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# Dynamic image based shape analysis of hard and lignite coal particles ground by laboratory ball and gyro mills

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ABSTRACT

A new real-time 3D dynamic image analysis system was used to measure the particle shapes of different type of coal samples (lignite and hard coals) ground by different mills (ball and gyro mills). Shape factors such as circularity, ellipse aspect ratio (EAR), bounding rectangle aspect ratio (BRAR) and Feret aspect ratio (FAR) described the results. At least 6400 particles were measured for each mill product indicating the accuracy of the results achieved with 99% statistical significance. Although experiments were performed on different ranked coal samples, there is a clear difference in the particle shapes generated by the grinding methods tested. Results indicated that the ball mill ground particles had the highest aspect ratios (EAR, BRAR, and FAR) with the lowest circularity. However, the gyro mill produced particles with highest circularity along with the lowest aspect ratios. Thus ball milled particles had the highest elongated particles with the lowest rounded particles. On the other hand, gyro mill products included the highest rounded particles and the lowest elongated particles. This relative difference in shape was attributed to the difference in grinding action involved in the ball and gyro mills. Results will find applications in various coal characterization, preparation, and utilization processes.


## 1. Introduction

Coal remains as the second largest energy source worldwide next to liquid fuels derived from petroleum and other liquid products. Over 30% of the total energy demand and 40% of the electricity generated come from various forms of coal worldwide. Besides, coal is an essential input for about 70% of the world steel production. Large reserves of coal worldwide will continue to place coal as a key energy source for the foreseeable future [1]. Furthermore, prices of coal over the years were steady unlike the petroleum-based raw materials. Based on U.S. Energy Information Administration (EIA), the world coal consumption rises at an average of 1.3%/year, and the projection for 2040 consumption is 232 EJ (220 quadrillion Btu) [2]. The International Energy Agency (IEA) has also projected that coal will be intensively used in the future because of the mentioned features [3]. In general, coal is an inexpensive, abundant, accessible, widely distributed, as well as it is easy to transport, store, and use.

The advent of mechanized mining increased the proportion of fines in the run-of-mine (ROM) coal, thereby supporting and speeding the development of markets for fine-sized coal [4]. The effect of increasing demand for improved cost efficiencies, the need to meet rigorous environmental regulations, and price rise of all inputs and products in general are significant elements contributing to the current emphasis on the recovery of fine coal [5].

Due to the increasing proportion of fines in the product, froth flotation is a widely used process for fine coals below 500 μm [6]. Flotation, which is based on differences in the physico-chemical surface properties of various minerals, is achieved by the attachment of hydrophobic particles to the air bubble. In this separation process, it is well known that particle shape influences the floatability of coal particles [7–13], hence it is important to determine the various particle shape parameters for better classification and utilization of ground coal.

The size and shape of coal particles also influence their heat and mass transfer characteristics, [14,15], as well as the performance of the fluidized separator [16]. In other words, the coal particle behavior in combustion is strongly influenced by its shape [17]. Some of the general shape factors relevant to particulate material are circularity and aspect ratios, which can be derived from the basic dimensions of the particle.

Although simpler measurement of particle size and particle size distribution can be determined using the standard mechanical sieving, measurement of shapes of particles needs sophisticated techniques. Shape measurement techniques should capture individual particles features (e.g. dimensions) to derive the shape features. In mining industry, as monitoring of particle size distribution is critical in improving the productivity and product quality [18], image based techniques have been widely used. Most of the imaging techniques collect image information on a two-dimensional basis, due to simplicity, whereas the

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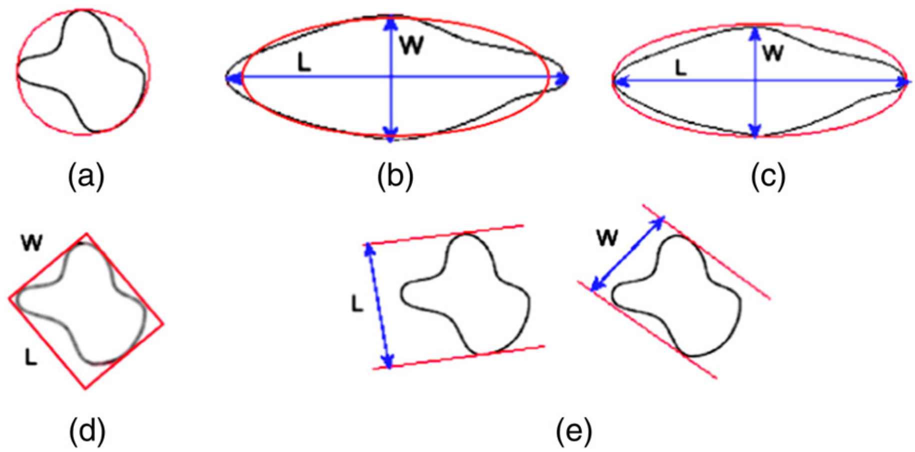


**Fig. 1.** Particle characterization models used in Micromeritics® Particle Insight Image Analyzer: (a) circle model—ECAD, (b) ellipse model—equivalent area ellipse, (c) ellipse model—bounding ellipse, (d) rectangle model, and (e) irregular model [26]. These models represent instantaneous 2D representation of the images in the 3D dynamic image analysis.

complete information requires a three-dimensional basis [19]. Thickness, usually the third dimension is lost in two-dimensional imaging techniques and is important in mass estimation in image analysis. In this study, a new real-time 3D dynamic image analysis system that captures high-resolution images of the particles suspended in a carrier liquid was used. This system uses the random orientation and particle recirculation for true 3D representation of the particle for accurate shape analysis. The 3D reconstruction of the particle was possible as the particle presents its various faces during suspension in the carrier liquid and its recirculation.

Therefore, the aim of this study is to characterize the particle shape of different types of coal particles (hard coal and lignite) ground using

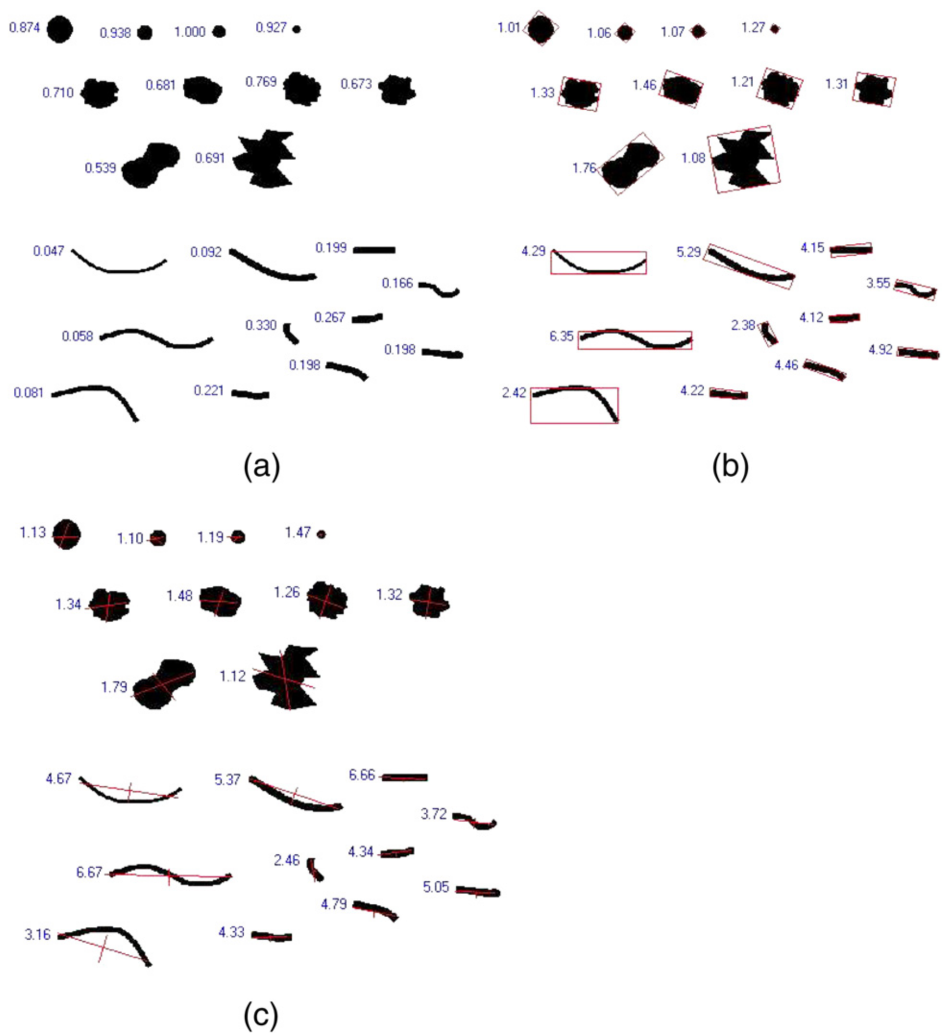


**Fig. 2.** Shape test images for (a) bounding rectangle aspect ratio (BRAR), (b) circularity, (c) Feret aspect ratio (FAR) [26].