Image Analysis for Particle Size Distribution

C. Shanthi [#1], R. Kingsley Porpatham [*2], N. Pappa [#3]
Department of Instrumentation Engineering, MIT Campus,
Anna University, Chennai, India
[#1]cgshanthi@gmail.com
*[2]2kingsleyporpatham@gmail.com
[#3]npappa@rediffmail.com

Abstract— **Particle size distribution (PSD) affects properties of particulate materials and is used for denoting their quality and performance. Among many techniques available to measure PSD, many are quite often offline methods and are time consuming. Also methods like sieving involve, handling of the material physically and electromagnetically, which is healthy, if avoided for certain materials. Thus the need for an online PSD analyzer and the advent of digital image processing has rendered the drift for innovation of image based particle analyzers. Also this method is purely inferential as the particles are not handled physically or electromagnetically as in cases like sieve analysis or tomography. In general, PSD estimation is based on considering a single parameter of the particle profile. Irregularities in analyzed particles increase the error in PSD estimation. Hence, two parameters, equivalent area diameter and Feret's diameter are included for the estimation to reduce the estimation error.**

Keyword - Particle Size Distribution, Image Processing, equivalent area diameter, Feret’s diameter, edge detection

I. INTRODUCTION

Particle size distribution influences many properties of particulate materials and is a valuable indicator of quality and performance of the particles. This is true for powders, suspensions, emulsions, and aerosols. In cement particle size distribution affects hydration rate & strength. Improvements in coal particle size distribution are beneficial to carbon burnout. Smaller particles dissolve more quickly and lead to higher suspension viscosities than larger ones. Smaller droplet sizes and higher surface charge will typically improve suspension and emulsion stability. Powder or droplets in the range of 2-5μm aerosolize better and will penetrate into lungs deeper than larger sizes. For these and many other reasons it is important to measure and control the particle size distribution of many products.

Using the digital image processing technique to find particle size distribution has many advantages. As fast computers are available, using computers to find PSD using digital image processing is very fast compared to traditional sieve analysis and other techniques. The computers can offer wide range of data analysis and data storage convenience. As it is fast, it can be employed in the online analysis for finding PSD, where a camera over the conveyor belt can do the job. In traditional techniques PSD was measured offline, by taking sample out of the conveyor belt. But image-processing is a purely inferential technique, and the particles are never handled physically as in sieve analysis or influenced by magnetic field as in case of tomography. So using digital image processing to find PSD can be done on all types of particles, even on those which have physical handling constraints and which seldom can be passed via magnetic field. In general, equivalent area diameter of the particle profiles are used to measure PSD. But here we use two parameters Feret's diameter and equivalent area diameter to measure the PSD.

S. Al-Thyabat and N.J. Miles [1][2], in their journal of Powder Technology, 'An improved estimation of size distribution from particle profile measurements', proposed technique which measures two parameters, equivalent area diameter and mean Feret's diameter, for each particle profile. The use of Feret's diameter technique gives a higher level of accuracy. Michael Mangold [3] proposed the application of the same technique in a conveyor belt, in an online fashion. Young-don ko and Helen Shang [4] discussed about NN based particle size distribution. Holleran. G and Reed. J.R [5], in ISSA International Congress put forward the importance of particle size distribution in emulsions and how they would deteriorate if PSD in not maintained strictly. F.S.Farbosa, M.C.R.Farage.et. al. [6] used image processing techniques for gradation in lightweight concrete. Yong Wu and Yi Pan [7], shows how cereal size can be analysed using image processing. This comes handy in food quality control sections. Zelin Zhang, Jianguo Yang, Lihua Ding and Yuemin Zhao [8],[9], [10] has proposed the image analyzing techniques for analysis of coal, which is of quite importance in thermal power plants and any coal handling Plants.

The rest of the paper is organized as follows. Section II discusses the Experimental approach. Section III describes about image processing techniques used. Section IV discusses Profile diameters. Section V deal with Results and discussions. Finally, the conclusion and future work are outlined in Section VI.

II.EXPERIMENTAL APPROACH

A. Sample Preparation

Samples are chosen with particles of different shape and size. The PSD of the chosen particles are calculated manually using sieve analysis. Fig.1 shows the top view of Gravels.

B. Image-Acquisition

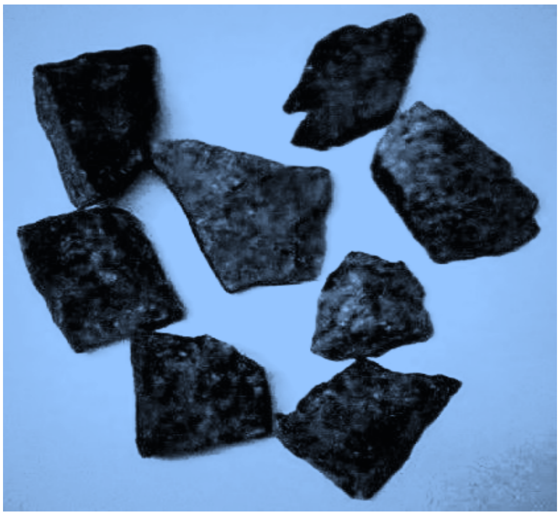


Fig. 1 Top View of Gravels

Image is acquired using a high speed digital camera, from a top view angle. Nikon CoolPix P510 camera is used. It has maximum shutter speed of 1/4000 sec and highest ISO sensitivity of 6400. When image is captured care has to be taken on focus, ISO sensitivity, exposure time of the camera. Lighting is added if ambient light is not sufficient. The resolution is set at 2 Mega Pixels, though the camera can capture at 16 Mega Pixels. Hence it can clearly show the particle features while reducing burden on processor.

III.IMAGE PROCESSING

A. *Pre-processing Operations*

Pre-processing operations is a precursor to make further steps easier. First the colour image is converted to grey image. Then filtering operation like median filtering is done to remove noise. Followed by it, illumination correction and contrast correction are done. This gives a grey image, with clear features that is easy to process on. The grey converted image is shown in Fig. 2.

Fig. 2. Grey image of Gravels

B. *Morphological Operations*

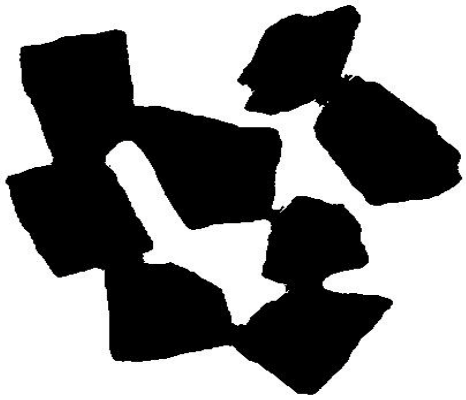
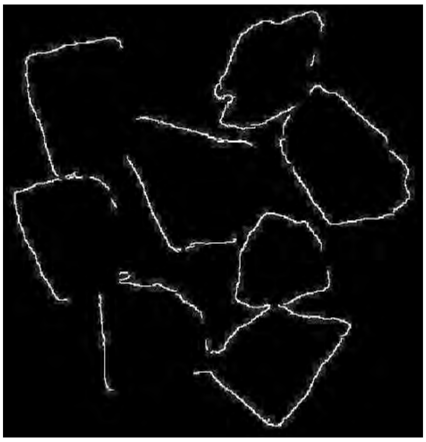


Fig. 2 Morphological Operations

Fig. 3 Thresholding

Morphology is a broad set of image processing operations that process images based on shapes. Morphological operations apply a structuring element to an input image, creating an output image of the same size. In a morphological operation, the value of each pixel in the output image is based on a comparison of the corresponding pixel in the input image with its neighbours. By choosing the size and shape of the neighbourhood, you can construct a morphological operation that is sensitive to specific shapes in the input image. The most basic morphological operations are dilation and erosion. This removes the noise and dust particles from the image (Fig.3).



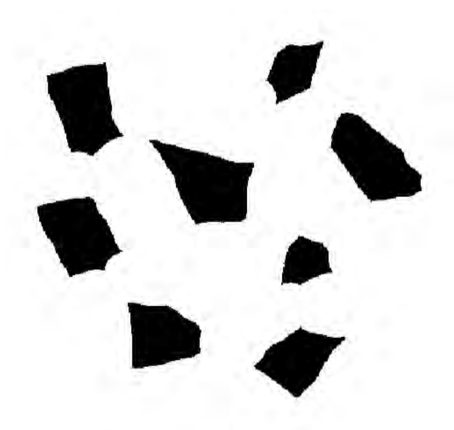


Fig. 4 Edge Detection.

Fig. 5 Segmentation.

A primary segmentation operation involves thresholding (Fig.4). It converts the image into binary from greyscale. Now, only the particle and the background is available to process on. As the word segmentation implies, it is used for segmenting the particles into individual profiles. Edge detection method is used to find the edges of the particles. Fig.5 gives the edge detected image. Then the edges are superimposed on the original image. Then erosion is carried, so the edges thicken and touching particles get separated. This reduces the size of the particles, but the particles remain proportional to the original particles and can be scaled back. The segmented image is in Fig.6.

IV. PROFILE DIAMETERS

Every parameter regarding particles of the particulate material is stored in separate profile. These parameters can vary depending on various objectives of the measurement. In general, in the pursuit for PSD measurement the parameter of most importance is diameter. Diameter of a circle is a single value. But the diameter of an irregular particle is calculated in several ways, and they give different results. This chapter deals with two diameter calculation methods. The two diameter calculating methods used are 'Equivalent area diameter' and 'Feret's Diameter'. These diameters calculated are in pixels which are later converted to desirable units.

A. *Equivalent Area Diameter*

Equivalent area diameter of a particle is the diameter of the circle which has the same area as that of the particle. The diameter is easy to be calculated.

$$\text{Equivalent area Diameter} = \sqrt{4 \times \text{Profile area}/\pi}$$

The equivalent area diameter is quite useful in places where PSD calculations are carried out for particles of circular or spherical nature. The chief advantage of this method is the programming simplicity and lesser computational burden. The diameters calculated are stored to their respective profiles. The calculated diameter is in pixel length. This has to be converted to meters or desired unit to give any useful meaning. However, its discrepancies creep in for less circular, tapered or elongated objects. So in order to overcome this, a more sophisticated yet accurate parameter called Feret's diameter is employed.

B. *Feret's Diameter*

The Maximum Feret's Diameter is expressed and represents the longest dimension of the particle independent of its angular rotation at the time the image was captured. It is also called as maximum diameter or maximum callipers. The Feret's Diameter is determined by isolating the corner pixels of the object's perimeter and taking the maximum distance between each corner pixel to all other corner pixels. Once the longest dimension (in pixels) has been determined, this value is converted to SI units.

Maximum Feret's diameter gives the value of the minimum sieve size through which the particle can pass through without any hindrance. But equivalent area diameter does not give the exact sieve size necessary. Feret's diameter (Fig.7) thus can replace the sieve analysis method very precisely.

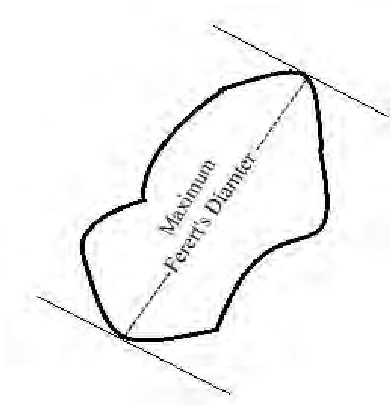


Fig. 6 Feret's Diameter

V. EXPERIMENTAL RESULTS

The particle size distribution, PSD, is expressed in probability density function. This gives the frequency with which particles belonging to a diameter range occur. Following are the probability density function of the actual diameter, equivalent diameter and feret's diameter. For the purpose of experiment two different images are considered. One image consists of non-touching particles (fig.8, fig.10) and the other with touching particles (fig.9, fig.11). the results of both methods using both the diameters are compared. Table I & Table II give the diameters of non-touching particles and touching particles respectively.

Fig. 7 Non-touching particles

Fig. 8 Touching Particles

TABLE I
Diameters of non-touching particles

S. No	Equivalent Area Diameter	Feret's Diameter
1	4.9	4.4
2	3.3	3.0
3	4.3	4.5
4	1.9	1.8
5	2.1	2.2
6	5.3	4.7
7	4.6	4.5
8	1.7	1.4
9	3.2	2.7
10	4.1	4.1
11	1.8	1.5
12	5.3	5.3
13	3.7	3.1
14	2.1	2.2
15	2.2	2.1
16	3.5	3.2
17	5.2	5.1
18	4.8	4.4

Table II
Diameters of touching particles

S. No	Equivalent Area Diameter	Feret's Diameter
1	4.9	4.6
2	5.1	4.9
3	4.5	3.9
4	5.3	5.3
5	4.3	4.5
6	3.5	3.4
7	3.1	2.8
8	5.2	5.1

VI. CONCLUSION

It is quite evident that, the calculated values of non-touching particles are more accurate. The accuracy level of measurement on touching particles is drastically low. It is also noteworthy to mention, that the accuracy level of measurement using Feret's diameter was higher. It was substantially higher in the case of touching particles. As discussed, measurement of PSD for non-overlapping particles is achieved using digital image processing techniques. This forms the base for the online PSD analyzer, which works on moving particles in a conveyor belt scenario. The results obtained are satisfactory and there a space for improvement in instances where particles touch each other. Feret's diameter shows a greater accuracy than the equivalent area diameter.

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