Measurement of Particle Size Distribution Attained From the Sago Sizing Mechanism

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Abstract— Particle size distribution (PSD) affects the properties of granular materials and is used for designating their quality and performance. Traditionally, the determination of particle size distribution derived from mechanical system (sieving) is a time consuming method and difficult to measure the cohesive and food materials. At present, the image analyses techniques are used to determine the particle size distribution especially for cohesive and agglomerated particles. In this work, the particle size distributions of three grades of sago pearls are investigated by using the image analysis methods. Three grades of sago pearls are experimentally obtained from the innovative sago sizing mechanism by the different rotational speeds of bowl. The mixed shapes of particles including elliptical and spherical on particle size distribution are investigated. It is observed that, the median particle size is between 7.0 mm to 8.0 mm at lowest rotational speed and 2.0 mm to 3.0 mm at highest rotational speed of the mechanism.

Key words: Sago Pearl, PSD, ImageTool, Feret's Diameter

I. Introduction

A new processing mechanism is devised to size the sago particles especially for small scale industries [1]. This sago sizing mechanism is to produce the various sizes of sago pearls with respect to the rotational speeds and other operating parameters. In this paper the particle size distribution (PSD) is analyzed for experimentally obtained sago pearls. The PSD is one of the basic and most important properties of granules and pearls. It will affect the properties of particulate materials and is used for designating their quality and performance. Distributions of sizes can be reported in terms of number, length, surface area or volume with the inter-relationships between them and also dependent on the particle shape. The characteristics of particle sizes (D10, D50 and D90) are of unique importance in granulation, sizing and mathematical modelling. The D10, D50 and D90 size of particles can be estimated without size analyses of the coarse and fine products are presented. Particle size analysis comprises the measurement and analysis of the three particle axes that define the three dimensional shape of a particle. For many applications, it is much more convenient to characterize particle size by only one variable, such as the length of the intermediate particle axes or the size of the sieve on which a particle is retained. Once the sizes of particles are determined, they are statistically analyzed, so that particle size distributions and statistical parameters describing them can be compared. Traditionally the particle size distribution is accomplished through sieving of bulk samples or by different particle size count methods. These are the simplest and probably the most commonly used methods for determining the particle size distribution. A granule mass is placed on top of a mechanical shaker that is made of a series of screens with sequentially smaller apertures. The horizontal sieve motion loosens the packing of particles allowing sub sieve particles to pass through. Finally, the weight of particle in each sieve is recorded and presented. The accuracy of sieving is dependent upon the shape of the particles [2, 3]. Using the sieving, particles passing through a sieve can actually have one dimension that is larger than the size of the sieve apertures. When the particle has its length greater than the aperture size can pass through the sieve without any difficulties as well as relatively flat particle can also pass through the sieve aperture, diagonally as shown in Figure 1 [3]. Therefore, the sieve aperture size is a measure of the lateral dimensions of the particles only. As a result, the breadth of a particle passing through a sieve can also be greater than the sieve size, although it has to be smaller than the diagonal length of the sieve aperture [2]. Similar to sieving there are several traditional methods for field sampling. Some of them are costly, time consuming and their results often depend on the observer's bias [4].

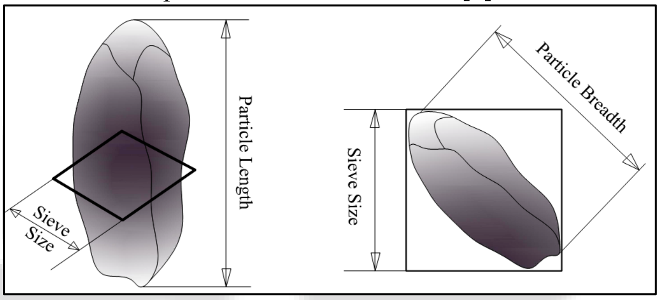

Fig. 1: Particle passing through a sieve aperture

The spherical particles, regularly shaped particles, and similarly shaped particles are possible to create a differentiation on the basis of linear dimension. Irregular particles are not possible to define a differentiation in terms of any linear dimension alone and the size must be defined in terms of some other size related property like area and volume. In several cases, it has been specified the size of the particle as the size of an equivalent sphere. A single dimension describing the size of a particle may be a true spherical diameter and for irregular particles will be the diameter of a sphere having equivalent properties to that of the particle. The particle size distribution is usually reported in terms of any one of the following diameter with irrespective of the actual particle shape as shown in Figure 2 [5].

- Feret's diameter, DF distance between two parallel tangents on opposite sides of the image of a randomly oriented particle [6]
- Martin's diameter, DM diameter of the particle at the point that divides a randomly oriented particle into two equal projected areas [6]
- The projected area diameter or equivalent area diameter (DA) is the diameter of a sphere having the same projected area as the particle. The projected area diameter of a particle can be related to the particle projected area by,

$$D_A = \sqrt{\frac{4 \text{ X Profile Area}}{\pi}} \quad (1)$$

Using the digital image analysis technique to find particle size distribution has many advantages. By using sieve the cohesive and agglomerated food materials are difficult to measure. So image analysis has been used for particle size measurement in the cohesive food granular materials. This method can be considered an alternative to mechanical sieving owing to the similarity of results, very valuable when fine particles need to be analyzed in a short time economically [7].

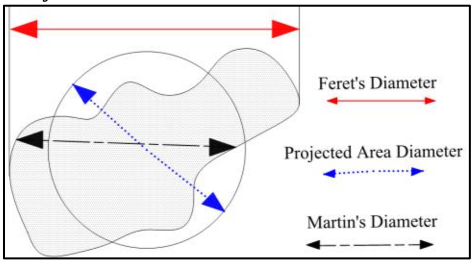

Fig. 2: Schematic of different particle diameters in 2D image

The image analysis is considered to be a significant technological advancement towards grain size distribution of soils with images obtained from digital cameras [8]. The automated particle size method using ImageTool and ImageJ is a technique for determining the grain size distribution by means of digital photographs [9]. Particle size is proposed to describe a particle in terms of a characteristic linear dimension. It has been normally express the size in terms of a diameter. In the image analysis different ways of measuring particle size, such as equivalent area diameter [10], Feret's diameter [2, 3], best-fit rectangle [11, 12] and Martin's diameter have been used. In 2014, Shanthi et al. [10] measured PSD using two parameters Feret's diameter and equivalent area diameter. In this study the sago particle size distribution is measured by using only one parameter of Feret's diameter. Feret's diameter is measured by using the profile projector and UTHSCSA ImageTool 3.0 software. The Feret's diameter is quite useful in places where PSD calculations are carried out for particles of circular or spherical nature. The chief advantage of using Feret's diameter is simple and lesser in computational burden. Other image analysis parameters are having some discrepancies in less circular, tapered or elongated objects. So in order to overcome this, a more sophisticated yet accurate parameter called Feret's diameter is employed. Feret's diameter is the mean value of distances cross the centroid between two parallel tangents which are on opposite sides of the target region in 0°, 45°, 90° and 135° [13] as shown in Figure 3. Therefore the mean Feret's diameter is calculated from number of diameters (Df1, Df2, Df3, Df4) by using the following equation (2).

$$D_F = \frac{(D_{f1}+D_{f2}+D_{f3}+D_{f4})}{4} \quad (2)$$

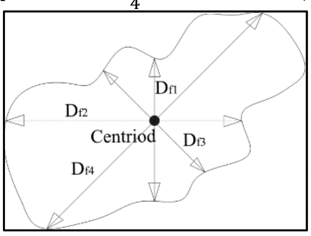

Fig. 3: Representation of Feret's diameter

Hence, the most common measurement used for the sizes of irregular grains under microscope is Feret's diameters of particles. Feret's diameter shows a greater accuracy than the equivalent area diameter [10]. Therefore the Feret's diameter is determined by using ImageTool 3.0 and profile projector and then compared the results.

II. MATERIALS AND METHODS

The sample is collected from the experimental results of sago sizing mechanism which is an innovative mechanism to produce different size of sago particles with respect to the rotational speeds and other operating parameters [1, 14]. The process of granulation and sizing is carried out for 10 to 20 minutes approximately based on the presence of water content. The study of sizing of sago particles is conducted for bowl diameter of 0.3 m, bowl height of 0.1 m and rod length of 0.7 m. The quantity of powder materials used per experiment is 0.25 kg. The experiments are performed for range of rotational speeds from 1.0 rads^{-1} to 5.0 rads^{-1}. The aim of this work is to determine the particle size distribution of sago pearls obtained from the sago sizing mechanism. For this purpose, three sago samples with different shapes and sizes are used. Different size fractions of sago pearls are used to determine particle size distribution as shown in Table 1 and Figure 4.

S. No	Rotational speed (rads^{-1})	Range of size (mm)	Particle shape
Sample 1	1.0	4.0 – 8.5	mixed
Sample 2	3.65	2.0 – 6.0	mixed
Sample 3	5.0	1.0 – 3.5	mixed

Table 1: The size fractions of the sago pearls used in this study

a) 1.0 rads^{-1} b) 3.65 rads^{-1} c) 5.0 rads^{-1}

Fig. 4: Digital images of sago particles

A. Measurement of size using profile projector

The sago pearls three dimensional element and the image analysis techniques treat particles as two-dimensional element because only the two dimensional projection of the particles is captured and measured. Each sample sizes are examined by using the profile projector to determine the Feret's diameter after the process of granulation and sizing. The profile projector projects a magnified profile image of an area or feature of an object onto a screen using diascopic illumination. The diameter can be measured directly on the screen or compared to a standard reference at the correct magnification using highly desirable telecentric lenses. For accuracy, it is important that the magnification does not change with perspective. The screen often has a grid and it can often be rotated through 360 degrees to align with an edge as displayed on the screen. The measurements can be performed using a simple digital read out device. A computer may be added to a profile projector system for edge detection, thereby eliminating some human error. In this method only one particle is measured at a time. The size of the sample sago pearls are measured by using the profile projector with an accuracy of 0.001 mm as shown in Figure 5.

B. Measurement of size using digital image (ImageTool)

Digital image processing systems are becoming increasingly employed in industrial applications, not just in research. To determine the size distribution of the sago pearls, the UTHSCSA ImageTool 3.0 [15] is used. ImageTool 3.0 analysis functions include dimensional measurement like distance, angle, perimeter, area and grayscale measurements like point, line, and area histogram with statistics. The result obtained by using this software is to determine the cumulative sago size distributions with the high quality digital image. The procedure for measuring the sago pearls size distributions using ImageTool 3.0 software is,

- A high quality image of the particles is needed before image processing performed through this software. The pictures of the surface of sago pearls must be taken perpendicular to the surface. Before using the software, the picture is measured using the appropriate scale which provides the master measurement.
- Upload the image and measure the particles size using the image tool (line measurement) and the table will progressively obtain as shown in Figure 6. Once the measurements are finished, copy the data and paste in the Excel work sheet.

The measurements in column are not in mm and transform the size into mm by using the master measurement of particle size and the measurement column are converted into log scale (ψ).

Fig. 5: Size measurement of sample pearls (profile projector)

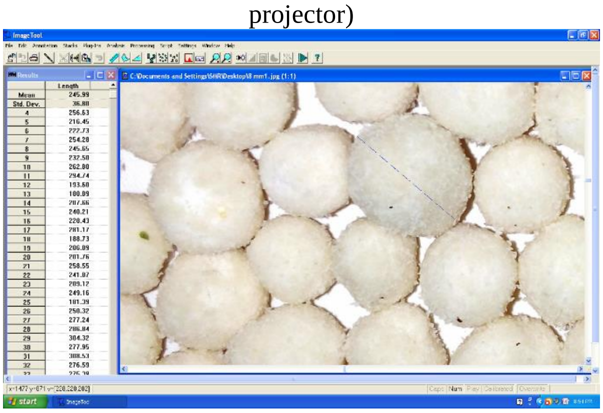

Fig. 6: Measurement of particle size using the UTHSCSA ImageTool 3.0

III. RESULTS AND DISCUSSION

The sago pearls size distribution is discussed in this section for different rotational speeds of bowl. Particle size distribution data can be presented numerically or graphically. When presented graphically the particle size distribution may be revealed either as a differential distribution or as a cumulative distribution in general with increasing particle diameter. When differentiates the cumulative distribution curve, the differential distribution is obtained and integrates the differential distribution curve, the cumulative distribution is obtained. The differential distribution presents a clear description of the distribution spread and the peak and whether the peak is skewed from the centre of the distribution. It will also show if the distribution is multi-modal with more than one peak. In a cumulative distribution small multi-modal peaks may not be easily observed, but this form of graphical output enables simple identification of the fractional distribution of sizes of particles. The values most frequently measured in this form are D10, D50, and D90 which will give an indication of size of the fine (D10), median (D50) and coarse (D90) fractions [16]. A particle size value indicating that, 10%, 50% and 90% of the distribution means that, a D10 of 1.23 mm means 10% of the sample is below 1.23 mm in size. The particle size on the x-axis is usually expressed in log scale (ψ) and cumulative % of mass is on y-axis, this allows the range of particle sizes to be equally visible on the diagram.

Using the UTHSCSA ImageTool 3.0 software, the results (Feret's diameter) are drawn for sago pearls size distribution and plotted in the following figures (figure 7 – figure 9). At lowest rotational speed of 1.0 rads^{-1}, the average pearl size (D50) is between 7 mm to 8 mm as shown in Figure 7. For D10 the diameter of ψ = 2.65 is equivalent to 22.87 = 6.2 mm and it means 10% of the sample is below 6.2 mm in size. Similarly the diameter of the sago pearls for 50% of the sample is below 7.3 mm in size and 90% of the sample is below 8.1 mm in size.

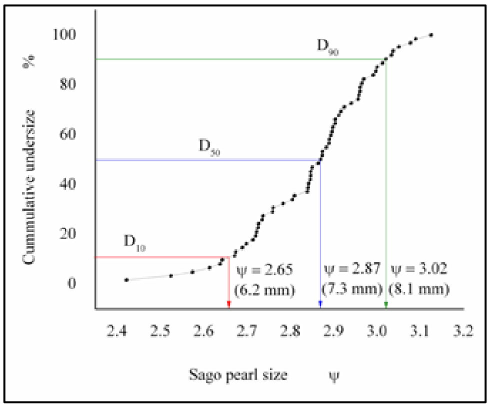

Fig. 7: Sago pearl size distributions at 1.0 rads^{-1} bowl rotation

At normal rotational speed of 3.65 rads^{-1}, the average pearls size is between 3 mm to 4 mm as shown in Figure 8. For D10 the diameter of ψ = 1.47 is equivalent to 21.47 = 2.8 mm and it means 10% of the sample is below 2.8 mm in size. Similarly the diameter of the sago pearls for 50% of the sample is below 3.6 mm in size and 90% of the sample is below 4.2 mm in size. At highest rotational speed of 5.0 rads^{-1}, the average pearls size is between 2 mm to 3 mm as shown in Figure 9. For D10 the diameter of ψ = 0.88 is equivalent to 20.88 = 1.8 mm and it means 10% of the sample is below 1.8 mm in size. Similarly the diameter of the sago pearls for 50% of the sample is below 2.3 mm in size and 90% of the sample is below 3.1 mm in size.

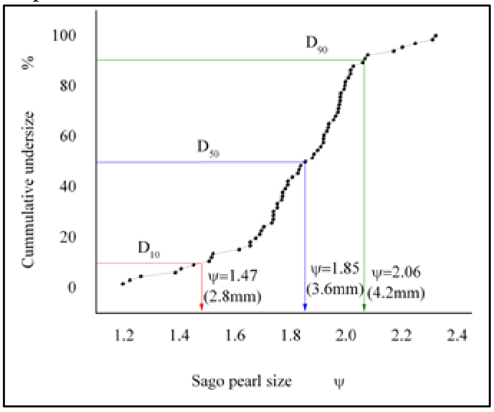

Fig. 8: Sago pearl size distributions at 3.65 $rads^{-1}$ bowl rotation

It is observed that the quality of final product (sago pearl), size and shape strongly depends on the rotational speed of the bowl for all preferred range of inclination angles of rod. The median diameter of the sago pearl is larger (7 - 8 mm) for lower rotational speed of the bowl and smaller (2 - 3 mm) for highest rotational speed. The primary reason for these results that, at higher rotational speed the particles are tightly enveloped with high density and other hand at lower speed the particles are loosely enveloped with the low density and the second case will be easily broken.

Finally, 10 sago pearls are randomly collected from each sample. The measurement is carried out on these samples to determine the Feret's diameter by using profile projector and UTHSCSA ImageTool 3.0 and presented in the Table 2. From these results, the profile projector measurement is well matched with the UTHSCSA ImageTool 3.0 measurement by acceptable average error of 4 - 5 % for all samples.

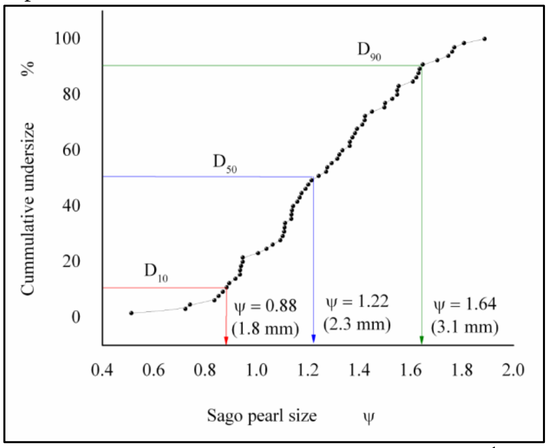

Fig. 9: Sago pearl size distributions at 5.0 $rads^{-1}$ bowl rotation

S. No	Sample 1 (1.0 $rads^{-1}$) mm			Sample 2 (3.65 $rads^{-1}$) mm			Sample 3 (5.0 $rads^{-1}$) mm		
	Profile projector	ImageTool 3.0	Error	Profile projector	ImageTool 3.0	Error	Profile projector	ImageTool 3.0	Error
1	6.51	6.55	-0.04	3.82	3.85	-0.03	1.56	1.5	0.06
2	6.78	6.71	0.07	4.56	4.51	0.05	3.65	3.57	0.08
3	7.13	7.15	-0.02	2.98	3.01	-0.03	2.67	2.59	0.08
4	6.74	6.77	-0.03	4.28	4.19	0.09	3.28	3.32	-0.04
5	7.70	7.67	0.03	5.89	5.95	-0.06	2.34	2.36	-0.02
6	8.16	8.21	-0.05	3.88	3.85	0.03	1.89	1.95	-0.06
7	7.47	7.51	-0.04	4.71	4.67	0.04	1.95	1.87	0.08
8	7.85	7.78	0.07	3.34	3.38	-0.04	2.53	2.48	0.05
9	5.90	6.01	-0.11	3.01	3.06	-0.05	2.76	2.82	-0.06
10	7.52	7.54	-0.02	2.16	2.1	0.06	2.01	1.98	0.03

Table 2: Comparison of Feret's diameter using ImageTool and profile projector

IV. CONCLUSION

It is quite evident that, the median pearls size is between 7.0 mm to 8.0 mm at lowest rotational speed (1.0 $rads^{-1}$), between 3.0 mm to 4 .0 mm at normal rotational speed (3.65 $rads^{-1}$) and between 2.0 mm to 3.0 mm at highest rotational speed (5.0 $rads^{-1}$) of the mechanism. This result reveals that, at higher rotational speed the sago particles are tightly packed and at lower speed the sago particles are loosely packed. Hence the sago pearls are obtained by the lower rotational speed will be easily broken. Both measurements of Feret's diameter are well matched. From these results it is concluded that, particle size decreased by increasing the rotational speed and increased by decreasing the rotational speed.

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REFERENCES

[1] S. M. Raj Kumar, R. Malayamurthi, R. Marappan, "Rolling and bouncing dynamics of particles in the inclined rotating bowl for sago sizing mechanism", Powder Technology 267, 279-288, 2014.
[2] C. F. Mora, A. K. H. Kwan, H. C. Chan, "Particle size distribution analysis of coarse aggregate using digital image processing" Cement and Concrete Research 28(6), 921–932, 1998.
[3] A. K. H. Kwan, C. F. Mora, H. C. Chan, "Particle shape analysis of coarse aggregate using digital image processing" Cement and Concrete Research 29, 1403–1410, 1999.
[4] G. S. Bevenger, R. M. King, "A pebble count procedure for assessing watershed cumulative effects", USDA Forest Service Research Paper RM-RP- 319, Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colerado, 1995.

[5] S. F. Liang, Z. Chao, “Principles of Gas-Solid, Size and Properties of Particles”, Cambridge University Press, 3-45, 1998.
[6] G. M. Henk, “Particle Size Measurements-Fundamentals, Practice and Quality” Springer Science, the Netherlands, 13 – 40, 2009.
[7] C. Igathinathane, U. Ulusoy, L. O. Pordesimo, “Comparison of particle size distribution of celestite mineral by machine vision ΣVolume approach and mechanical sieving”, Powder Technology, 215, 177-278, 2011.
[8] A. Seracettin, A. Suat, H. A. Samet, “Effect of particle size and shape on the grain-size distribution using image analysis”, International Journal of Civil and Structural Engineering, 1(4), 968 – 985, 2011.
[9] G. Harb, J. Schneider, “Application of two Automated Grain Sizing Approaches and Comparison with Traditional Methods.”,In: Proceedings of 33rd IAHR Congress 2009: Water Engineering for a Sustainable Environment, 4973 – 4979, 2009.
[10] C. Shanthi, R. Kingsley Porpatham, N. Pappa, “Image Analysis for Particle Size Distribution”, International Journal of Engineering and Technology, 6(3), 1340 – 1345, 2014.
[11] A. Tobias, M. J. Thurley, J. E. Carlson, “A machine vision system for estimation of size distributions by weight of limestone particles”, Minerals Engineering 25, 38–46, 2012.
[12] W. X. Wang, “Image analysis of particles by modified Ferret method- best fit rectangle”, Powder Technology, 165, 1–10, 2006.
[13] Z. Zelin, Y. Jianguo, S. U. Xiaolan, D. Lihua, “Analysis of large particle sizes using a machine vision system”, Physicochemical problems of mineral processing, 49(2), 397−405, 2013.
[14] S. M. Raj Kumar, R. Malayamurthi, R. Marappan, “A review on techniques for sago pearl granulation and sizing process”, International Journal of Applied Engineering Research, 10(55), 3811 – 3818, 2015.
[15] S. Brent Dove, 2002, UTHSCSA ImageTool Version 3.0 Final, Dental Diagnostic Science, http://compdent.uthscsa.edu/dig/itdesc.html. Accessed on 12 January 2016.
[16] K. Mingard, R. Morrell, P. Jackson, S. Lawson, S. Patel, R. Buxton, “Measurement Good Practice Guide No 111”, National Physical Laboratory, Teddington, Middlesex, TW11 0LW, 2009.