many prior studies suggest that size distribution is an important determinant of the quality of ore. In the iron ore industry, the size of the ore has a bigger role in the economics of minerals. The course (10-40 mm) ore used in blast furnaces is the costliest as compared to other lesser size (5-20 mm, 3-10 mm, and <10 mm) ore with the same assay value. Size determination also plays a vital role in subsequent plant operations. Physical properties of minerals are consequences of the particle size distribution (PSD) of the material (Bunt, 1983). Sampling plays a big role and accuracy in sampling helps in the determination of the appropriate particle size of bulk mass (Rawle, 2015).

Several methods such as microscopy, sedimentation, permeametry, electrozone sensing, laser diffraction, etc. can be used for particle size analysis (Rhodes, 2008). J. Kaszubkiewicz et al. (Kaszubkiewicz et al., 2020) used an automated dynamometer method integrated with an x-y sample changer for analysis of particle size. Sieving accuracy can be improved through proper practice and following the sieving protocols (Bartley III et al., 2019). They also found the importance of the particle's length-to-width ratio and agitation time as the basis of sieve analysis. C. Ullmann et al. (Ullmann et al., 2017) published their work on Analytical centrifugation (AC) for the measurement of PSD with real-world materials. F. A. Tassew et al. (Tassew et al., 2019) worked on microscopic image analysis for the determination of particle size distribution. I.D. Morrison and E.F. Grabowski (Morrison et al., 1985) used the quasi-elastic light scattering (QELS) technique for the analysis of particle size distribution. According to T. Allen (Allen, 2013), the size distribution in sieving is dependent on factors like duration, sieve aperture, wear, equipment, sampling, etc. M. R. Murphy and J. S. Zhu (Murphy & Zhu, 1997) suggest that the size analysis of any sample is affected by the type of method used and feed characteristics. Study shows dynamic image analysis can produce more accurate particle size distribution data than mechanical sieving (Ulusoy & Igathinathane, 2016).

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Despite the availability of all these instruments, the most used size analysis method in the mineral industry is sieving. However sieving methods can only be used effectively for particle size ranges of 5 to 100,000 microns (Wills & Finch, 2015). Sieving can be done either with dry material or with wet material. The sieving method is well described in IS-1607 published by BIS, New Delhi which is followed in India. In the basic method, the collected ore from the mine or plant is first screened with different test sieves, and fractions are weighed to determine the weight percentage of each size range. A graph may be drawn between average size and cumulative weight percent passing for determination of mean size and d_{80} size of the material. The other way of determining these values is through interpolation. Aluvihara et al. compared the dry sieving technique with the wet sieving technique to determine the average grain size of various clay minerals (Aluvihara et al., 2020). By using a sign test, wet sieving was found more suitable for particle size analysis of soil samples (Robertson et al., 1984). Hand screening and mechanical sieving were the general methods used in most particle-oriented industries. When it comes to efficiency hand screening is less efficient compared to mechanical sieving as a gyratory motion can be produced using a mechanical sieve shaker. In industry, the type of method used depends upon many factors like place of sieving, accuracy requirement, size of the ore, etc. Factors such as tapping, duration, etc. also help in improving the sieving data by improving the passage of finer particles through the apertures (Liu, 2009).

The current experiment is designed to compare various sieving methods that are being used generally to determine the particle size distribution. The validation of data from all these methods is done by calculating R^2 and T-test to get a meaningful result. This study may allow the mineral industry to choose an appropriate method for the determination of the size of bulk samples.

II. MATERIAL AND METHOD

A sample of 10 kg was collected from a mine in the Joda-Barbil region of India and brought to the institute laboratory. The sample was dried at 100^0 C for about an hour to remove the surface moisture associated with the material. Four duplicate samples were prepared approximately of 1000 g each of -10 mm size for study purposes. Seven numbers of sieves of different sizes were chosen for this study.

Sieving was done using four different methods at the laboratory as shown in Table I. In method 1 the dried material was screened using successive sieves of different sizes from top to bottom by using hand for about 30 minutes. In the second method hand screening was done but using water as the screening media to increase the efficiency of screening. The amount of water used was 3 liters and the time of screening was 30 minutes for the above purpose. In method 3, a ro-tap sieve shaker was used for screening of material but the time of operation was reduced to 15 minutes which is the standard time for sieving. In method 4, a water pipe was introduced to the top of the screen during mechanical sieving. The water was injected at a rate of 10 liters per hour rate and the operation was done for 15 minutes. All these methods used were in accordance with the laboratory practices but with some variables.

Table I. Brief description of different methods

Sl. No.	Method details	Duration of sieving	Condition of sieving
1	Dry manual sieving (DMS)	30 minutes	-
2	Wet manual sieving (WMS)	30 minutes	Water addition at 6 liters per hour
3	Dry sieving by sieve shaker (DSS)	15 minutes	-
4	Wet sieving by sieve shaker (WSS)	15 minutes	Water addition at 10 liters per hour

In the case of wet sieving the material from the sieves was taken for drying and dried for 2 hours at 1100 C for the removal of surface moisture. The sieved materials from each method were weighed and the weights of each sample were recorded for analysis.

The following parameters are taken into consideration for comparing the data from these methods.

1. Column chart of mass percentage
2. Scatter graph between average size and mass percent
3. 80% passing size and mean size
4. R square value
5. Paired sample T-test

III. RESULTS AND DISCUSSION

A. A. Sieve Analysis Results

The mass fraction data collected from each method were plotted as a column chart and X-Y scatter graph. The use of a column chart was to compare the mass percentage from each fraction. As we move upward the slopes of connecting lines among columns increase (Fig.1). As we move towards the right, we can observe that due to mechanical action or the addition of moisture, the fine particles are moving towards the lower pan. So, there is a decrease in mass fraction in the higher size range and vice versa.

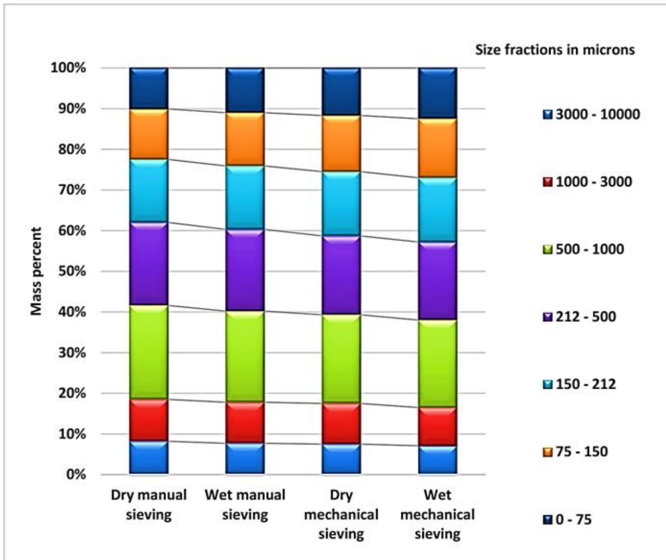

Fig. 1. Column chart showing the mass percent of different methods

The scatter graph plotted (Fig.2) between the log of average size to the corresponding mass percent has very little to differentiate among the methods. The only difference among these can be observed at the starting, ending, and peak of the curves as misplacement chances at all these points are significant. For all methods, the distribution can be seen as normal.

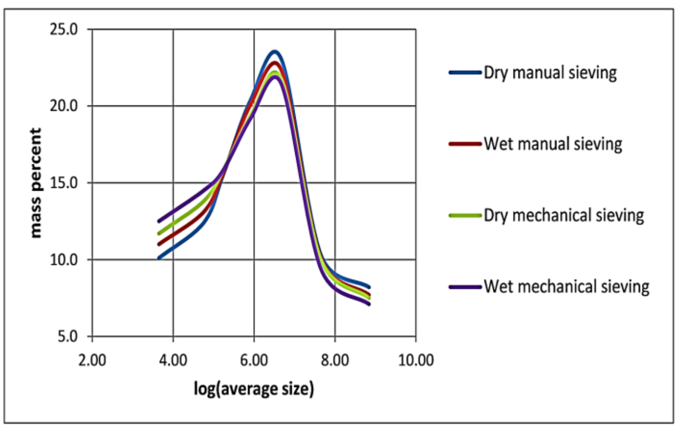

Fig. 2. Scatter graph between the log of average size of screen to mass percent

B. B. 80% passing size, mean size, and R square value

The mass percent collected were then tabulated with size fraction, cumulative mass percentage retained, and other parameters. 80% passing size and mean size for each method were calculated using the interpolation method. As we move towards the right, we can observe that there is a decrease in values of d_{80} and mean size (Table II). It is so because some fine material might not have passed in manual methods and retained with coarse material. This indicates the higher efficiency of the wet mechanical sieving process. The R^2 values were calculated from the graph between average size and cumulative mass percentage retained in each fraction. For all the methods the value is around 0.5, which indicates that only 50% of the data fit the regression model. But when we compare from dry manual to wet mechanical the value is decreasing and shows an increase in non-uniformity.

Table II. Estimation of 80% passing size, mean size, and R square value

Size fraction (in micron)	**Average size (in micron)**	**Cumulative mass % retained**			
		DMS	**WMS**	**DSS**	**WSS**
0 - 75	37.5	10.1	11	11.7	12.5
75 - 150	112.5	22.5	24.1	25.5	27
150 - 212	181	38	39.7	41.3	42.8
212 - 500	356	58.4	59.8	60.7	62
500 - 1000	750	81.5	82.2	82.5	83.5
1000 -3000	2000	91.8	92.3	92.5	92.9
3000 -10000	6500	100	100	100	100
80 % passing size		**724.42**	**711.30**	**704.82**	**685.86**
Mean size		**283.94**	**270.68**	**259.48**	**246.63**
R square value		**0.514**	**0.507**	**0.503**	**0.494**

C. C.Paired T-tests for two sample mean

T-tests were performed for each pair of samples to compare the methods of sieving, the null hypothesis being both processes are identical. The α value for these tests was taken as 0.05. The comparisons of all data sets are tabled in Table III. The mean of all pairs of data sets are same i.e., 14.29 indicates that the samples are identical. The value of variance in dry manual sieving is more than in wet manual sieving, wet mechanical sieving, and dry mechanical sieving. More variance indicates more spreading of the collected data which can be seen in dry manual sieving. This may be because of the inefficient sieving in dry manual sieving than other methods. The t stat value is less than the t critical value indicating the two methods are symmetrical. P two tail value of 1 which is more than the α value of 0.5 indicates that there is very little difference between the two data sets. Pearson correlation of all pairs of data nearly equals 1 indicating all the data lying exactly in one line.

Table III. Paired t-test two samples for means

Sieving Method Comparison	DMS-WMS	DSS-WSS	DMS-DSS	WMS-WSS
Mean	14.29	14.29	14.29	14.29
Variance ($1^{st}/2^{nd}$)	31.76/ 29.08	26.04/ 26.20	31.76/ 26.04	29.08/ 26.20
Observation	7	7	7	7
Pearson Correlation	0.99	0.99	0.98	0.98
Hypothesized Mean Difference	0	0	0	0
Df	6	6	6	6
T Stat	0	0	0	0
P(T<=t) one tail	0.5	0.5	0.5	0.5
t Critical one-tail	1.94	1.94	1.94	1.94
P(T<=t) two-tail	1	1	1	1
t Critical two-tail	2.45	2.45	2.45	2.45

IV. CONCLUSIONS

In this study, it is demonstrated that there is very little difference among the various methods used for sieving. The estimated mean particle size of the sample is maximum for dry mechanical sieving (283.94 microns) and minimum for wet mechanical sieving (246.63 microns). The R square value is decreasing from dry manual to wet mechanical which means there is an increase in non-uniformity of particle size distribution. Other differences observed are the slope in the column chart and variance in the T-test. These differences arise because of various factors like misplacement, near-size particles, moisture, etc. In manual sieving, some misplacement of fine particles occurs which reports to the course materials. Near-size material is always a problem in dry sieving which may choke screen apertures sometimes. Both the slope and variance difference indicate that the effectiveness of screening increases from the manual to mechanical method and from the dry to wet method. In the T-test, it can be observed that all the processes are identical, and only difference can be observed in variance. No method may be perfect as every method has some advantages and disadvantages. But by improving the consistency and practice of sieving appropriate size analysis can be done by a method.

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