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

Mahaveer D. Kurkuri, Cooper Randall, Dusan Losic*

School of Chemical Engineering,
The University of Adelaide, The University of Adelaide,
North Engineering Building, Adelaide, SA 5005, Australia

*Corresponding author email: dusan.losic@adelaide.edu.au

ABSTRACT

In this work a new optical method of measuring the static angles of repose of hard wheat grain is presented. Conventional methods of angle of repose are based on manual measurements angle by protector or calculation from measured diameter and height of the pile using the trigonometric equation. These methods are based on the assumption that the stacked grain forms isosceles triangle, and that left and right contact angles are equal, which is not correct as the grain pile is not ideally cone shape with perfectly straight slope. To address limitation of these standard methods we introduced new method based on real shape of grain pile taken by digital camera followed by calculation of angle of repose using the software. To prove this concept, a low cost web camera and commercially available software Image J connected to the notebook computer were used. Comparative measurements angle of repose on of several wheat grain samples by conventional and new method were performed. Our results indicates slight disagreement between these methods showing 10° to 15° higher values for optical method which is more accurate.

INTRODUCTION

The angle of repose (AoR) measures the angle of inclination of the free surface to the horizontal of a bulk solid pile. This gravity-driven physical event is one of the primary parameter of granular materials that indicates the inter-particulate friction related to the particles density, size, surface area, shape and 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 the macroscopic scale. The AoR has been specifically used in grain industry to characterize the flow behaviour of grains and design agricultural machineries and processes including the transport, storage, mixtures, dryers, and milling systems (Spurling et al., 2000). In case of stored grains in silo when natural or synthetic based pesticides are applied, the change in frictional properties and fluidity of the grains could make the difficulties to load/unload grains from silos, and their transport to ships and other storage facilities (Jayas et al. 1992; Kalkan et al.2011).
Several conventional methods are being used for determination of AoR, including measuring the angle of repose of a pile stacked on a fixed bed, free-standing pile formed by pouring the grains through a fixed funnel, the angle for particulate materials to slide by tilting a rectangular box, and the angle formed by materials in a revolving cylinder (Fraczek et al. 2007; Ileleji and Zhou 2008; Khazaei and Ghanbari 2010). These methods can be used to measure static or dynamic AoR, however, results using different “piling” methods are slightly different suggesting that AoR tests can only be considered as “qualitative and relative data.” Low accuracy and inconsistency of these methods are relevant to the method how the grain pile is created and which technique is used to measure the AoR. In most of the piling method for example, grains naturally flow through a funnel slowly onto a surface from a predetermined height to form the pile (Fraczek et al., 2007). The AoR of formed pile is measured manually by protector or calculated from measured diameter and height of the pile using the trigonometric equation (Kingsly et al., 2006; Koocheki et al., 2007). However, it is apparent that the grain pile is not ideally symmetrical cone shape with perfectly straight slope which are assumed to be prerequisite for both methods. Therefore, these methods cannot provide accurate results because the geometrical shape of the grain pile is more conical shape with slightly truncated top. 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 method. Differences in angle $\alpha_c$ and $\alpha_o$ between these methods is noticeable](image-url)

The aim of this work is to present a new method for 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 from the grain pile and the image processing 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 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 was 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 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 rule 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 (contact angle) of grain for all samples

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

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

Angle of repose (AoR) measurements by image processing method

The same grain pile formed for conventional AoR measurements was used for comparative measurement by new method. The set-up of this method is presented in Figure 2, which consist web camera (ProScope, USA) connected to notebook computer. The photo of every grain pile sample is 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 used to measure AoR from grain pile images after the positioning at least five points on the periphery of the image as shown in Figure 2.
RESULTS AND DISCUSSION

Typical photo obtained from formed wheat grain pile used for image processing and calculation of AoR is presented in Figure 3A. The calculation of AoR involves several steps which includes opening image file (jpeg) using Image J software and conversion 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).
Fig. 3: New optical method 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 least 5 points selected at the periphery of the image. C) Finally, complete the loop is created on the grain pile showing its real shape. This created tangent is used for computer calculation of AoR on the left and right side which was averaged as final AoR.

In the new proposed method, the Image J software has the capability to join the roughly selected points at the periphery of the stacked grain pile image accurately followed by forming a perfect loop as shown in Figure 3C, finally displaying the individual AoR (top left corner of Figure 3C). Unlike in conventional method where the assumption is made that the stacked grain is symmetrical cone shaped and measuring the height and base of the stacked grain the AoR is calculated based on using a simple trigonometric equation. As a matter of fact the stacked grain pile is never cone shaped but concave shaped, the images shown in Figure 3 are for the neat wheat grains, more often the stored grains are treated with either natural or synthetic protectants so 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 compared with conventional method a range of different grain samples were prepared by treatment of 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, where the new method showed consistently higher values of AoR. The AoR data measured by new method were consistently higher in the range of 11.7° to 15.4°, and standard deviation of 0 to 3.8° for conventional method and 0 to 3.2° for the proposed new 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 when 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 contact angle (left and right side) separately; hence the contact angle values measured by our optical based method are more accurate compared to the conventional method.

![Fig. 4: AoR values measured by both the techniques for the hard wheat grains treated with natural material at different dosages.](image)

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 a relative values for different grain samples locally, but they don’t represent the absolute values of AoR. This could cause the problems in international grain market if absolute values of AoR are requested. Importantly, from scientific perspective our results clearly showed that the AoR data generated by conventional method is not true representative of AoR values. The
Fig. 5 Correlation data of AoR values for the same hard wheat grain samples measured by new optical and conventional method both the techniques 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 showed comparative results with conventional methods. The method is based on simple and quick process, which combine two steps: taking photo of grain pile using inexpensive web camera, and calculation of AoR by image processing software (Image J). Comparative measurements of large number of grain samples showed that new methods 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 and that left and right contact angles are equal which are major cause of AoR errors using conventional method.

ACKNOWLEDGMENTS

The authors acknowledge the financial support of the Grains Research and Development Corporation (GRDC), Australian Research Council (Australian Future Fellowship FT 0770930) and the University of Adelaide.
REFERENCES


