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The use of the photogrammetric method for measurement of the repose angle of granular materials

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ABSTRACT

The paper addresses a vitally important issue of precise determination of the angle of repose of granular materials. For calculation of the said angle, a photogrammetric 3D coordinate measurement method has been proposed. With the view of method verification, 600 independent measurement results were obtained, based on which the angle of repose of examined plant granular materials (triticale) was determined with a statement of the associated measurement uncertainty. The conducted analysis has shown that the proposed method is useful and capable of low (as for biological materials) measurement uncertainty congruent with the requirements of automated systems, and as such may be helpful in laying down the standard specification for measuring of the angle of repose, using coordinate metrology.

1. Introduction

Granular materials can be viewed as raw materials consisting of solid particles exhibiting specific granulometric composition. They are in widespread use and find application in any human economic activity, i.e., food, agriculture, construction, energy, and pharmaceutics. Regardless of the application of a given granular material, it can be generally stated that during industrial processing they are subjected to the same technological processes and single operations. Table 1 shows the examples of particulate solids and the areas of their application.

The prevalence of these materials encourages many researchers to explore and catalog their physical properties in order to understand their behavior during the mentioned technological operations [1,2]. This knowledge is crucial for the design of appropriate machines and equipment, especially automated systems. The properties describing a given granular material comprise granulometric composition, shape, bulk density, porosity, mechanical features, external and internal friction, and the angle of repose.

One of the basic parameters characterizing granular materials, the key one – in author's opinion – in the design of automated discharge and transport systems, is the angle of repose. Broadly speaking, when particles are poured onto a flat surface, a conical pile is formed. The angle between the slant height and the base of a cone is known as the angle of repose. The value of the angle of repose affects the behavior of a given granular material during transport and discharge, owing to which it is perceived as a decisive factor in the design of conveyors and silos. Its value depends on friction between moving particles, which – to a large extent – is dependent on moisture, granulometric composition, shape, size, and surface texture of the particles.

The angle of repose becomes the subject of interest of numerous researchers either when a new kind of particulate matter is to be investigated or once the behavior of a given granular material has to be verified under altered conditions. Therefore, there is no universal method by which the angle of repose can be measured. The process of repose angle determination can be divided into two stages: (1) the study of how a piled cone is formed; and (2) the study of how the acquired repose angle is measured.

The basic methods of cone formation include "emptying" (Fig. 1a), "piling" (Fig. 1b), "submerging" (Fig. 1c), "pouring" (Fig. 1d) [3–12]. There are also "rotating" and "aerating" methods [13–16]. Considering that the methods slightly differ from one another, they are accompanied by various physical conditions (e.g., molecular kinetic energy), thereby producing somewhat different results.

The basic issue, therefore, is to measure the angle of repose, i.e., the one formed between the slant height and the base of a cone (Fig. 1e), and – what is hugely important – to perform measurement with utmost

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Table 1
Areas of application of granular materials.

Areas of application	Granular materials	Technological process
Pharmaceutics cosmetics	Powders	Crushing
	Reinforcing materials	
Food	Comminuted fruit	Sorting
	Vegetables	
	Flour	Mixing
	Cereal	
Agriculture	Grain seeds	Agglomerating
	Mineral fertilizers	
	Animal feed	Storing
Construction	Aggregates	
	Sand	Precise dosing
	Cement	
Energy	Coal	Transporting
	Slag	
	Comminuted biomass	

accuracy. In the majority of the quoted works, this issue seems to have been overlooked or at least insufficiently discussed. However, it belongs to key factors which need to be incorporated into the methodology in order to avoid misinterpretation of the value of the repose angle. In most cases, the quoted authors invoke optical methods inherent in image analysis carried out on the basis of a single or a set of pictures [10,13–15,17,18]. The use of a laser device for the assessment of the repose angle of landslide debris deposits may serve as another example [19]. The full methodology and algorithm for the determination of the angle of repose are provided by [3]; the method involves precise positioning of the camera relative to the pile, measured using a laser device as well as being based on the analysis the inclined plane (slant height) of the pile in order to calculate a regression line; the proposed method, however, lacks the analysis of measurement uncertainty. Still, these are all considerations relating to a two-dimensional (2D) plane.

In the authors' view, indicative determination of the angle of repose, in many studies, e.g., the ones bordering on agronomy and physics, appears to be sufficient, however, from the metrological point of view, the issue requires more attention. Moreover, the analysis of the issue

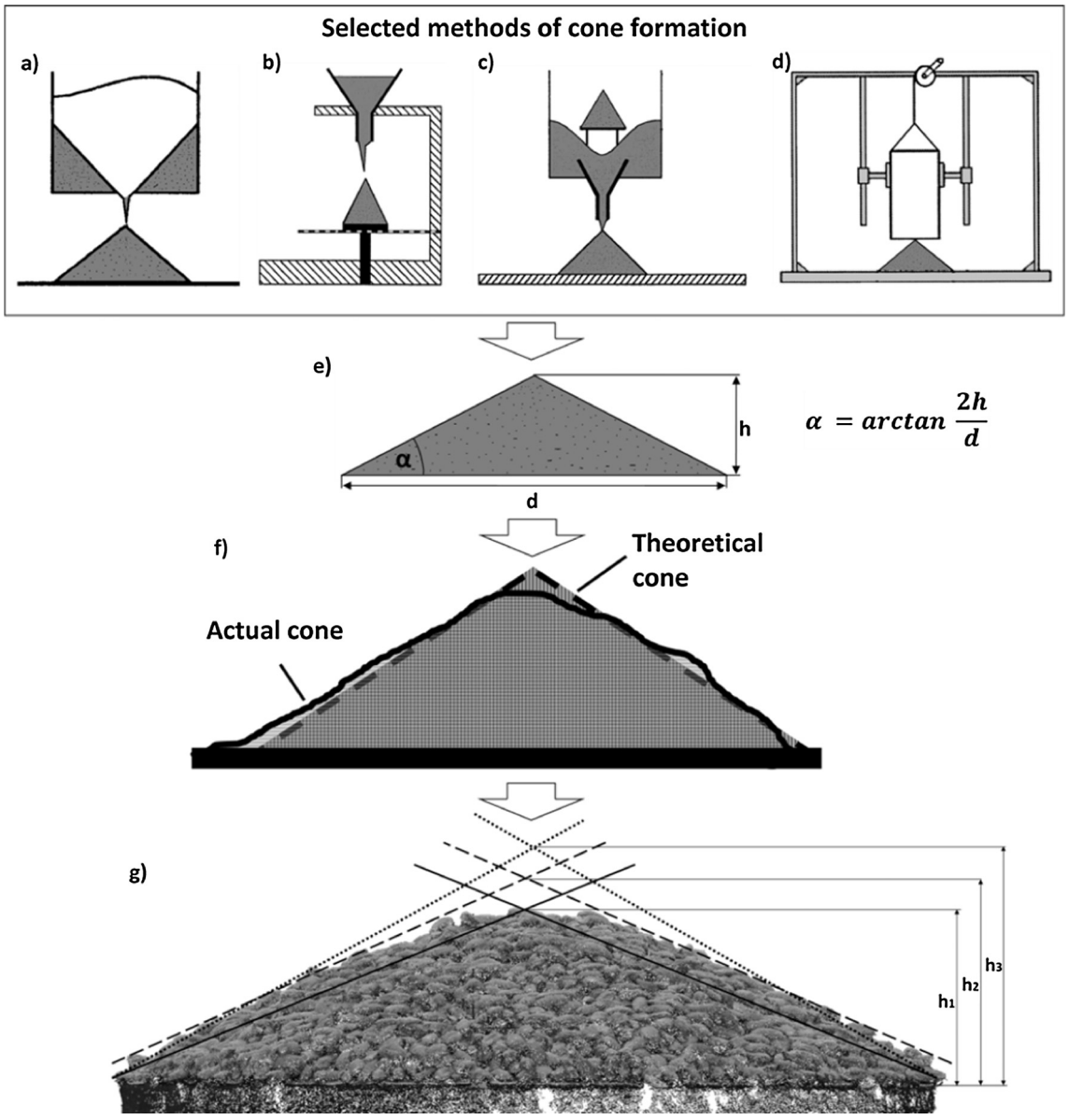

Fig. 1. Selected methods of cone formation. (a) "emptying", (b) "piling", (c) "submerging", (d) "pouring", (e) analytical determination of the angle of repose, (f) actual cone vs. theoretical cone, (g) the interpretation problems of the right edge and the height of a pile.