NEW METHOD OF MEASURING THE ANGLE OF REPOSE OF HARD WHEAT GRAIN

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ABSTRACT

In this work a new optical method of measuring the static angles of repose of hard wheat grain is presented. Conventional methods of measuring angle of repose are based on manual measurements of angle by protractor or calculation from measured diameter and height of the pile using the trigonometric equation. These methods are based on the assumption that the stacked grains form a symmetrical cone, and the left and right contact angles are equal, which is not correct as grain piles are rarely of an ideal cone shape with perfectly straight surfaces. To address the limitations of these standard methods we are introducing a new method based on the real shape of a grain pile taken by photographic image. These images taken by a digital camera were analysed to allow the calculation of the angle of repose using computer software. For this work a low cost web camera connected to the note book computer and freely available software Image J were used. Measurements of the angle of repose for several wheat grain piles using existing and the new method were performed. Our results indicate slight disagreement between these two methods showing 10° to 15° higher values for the new optical method proving it to be more accurate.

INTRODUCTION

The angle of repose (AoR) measures the angle of inclination of the free surface to the horizontal plane of a bulk solid pile. This gravity-driven physical event is one of the primary parameters of granular material that indicates the inter-particulate friction related to the particles density, size, surface area, shape and the coefficient of friction (Littlefield *et al.*, 2011). These properties are important for processes of translocation of granular material relevant to many practical applications. Hence, it is not surprising that the angle of repose was used as a quick and simple assessment to characterize the flow behaviour of granular materials on a macroscopic scale. The AoR has been specifically used in grain industry to characterize the flow behaviour of grains in order to design agricultural machines and processes including the transport, storage and mixing, of grain and is applied to drying, and milling systems (Spurling *et al.*, 2000). In case of grains stored in silos, when natural or synthetic based pesticides are applied, the change in frictional properties between the grain kernels and hence the fluidity of the grains could
make loading or unloading grains from the silos and their transport to ships difficult (Jayas et al. 1992; Kalkan et al. 2011).

Several conventional methods are used for the determination of AoR, including measuring the angle of repose of a pile stacked on a fixed bed, using a free-standing pile formed by pouring the grains through a fixed funnel, by measuring the angle at which particulate materials slide when a rectangular box containing grain is tilted and by measuring the angle formed by the materials in a revolving cylinder (Fraczek et al. 2007; Ileleji and Zhou 2008; Khazaei and Ghanbari 2010; Tabatabaeefar 2003; Karimi et al. 2009). These methods can be used to measure static or dynamic AoR, however, results using different “piling” methods are slightly different and suggest that the AoR tests can only be considered as “qualitative and relative data.” The low accuracy and inconsistency of AoR values from these methods are due to the type of method adopted and the way the grain piles were created.

The AoR of a formed pile is measured manually by protractor or calculated from measured diameter and height of the pile using a trigonometric equation (Kingsly et al., 2006; Koocheki et al., 2007). However, it is apparent that the grain piles are not ideally symmetrical or cone shaped with perfectly straight surfaces which are a prerequisite for both methods, however the actual shape of the piled grain is of convex shape (Figure 1a-b), therefore, these methods cannot provide accurate results. The scheme in Figure 1a-b illustrates an impact of these differences on measurements of angle showing significant differences in AoR and inaccuracy of conventional methods. To address this problem an alternative approach has been recently proposed to measure AoR by computer image analysis: the AoR values were computed by stitching the slope coordinates which were approximated by a line using least square method (Fraczek et al. 2007). However, even though, this method offers more accurate measurements of AoR, the method is too long, complicated and not suitable for routine practical applications.

Fig. 1: Scheme showing angle measurements for two methods on grain pile (a) conventional method (b) new proposed method. Differences in angle $\alpha_c$ and $\alpha_o$ between these methods is noticeable

The aim of this work is to present a new method for the accurate measurement of AoR in grains based on photographic image analysis. The method is based on very simple set-up which includes an inexpensive web camera for taking image of the grain pile and the image is processed by using computer software “Image J” (NIH, USA). This software is freely available with “Drop Analysis” plugin and has been extensively used for the contact angle measurement of the water droplets on various substrates (Stalder et
al. 2006; Kurkuri et al. 2008). The software contains several features which enable to perform high accuracy shape analysis from grain pile image and precise measurements of AoR including left and right side angles of the pile (Figure 1b). To validate our method, comparative measurements of AoR using conventional method and new method on selected wheat samples were performed.

MATERIALS AND METHODS

Materials
Hard wheat grains of Katana grade cropped in the year 2009 were purchased from local farmer, Gawler, South Australia, Australia. Diatomaceous earth (DE) was obtained from Mt Sylvia, Australia. The images were collected with the web camera (ProScope, USA) via the software supplied with the camera.

Angle of repose (AoR) measurements by conventional method
Static angle of repose (AoR) measurements by conventional method was determined from already formed wheat pile. Briefly, wheat samples (350 g) were poured onto an elevated plastic horizontal surface of diameter 9 cm through a funnel from a height of 6 cm distance (from end of the funnel to elevated base). The height of the formed pile was measured using a meter ruler attached to a clamp and retort stand. The meter ruler was positioned vertically against the base of the horizontal surface so as to not perturb the stacking of grain samples. The following equation was used to calculate the angle of repose of grains

\[
\text{Angle of repose} = \tan^{-1} \left( \frac{2h}{b} \right)
\]

where \( h \) is height of stacked wheat from base on the elevated horizontal surface as measured by the meter ruler, and \( b \) is the radius of the base of the horizontal surface onto which wheat was stacked.

Angle of repose (AoR) measurements by the image processing method
The same grain pile formed for conventional AoR measurements was used for comparative measurement by our new method. The set-up of this method is presented in Figure 2, which consists of a web camera (ProScope, USA) connected to a notebook computer. The photo of every grain pile sample was acquired by the camera, and the images were converted to greyscale and processed with Image J 1.45s (Wayne Rasband National Institute of Health, USA). The tool “Drop snake” from the Image J plugin Drop Analysis was used to measure AoR from grain pile images after positioning at least five points on the periphery of the grain image as shown in Figure 3.
RESULTS AND DISCUSSION

Typical photo obtained from formed wheat grain pile used for image processing and calculation of AoR is presented in Figure 3. The calculation of AoR involves several steps which includes opening image file (JPEG) using Image J software and converting it into greyscale image. The tool “Drop snake” from the Image J plugin “Drop Analysis” is used (Figure 3B) to select at least 5 points at the periphery of the grain pile and finally when prompted with the double click on the last point, the software detects the interface more precisely and forms the loop and finally displays the individual left and right contact angle or AoR (Figure 3C).

In the new proposed method, the Image J software has the capability to accurately join the roughly selected points at the periphery of the stacked grain pile in the image followed by forming a perfect loop as shown in Figure 3C, finally calculating the individual AoR (top left corner of Figure 3C). In conventional methods where assumption is made that the stacked grain is symmetrical cone shaped, the AoR is calculated by measuring the height and base of the stacked grain by using a simple trigonometric equation. As a matter of fact the stacked grain pile is never cone shaped.
Fig. 3: Optical method used to measure AoR of stacked grain showing steps during measurements. (A) the original JPEG image taken by digital camera and opened by image processing software (Image J, NIH, USA), and (B) converted to greyscale followed by selecting the “Drop snake” from the Image J plugin “Drop Analysis” with at least 5 points selected at the periphery of the image. C) Finally, the complete loop is created on the grain pile showing its real shape. Thus created tangent was used by the computer for the calculation of AoR on the left and right side which was averaged as final AoR.

but of convex shaped, the images shown in Figure 3 for example are for the untreated wheat grains, however very often the stored grains are treated with either natural or synthetic protectants hence the higher AoR are obvious, in such cases the conventional method offers more erroneous data, where as the proposed new method offers most accurate AoR.

In order to evaluate the new method, the data obtained by our proposed method were compared with the data of the conventional method, a range of different grain samples were prepared by treating a natural material (Diatomaceous Earth) at different known concentrations which is known to have significant impact on AoR. The measurements
of AoR data were performed with both the methods and the results are presented in Figure 4. The comparison of the AoR data measured by both the methods showed considerable differences. The AoR data measured by new method were consistently higher in the range of 11.7° to 15.4°, and standard deviations were in the range of 0 to 3.2° for the new method and 0 to 3.8° for conventional method. The discrepancies in both the methods is due to the entirely different approaches of measurements; in case of conventional method it is assumed that the stacked grain is compatible with right angle triangle theorem and that left and right contact angles are equal. In an ideal situation if the grain mass is a highly symmetrical cone shape, the standard method is applicable, this may be the case with untreated grain to some extent. However, as the size, shape, density, texture and composition of individual grains may vary in a sample it is unlikely that the grain mass will reproducibly form a perfectly stacked cone shape. The new method of AoR measurements by Image J software considers the curve nature of the stacked grains and measures the individual AoR (contact angle) (left and right side) separately; hence the AoR values measured by our optical based method are more accurate compared to the conventional method.

Figure 5 presents the correlation of the data set generated by both the methods. The comparative data points are in a linear fashion with minor deviation from the straight line, which is well within the standard deviation values. However, the AoR values measured by conventional method can be used as relative values for different grain samples locally, but they don’t represent the absolute values of AoR. This could cause problems in international grain market if absolute values of AoR are requested. Importantly, from scientific perspective our results clearly show that the AoR data generated by conventional method is not a true representative of AoR values.
The observed differences (10-15%), will further amplify for samples with higher value of AoR. Our proposed new method is simple, more accurate and generic and the analysis can be performed with a simple digital photo of the grain pile of any size taken anywhere including in laboratories, silos, grain field, bunkers and industries.

CONCLUSION

This study demonstrates application of a new optical method for the measurements of AoR of stacked grains and shows comparative results with conventional methods. The method is based on simple process, which combines two steps: taking photo of grain pile using inexpensive web camera, and calculation of AoR by image processing computer software (Image J). Comparative measurements of large number of grain samples showed that new method gives higher values of AoR (average 10-15%) in comparison with conventional method. This new method is more accurate as measurement is based on real shape of grain pile and it eliminates assumptions that the freely stacked grain will reproducibly form a symmetrical cone shape, which are a major cause of AoR error using conventional method.

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