A thorough investigation of the sawdust’s angle of repose subjected to a spectrum of stimulating vibration frequencies, using a specially developed testing device.

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Abstract. The transportation and storage of powdered bulk materials is an important part of the manufacturing process of many products and requires equally important productive resources such as time, space and capital. Accurate estimation of these materials’ mechanical properties, especially those related to the above processes, such as the angle of repose provides information necessary for the design of optimized mechanical systems that minimize production costs. In the context of the present study, a mechanical device has been developed at the Machine Design Laboratory of the School of Pedagogical & Technological Education (ASPETE) for the determination of the angle of repose of bulk materials, a dimension necessary for many calculations related to machinery, such as maximum capacity e.g. of conveyor bolts, straps and lifts. This device allows studying this property very accurately under various vibration conditions, thus giving more realistic and much more useful results. Measurements were conducted on dry and wet sawdust, a raw material of many important product, and angle-of-repose diagrams were generated with respect to stimulating vibration frequency.

1. Introduction

The widespread industrial usage of sawdust as raw material for the production of various intermediates or end products, such as wood pulp, wood clay, engineered wood etc., as well as its usage as fuel, have made it necessary to acquire detailed information on its mechanical properties, and in particular on those related to its handling, conveyance and storage [1-7]. Accurate values of these material parameters are essential to the designer engineer as well as to the production engineer to assure reliable processing of the material and to achieve maximal equipment efficiency. Among them, Angle of Repose-AOP, under both static and dynamic conditions (also called, in the latter case, Angle of Surcharge –AOS), plays a significant role in the determination of the volumetric flow-rate of conveyors [8] and of the volumetric capacity of silo containers [9] (figure 1 and 2).
A number of methods, for the measurement of either static or dynamic angle of repose, have been described at the literature, among which, most commonly referred are the fixed funnel method [10], the tilting plane method [11] and the rotating cylinder method [12]. In the existing literature, results of these methods are presented [13] where the static and dynamic angles of repose of various materials are recorded. In these results, it is assumed that each material exhibits the same dynamic angle of repose under any excitation condition. It is questionable, though, whether such an assumption can provide a realistic and credible basis for the design of conveyors in which, due to their operation, various types of vibration may occur. Under such conditions, differentiation from the expected value of the dynamic angle of repose may considerably reduce the conveyor capacity hence reducing productivity. On the other hand, imposing specific excitation frequencies could, by affecting the dynamic angle of repose, improve the material's ability to flow where necessary. The purpose of the present study is to study the dynamic angle of repose of sawdust under the influence of various excitation frequencies using a vibrating tilting plane. Since, serious transport and storage problems, have been related [14] to changes in the moisture content of wood products, two series of experiments were conducted, one with dry sawdust and one with sawdust containing a 30% moisture. The results clearly show the correlation of the dynamic angle of repose and the exciting vibration.

2. Method

The material used in the experiment was sawdust, donated by a local provider of wooden raw material for do-it-yourself projects. It was a by-product of processing a variety of woods, mainly pine and oak. Half a kilogram of this material stayed in an oven for one hour at a temperature of 100°C, with a quantity of sea salt also present. This drying process was conducted in a sequence of ten 100gr batches. In each batch, an, approximately 10mm thick, layer of sawdust was spread on a baking tray. After drying, the product was collected in an air-tight container. Static angle of repose was measured using the fixed funnel method, where the granular material is poured from a funnel at a certain height onto a flat area and the angle of the conical pile is photographically measured (figure.3) For the measurement of the dynamic angle of repose the rotating cylinder method was used, (Figure 4) where the material is placed in a cylinder (or drum) with one transparent base and, while the cylinder is rotated, the materials move and rotate within the cylinder to a maximum angle, which can be photographically measured through the transparent base.

Finally, the tilting plane method was used, where the granular material is placed on the flat surface which is gradually tilted until the material begins to slide and the tilt angle is then measured. In our case a special tilt plane device (figure 5) was constructed, able to apply a spectrum of exciting frequencies to the material. The device comprises of a ramp, made of steel, which can be tilted at an
angle by means of a lifting mechanism. The bulk material of interest is put on the ramp which is tilted and the angle is measured in the protractor. At the bottom of the ramp, an electric motor is fitted with a small rotating cam. The rotation speed of the cam, thus the exciting frequency, was set, using a single phase AC motor speed controller, the speed being measured then using a non-contact, digital, laser tachometer. The experiment’s protocol was to place the ramp on a horizontal level and put on it a quantity (200 gr) of sawdust. The ramp was then tilted to a certain angle \( \phi \) and the motor was started, its rotation speed \( n \) (RPM) being gradually raised until the material flew down of the ramp. This was repeated for a series of angles \( \phi \), and the corresponding rotation velocities \( n \), driving the material to flow from the ramp, were determined.

![Figure 5](image)

**Figure 5.** The tilt plane device. Tilting ramp (1) Lifting mechanism (2) Protractor (3) Electric motor (4) with a small rotating cam.

The whole experiment was repeated using wet sawdust. In order to obtain material of 30% w/w moisture content, the required amount of deionized water was added in the dry mass and the whole was mechanically stirred for one hour. A sample of the resulting material was weighed in a high-precision balance and, after being dried, it was weighed again and the moisture content of the original sample was determined equal to 31.2% w/w.

### 3. Results

Using the fixed funnel method, static angles of repose \( \beta_s=40^\circ \) and \( \beta_{sw}=40^\circ \), for dry and wet material respectively, were measured photographically, using an on-line “protractor”, as shown in figure 6a and 6b.

![Figure 6a](image)  **Figure 6a.** Static angle of repose on a flat plane for dry sawdust \( \beta_s=40^\circ \).

![Figure 6b](image)  **Figure 6b.** Static angle of repose on a flat plane for wet sawdust \( \beta_{sw}=40^\circ \).

Dynamic angles of repose \( \beta_d=26^\circ \) and \( \beta_{dw}=24^\circ \) for dry and wet material respectively, were also measured photographically, using the rotating cylinder method figure 7a and 7b.

![Figure 7a](image)  **Figure 7a.** Dynamic angles of repose in a rotating cylinder (drum) for dry sawdust \( \beta_d=26^\circ \).

![Figure 7b](image)  **Figure 7b.** Dynamic angles of repose in a rotating cylinder (drum) for wet sawdust \( \beta_{dw}=24^\circ \).
The tilting plane method, using the vibrating ramp, provided us with values of dynamic angles of repose $\beta_d$ and $\beta_{dw}$ for dry and wet material, versus the exciting vibration level. Results are tabulated in table 1 and graphically presented in figure 8.

Table 1. Dynamic angles of repose vs exciting frequencies for dry and wet sawdust.

| RPM  | Hz   | Degrees | RPM  | Hz   | Degrees |
|------|------|---------|------|------|---------|
| 800  | 13.33| 29      | 820  | 13.67| 29      |
| 850  | 14.17| 23      | 860  | 14.33| 23      |
| 900  | 15.00| 20      | 910  | 15.17| 20      |
| 950  | 15.83| 17      | 990  | 16.50| 17      |
| 1,000| 16.67| 16.5    | 1,050| 17.50| 16.5    |
| 1,100| 18.33| 13      | 1,100| 18.33| 13      |

Figure 8. Dynamic angles of repose vs exciting frequencies for dry and wet sawdust.

4. Conclusions

The results of the experiment showed that the dynamic angle of repose of a granular material, such as sawdust, is not constant but changes significantly when the excitation frequency changes. By increasing the exciting frequency from 13 to 18 Hz, the Dynamic Angle of Repose dropped from 29° to only 13°. Consequently, conveying capacity of machinery like e.g. belt conveyors can be reduced by 20-25%. On the other hand, by imposing frequencies around 18 Hz, the material could flow, under the influence of gravity on slopes equal to or even less than 13°. In the case of wet saw sand, no substantial modification in the materials behaviour has been observed compared to the dry material. The procedure, introduced in this work, can be used for the experimental study of other biomass products, such as wood chips and pellets, as well as other granular materials used in the chemical and food industries.

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