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Evaluating grain flow from different discharge gates of a grain seeder

Davood Kalantari

Department of Biosystems Engineering, Sari Agricultural Sciences and Natural Resources University (SANRU), Sari, Iran

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ABSTRACT

An analytical and experimental study is performed in this study to evaluate the discharge rate of grain flow from different discharge gates of a grain seeder. Three different apertures (circular, rectangular, and square with approximately the same area) are considered in the experiments. Based on the results obtained in this study, discharge rate of the circular aperture is the maximum. In contrast, the square aperture has a minimum discharge rate. It is also found that, with increasing the grain height in the tank, the discharge rate does not change significantly. Regarding the non-uniform and oscillating discharge from a square aperture, it is not recommended to be used for discharging grain materials from a reservoir, grain drills, storage tanks, or silos.

1. Introduction

Approximately 65–70 percent of carbohydrates, proteins, many vitamins of B class, mineral materials, and infrequent components of Iranians' regimes are supplied through cereals and their products (Rajabzadeh, 1996). This report indicates the importance of academic research on grain production and also grain drills. Senapati et al. (1992) compared 5 kinds of grain drills. In their research, 11 factors were considered the comparative criteria in grain drills. Their final results showed that combined drills (grain drills with seed and fertilizer tank) had the best performance for Asian-India region.

Discharge apertures and feeding devices of a grain drill usually lie in the bottom of the seed tank, as shown in Fig. 1. According to the figure, different types of apertures, e.g. rectangular, circular, or square, can be found in grain seeders based on the designer's and manufacturer's decisions. In order to prevent arching in front of the hole due to the internal friction between seeds, a mixer is usually installed inside the seed tank. Installation of the mixer inside the tank reduces the bulk density of grains and increases the flow ability (Enstad, 1981). Continuous and uniform discharge of seed mass through the hole is a necessary condition for consistent seed distribution. However, due to the differences between the forms, size, and weight of grains (among types of seeds and between their varieties), the discharging process in grain drills has become a complex issue.

The grain discharge from a reservoir may experience three regimes: continuous flow, intermittent flow, and discharge blockage due to arching (Aguirre et al., 2014; Mankoc et al., 2007; Boehrnsen et al., 2004). In the continuous flow regime, it is supposed that the mass flow rate (the discharged mass per unit time) can be estimated using the so-called Beverloo's law as (Aguirre et al., 2014; Beverloo et al., 1961):

$$W = C_{\rho_a}\sqrt{g}\left(D_0 - kd_p\right)^{5/2} \tag{1}$$

where W is the average discharge rate of mass through the orifice (aperture), C is the discharge coefficient, k is the shape coefficient, ρ_a is the apparent bulk density, D_0 is the diameter of the opening, d_p is the mean particle diameter, and g is the acceleration of gravity.

Another interesting semi-empirical expression for the mass flow rate (W) of gravitational discharge of granular solids through a horizontal aperture was given by Harmens (1963):

$$W = \rho_a A\sqrt{gD_0}\left\{0.505 - 0.160f - \frac{0.38\left(\frac{d_p}{D_0}\right)^{1.5}}{0.045 + \left(\frac{d_p}{D_0}\right)^{0.5}}\right\}F(f,\phi) \tag{2}$$

where function F is defined as:

E-mail address: d.kalantari@sanru.ac.ir.

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1881-8366/

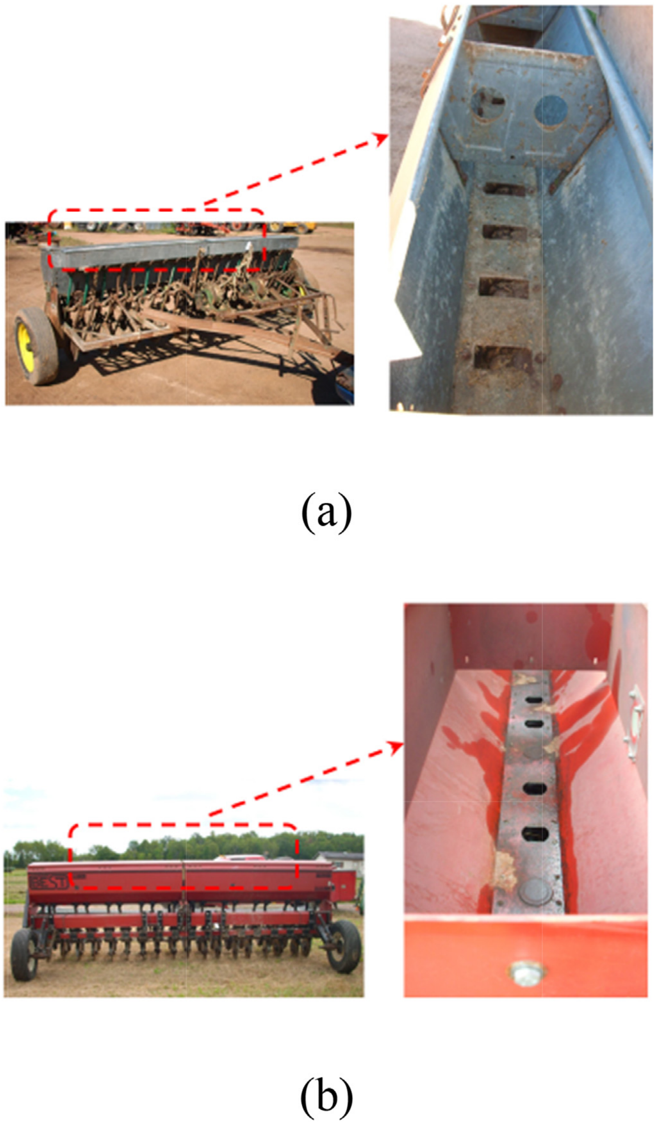

Fig. 1. Discharge aperture of grain drills: a) Rectangular aperture, and b) Circular aperture.

$$F(f,\phi)=\begin{cases}(f\tan(\phi/2)^{-0.35}, & \tan\left(\dfrac{\phi}{2}\right)<1\\[2ex] 1, & \tan\left(\dfrac{\phi}{2}\right)\geq 1\end{cases} \tag{3}$$

In the above-given expressions, ϕ stands for the hopper bottom angle (see Fig. 2), A stands for the aperture area ($A=\pi D_0^2/4$) and f stands for the friction factor defined by $f = tan\alpha$, where α is the static angle of repose.

Regarding the increasing importance of mechanization of grain farming in the recent years, it is necessary to measure and control the discharge rate of seeds and granular pesticides from grain seeders or granular material distributers. Therefore, an analytical study complemented with an experimental measurement is presented in this study for the evaluation of discharge rate of wheat grain from different apertures. Three different apertures (circular, rectangular, and square with the same area) are considered in this study and their discharge rate is compared with each other using the theoretical derivations and experimental measurements.

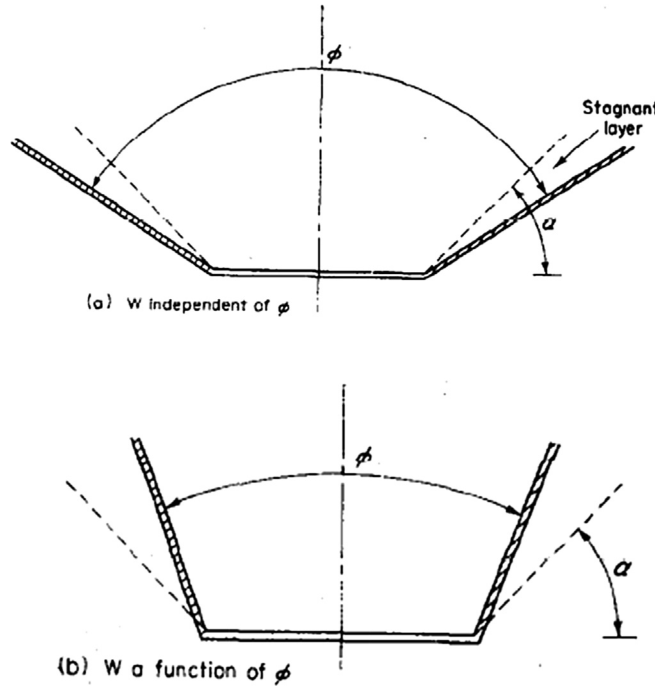

Fig. 2. Two possible situations at the bottom of the hopper (Harmens, 1963).

2. Materials and methods

Physical and frictional characteristics of Alvand wheat cultivar used in the present experiments at 12% moisture content are listed in Table 1 (Razavi and Akbari, 2006).

For measuring grain discharge, a cylindrical tank with the diameter of 35 cm and a conical bottom with the half-angle of 45° were constructed from galvanized iron as a model of a grain drill tank (Fig. 3). The end of the conical part was built with three different interchangeable apertures: circular (d ≈ 6 cm), square (a = 5.4 cm), and rectangular (a × b = 6.8 × 4.3 cm^2) gates with approximately the same cross-sectional area of 29 cm^2 (see Fig. 3). For each measurement, wheat was filled inside the tank with height ranging from 35 cm to 130 cm with seven 15 cm height intervals. Discharge rate of each gate was measured by collecting the discharged grains in another container. Mass and volume discharge rates were then calculated after measuring the weight and volume of the collected grains inside the container and taking into account the time of discharge using the expressions W = M/Δt and Q = V/Δt, respectively. Using this method, outlet discharge (W or Q) and discharge coefficient (σ) were calculated for each height. SAS 9.1 software was used for the statistical analysis. Mean comparisons were performed by Duncan's multiple range test.

3. Theoretical analysis

According to Fig. 4, seed mass is located in a cylindrical hopper with the circular hole of d in diameter located at its bottom. Seeds flow out with the diameter of d_1 smaller than the aperture diameter ($d_1 < d$); thus, the active bulk of the seeds passing through the circular aperture is equal to the ABDC (see Fig. 4), while the rest of the seeds is stagnated in ABEF and CDGH areas. Slope angle of falling surfaces near the aperture (discharge repose angle) is defined by α; $\alpha = 45° - \delta/2$ (δ being the internal friction angle of seeds). The value of δ was given by Bernacki et al. (1976) in the