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Optimal pixel resolution for sand particles size and shape analysis

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ABSTRACT

In this paper, the influence of different scanning resolutions and the use of image analysis softwares for the image analysis, SigmaScan Pro, ImageJ and Matlab, on size and shape factors commonly used in particles characterization were investigated. In our previous paper [1] the characterization of polydisperse sand particles was performed, and the need had arisen to examine the impact of different scanning resolutions on shape factors in more detail. The particles analyzed were the polydisperse fractions of quartz filtration sand with sieve diameters in the intervals of 0.85–1.030 mm, 1.406–1.600 mm and 2.00–2.83 mm. The particles size and shape were analyzed using the scanned image of about 150 particles in each fraction. In addition, the images of circles of similar dimensions were generated to serve as reference particles. The scanning resolutions used in this study were from 75 to 4800 dpi, and grayscale thresholds were optimized for discrimination of the particles from the background. The obtained results indicate that the resolution (i.e. the pixel size) and the algorithms used in image analysis softwares have significant influence on the obtained shape factors. The most significant effect was observed in the calculated values of the particles perimeters, while the effect was less pronounced in the results obtained for the particles projected area. The analysis of images of generated circles confirmed that the resolution had the largest effect on particle perimeter. The use of the resolutions of 300–600 dpi for the determination of particle shape and size can be recommended for particles of ~1 mm and larger, because of reasonable results, low storage space and less time for image analysis.

1. Introduction

Shape is a fundamental property of all objects, but it remains one of the most difficult to characterize and quantify for all but for the simplest of shapes. Despite a large amount of literature on the subject, there remains widespread confusion regarding the meaning and relative value of different measures of particle shapes [2].

The particle shape is an important factor that determines the behavior of particulate systems in various fields of science and engineering [3–7]. Size and shape, for example, define the geometric arrangement of particles (packing), which affects the voidage, fluid-particles interactions or physical resistance. Therefore, the size and shape characterization and analysis of particles is very important for improved development of particulate processes.

The correct characterization is particularly important when polydisperse mixtures of non-spherical particles are used, as is the case in sand filters, which are used for drinking water production. Quartz filtration sand is used as a filtration media in these devices. It is a natural material composed of particles of different shapes and sizes. To be able to adequately predict the behavior of packed and fluidized beds of non-spherical particles with wide size distribution and non-uniform shape, it is very important to determine the representative particle diameter and shape factor as well as their distributions [8].

The lack of models and correlations for prediction of mechanical and hydrodynamic behavior of irregularly shaped particles can be attributed to the variety and complexity of particle shapes [2], the difficulty of defining shape parameters suitable for modeling, and the lack of classifying techniques to characterize particle shape [9].

In order to characterize the particle shape several shape factors were introduced in the last few decades. Shape factors are mathematical functions that require previous determination of particle size, such as length, diameter, perimeter, area or volume. They are categorized in 1D, 2D and 3D shape factors [10]. 1D shape parameters are based on the particle lengths in three dimensions (flatness, elongation). 2D shape parameters are determined through image analysis of particle projections (projection perimeter, area, diameters of inscribed and circumscribed circles) [5,7,10,11]. The well-known 3D shape factor is sphericity, defined as the ratio between surface area of a sphere with the same volume as the particle and the surface area of the particle. Sphericity is a measure of the degree to which the shape of a particle approximates that of a true sphere [2,12]. In order to calculate sphericity particle volume and surface area need to be measured using a 3D laser

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scanning or scanning electron microscope [10]. X-ray microtomography seems to be a very useful technique for 3D visualization and quantitative analysis of the microstructure of particles and analysis of 3D particle size and shape, as a technique for nondestructive characterization of material microstructure at a micron level spatial resolution [13,14,15]. The available literature shows that there is no agreement on the usage of shape parameters and is not clear which parameter is the best [2,12,16].

Recent development in digital image analysis and processing indicates that image analysis is a promising methodology for particle characterization. Particle shape determination using computer assisted methods is of great help, reducing dramatically the measuring time [17]. The benefits of using computer technology are obvious: a large number of measurements can be taken in a short time, and they provide an economic, consistent and objective analytical method. Automatic image analysis consists of: image formation, image scanning, digitized particle boundary detection, digitized particle analysis by count, shape, size or other selected parameter, data processing and analysis and data presentation. Possible measurement errors may occur at any stage of this process [18]. Although image analysis yields an exact value for size and shape parameters there are still several sources of error or uncertainty in the results. The orientation of the imaged particle and the quality of the images will result in size and shape variations. However, when compared to the indirect method of sieving, where the size is only indirectly measured image analysis yields more information about each particle [19]. One of the most important parameters that should be taken into account in the process of digital particle characterization is the resolution of the analyzed image. It might appear that it would be ideal to use the highest resolution (smallest pixel size) possible in image analysis. However, higher resolution clearly results in much larger files, and the image analysis software needs to manage a large number of pixels, which greatly increases the time required. It is therefore desirable to determine the minimum resolution at which particle dimensions can be accurately determined [20,21].

This paper is concerned with the influence of different scanning resolutions and the use of different image analysis softwares on particle characterization. Particle characterization was carried out on several fractions of polydisperse quartz filtration sand particles. The particles were chosen as a continuation of our previous work [1], where different methods for particle characterization were evaluated. The evaluated methods included the ones based on pressure drop of the packed beds of particles, terminal velocity of the particles and voidage at minimal fluidization as well as 2D shape factor determination based on digital image analysis.

The aim of this paper was to determine the minimum pixel resolution of a digital image of the particle which would lead to the desired accuracy in size and shape characterization. The particle characterization in two dimensions (2D) was chosen due to the manageable and convenient methodology that can be used for image capturing and in order to avoid expensive equipment which is not widely available. Three image analysis softwares, ImageJ, SigmaScan Pro and Matlab (Image Region Analyzer) were used as images analysis tools.

2. Materials and methods

In this work three polydisperse fractions of quartz filtration sand particles were chosen and analyzed. The material was obtained from the company "Kaolin"-Valjevo and used also in our previous work [1]. The sieve diameters of the chosen fractions were in the intervals of 0.850–1.030 mm, 1.406–1.600 mm and 2.000–2.830 mm.

The basic particles characteristics are shown in Table 1, where d_R is ratio between two successive sieve sizes, $d_{s,n}$ and $d_{s,n+1}$, and d_m is the mean sieving diameter [$(d_{s,n} + d_{s,n+1})/2$].

2D image analysis can be performed using the simple equipment required to take pictures (e.g. regular camera, 2D scanner or the use of microscope for smaller particles). In our work images were captured by a 2D scanner Hp Scanjet 300 and were stored at different resolutions in TIFF format (Tagged Image File Format, uncompressed) for processing. Using a scanner in image capture eliminates problems caused by uneven illumination, different distances between objects and imaging/acquisition device. These conditions are always constant and the scale of the objects depends only of the image resolution. Hardware, optical and enhanced resolution of the 2D scanner HP Scanjet 300 were: up to 4800 × 4800 dpi, up to 4800 dpi and up to 19,200 dpi, respectively. Scanning resolutions of up to 4800 dpi were used in this work, which are equal to maximum hardware and optical resolutions. Considering the possibility of running the image analysis softwares in different computer systems and platforms, monitor resolutions, and usage of different image acquisition devices, a proper calibration is important. The scanner that was used for this study was new, and it was factory calibrated. Scanner calibration should be carried out only if offset problems with the scanned images are noticed. The monitor was also calibrated.

Table 1
Basic particles characteristics.

Particles	$d_{s,n+1}$ mm	$d_{s,n}$ mm	d_m mm	d_R	ρ_p kg/m^3
I	2.000	2.830	2.415	1.415	2638
II	1.406	1.600	1.503	1.138	2638
III	0.850	1.030	0.940	1.212	2638

Before scanning the sample particles, they were carefully distributed on a contrasting background at the distance of 3–5 mm between them, to avoid overlap and touching each other (Fig. 1). This is very important, as in the analysis of the resulting images the overlapping particles would be considered by the software as one particle. This would lead to incorrect results in size and shape factor of the particles. In 2D image analysis, the particle is assumed to lay over its most stable axis, e.g. longest and intermediate axis lie more or less parallel to the surface (e.g. scanner glass) while the shortest axis is perpendicular or random.

Due to the statistical error of measurement, better results are obtained when the number of scanned particles is large. As the width of the distribution increases, the number of particles required to ensure that the sample population will be indicative of the original sample also increases. Numerous approaches of determining the appropriate number of particles have been proposed [22].

In our work, the number of scanned particles fluctuated over 150 particles per scan, in order to reach a compromise between operating time and reliability of experimental results. The projected diameter, perimeter, circularity, roundness, etc., were determined for scanned sample of about 150 randomly selected particles (Fig. 1), using ImageJ, SigmaScan Pro and Matlab softwares [23,24,25].

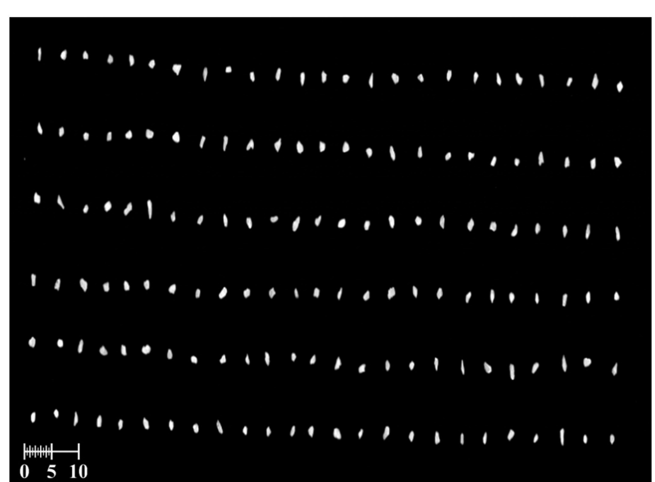

Fig. 1. An example of scanned image of irregular sand particles.