Design and Optimization of the Vertical Plate Metering Device for Alfalfa Seeds Precision Based on Engineering Discrete Element Method (EDEM)

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Abstract
The vertical plate seed metering device enhancement and constraints mass flow rate when added to the device improve mass flow performance of alfalfa vertical plate device. Alfalfa forage crop is a potential feeding nutrient and the backbone of dairy production success in China. Engineering discrete element method EDEM was adopted for simulation computing and analysis of the seed-filling performance of the vertical plate metering device with three cell shapes under desired rotational speeds. The results showed significant differences at $P< 0.05$ of seed filing performance in relation to the rotational speed and cell shapes. Triangular cell shape had indicated the lower mass flow at $8x10^{-5}$ kg/s compared to the V-shape of $12x10^{-4}$ kg/s and U-shape of $8x10^{-3}$ kg/s, 20 to 30% reduction, respectively. The rotational velocity of the vertical plate exceeded 30rpm the cell units reach the optimum seed filling efficiency resulted in 30% decrease of the mass flow rate, the results indicated more seeds disturbance, reduces seed filling by enhancing seeds accessibility and falling, from cells. Furthermore, the T-shape had a lower seed filling and higher seeds releasing in comparison to the V-shape and U-shape cells. The lower seed filling found to be the higher filling efficiency while the higher seed filling leads to the lower filling efficiency.
Keywords: Alfalfa seed model, cell, filling performance, mass flow, simulation EDEM

1. Introduction

Alfalfa forage gained its nutrient leverage as the potential feeding material for the dairy industrial progress. Alfalfa seeds are small, with irregular shapes. These morphological properties result into higher seeding rate than the desired rate, therefore improving seeding rate has been the focus on the recent studies on alfalfa seeds precision and metering device(Liu Qi and ho Chnu 2016). A number of innovative studies have been carried out on cell wheel seeding device; the findings were significantly focused on the hole shape and the size to fit the seed particles as to satisfy the objective filling performance (Pasha et al. 2016).

The cell vertical plate metering device has been widely introduced for the sowing of different seeds. Hence, the feature of the cell vertical plate device has constraints requirement for the shape and size of the seed particles, as well seed sensitivity to the material surfaces, seed filling efficiency which greatly influenced by the operation speeds (Yuan et al. 2016; Han et al. 2018).

Alfalfas as potential feeding forage; widely grown for various purposes, due to seed sizes, easy damage and to overcome changes of achieving the advisable seeding precision. To resolve the formed of high damage and achieving required mass flow efficiency of metering device, the EDEM simulation was adopted for computing and analysis of seed filling performance of vertical plate cell under rotational velocities, cell shapes and seed quantity within the seed chamber; the metering structure provides a constructive mechanical system for alfalfa seed handling and seeding patter. In order to reach less seed damage and quality of seed mass flow rate (kg/s), figure out the seeding rate and providing a base for the sensible parameter.

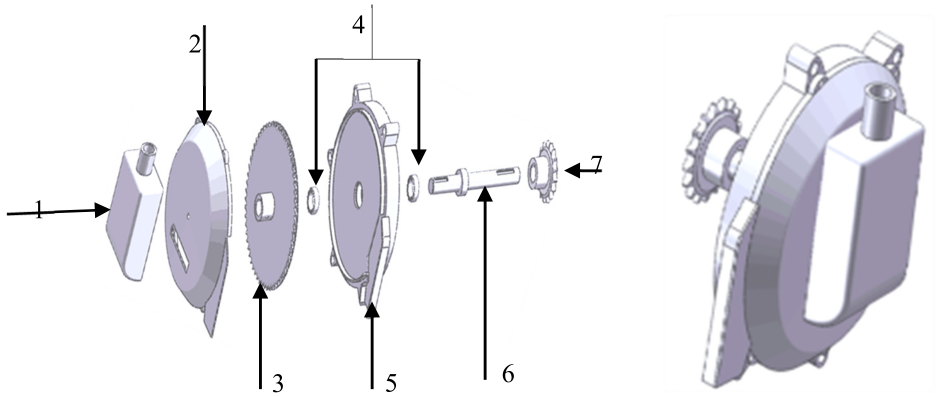


Figure 1: Vertical plate metering device, (1. Seed hopper, 2. Seed chamber, 3. Vertical plate metering device, 4. Bearing ring, 5. Main meter frame, 6. Driving shaft, 7. Governing gear

Discrete element methods are the most credible computational achievement on utilizing analysis of 3D model created by CAD, CAE, CAT applications and validates the feasibility feature, by simulating the actual operation and collecting videos and images for the situation to be adopted for performance index as such as, seeding-filling, hole features, seed group disturbance, particle shapes and flowchart (Jiajie, et al., 2013; Ma, Li, and Xu 2015;Lei, Liao, and Liao 2016).

The performance analysis of the metering device conventionally for decades carried on cost, labor, and material resources comparison. The computational revolutions software application EDEM has been greatly introduced in the simulation solutions addressing matters(Paulick, Morgeneyer, and Kwade 2015) (Rosentrater 2016).

Numerical simulation software's have been adopted to drill in the various processing of granular technology as such as separation to straw in the combined harvester, flow process of seed crop, and grain dryer progresses(Patwa 2014).

In order to reach a mass flow efficiency of alfalfa seeding patterns. The current study aimed at determining the mass flow performance of alfalfa seeding pattern. In order to achieve this objective the study seeks to; (i) to determine rotating vertical plate cell velocity, (ii) to investigate the adequate cell shape alfalfa precision seeding, (iii) To evaluate sufficient seed height in the seed chamber to meet with low alfalfa seeding rate. Alfalfa contact model was created by engineering discrete element method. However, the theories to analyze packages were set, the normal and tangential forces from the influence contact between the particles, seeds disturbance.

The impact of rotational speeds of the vertical plate, cell shapes; seed height and its reflections on seed filling, average particle speeds, and mass flow rate with respect to the time interval. The simulation results were verified to obtain the discrete feasibility analysis method. The analysis on seed filling performance of vertical plate device by EDEM cuts down the cost, time and guaranteed key references for the seeding improvement of the alfalfa crop.

2. Engineering discrete element method theories

2.1 Establishment of simulation parameters

The study selected granular-pulverized alfalfa seeds as a study subject. 3D model exported to EDEM 2.7 software, the required parameters were defined in the mechanism module: the model was set as it was chosen the units, tools, options (velocity to m/s, length to mm), the model title and description were entered, and the gravity was set to -9.80 m /s-2 in the z-direction. The materials; set the name, Poisson's ratio, shear modulus, and density and interactions were introduced.

The contact model was set for a particle to geometry from interaction pull-down was set and a geometry defined for creating loading plane. The simulation was run for a couple of time repeatedly at a velocity of 10, 30 and 50rpm for each meter type to determine the design faults and necessary restructuring was made to meet the optimum seeding rate.

2.2 Particles and contact model

The base of the actual shape of alfalfa seed particles, varied and irregular the particle size, as far to permit the target particle performance requirements, the particle shape was set to ellipsoidal in the simulation process, as displayed in figure1. The particles consist of five sphere models built directly in EDEM software.

In the EDEM analysis method, the model was considered two phases divided into soft and hard particle contacts, the contact force obtained as an impact of overlapping and displacement by considering the effects of multiple particles, which the contact force influenced seed disturbance, and no surface adhesion on alfalfa seeds, soft particle model was adopted as the Hertz-Mindlin (Paulick, et al., 2015).

A simplified model as the damped oscillation of spring oscillator with couplers and slides presented in the differential formula (1):

$$m_d.\frac{dx}{dt} + \mu_{cd}.\frac{dx}{dt} + \mu e = 0 \quad (1)$$

Where: m_d mass of model particles, x is the displacement deviated from equilibrium post friction, μ_{cd} is contact damping coefficient and μe is elastic coefficient of spring.

3. Simulation analysis

3.1 Contact force analysis

The contact force is divided into the normal and tangential force, in which normal force consists of consists 3D semi-spherical particle, based on the Hertz-Mindlin elastic theory the normal and tangential forces are displayed in the following equation(Rojek et al. 2015):

$$F_n = (-M_n a^{1.5} - \mu_{nd}.v_{rs(h-g)}.\overline{N})\overline{N} \quad (2)$$

$$F_t = -M_t\delta - \mu_{td}v_s \quad (3)$$

Where: M_n is the modulus of normal elasticity, M_t is the modulus of tangential elasticity, μ_{nd} is the normal damping coefficient, μ_{td} is the tangential damping coefficient, a normal overlap, $v_{rs(ai-bi)}$ is the relative speed of particles (h, g), v_s is the sliding speed of the contact point, δ is the tangential displacement, $\overline{N}$ is the normal vector of the contact surface between particle i and j. as the expressed equation is tenable

$$|F_t| \geq \mu|F_n| \quad (4)$$

Therefore, the relative sliding can be calculated between i and j particles as follows:

$$F_t = -\mu_s\ |F_n|.n_t \quad (5)$$

Where: μs is the static friction factor which obtained from the physical properties of alfalfa seeds, is the tangential unit vector (Eq. 5), the internal friction force defined as taa ngential force in the model, and determined by seed disturbance factor and normal force.

The relative movement of the alfalfa particles resulted from the internal friction which seems to be greater at higher seed bulk, weaker the seed movement at the center which is not conducive to the seed filling of the metering device. However, the relative movement trend created light seeds bulk at trend edges, facilitate the relative movement among seeds and improves the seed filling efficiency as well releasing of the access seeds(Rosentrater 2016).

3.2 Simulation variables

In this study, a fundamental aspect of the simulation is to investigate the rotating velocities, cell shapes and seed height within the chamber and their influence on alfalfa seed amass flow rate. The results obtained from simulation are illustrated in form of the cell filling performance and seed discharge capability in which cell shapes have a greater influence on the mass flow, so not control the discharge outlet and material falling. Therefore, the cell filling and Fr and the average filling can be calculated applying to following equation (Lai et al. 2018):

$$Q_{r=}\left(\frac{VcN\omega}{60x10^6}\right) \quad (6)$$

Where: Q_r is the mass flow, V_c is the average seed number cell and N is the number of cell in pate sphere N= 60

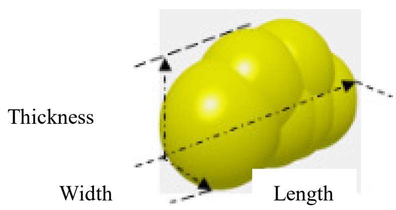


Figure2. Alfalfa seed model established in EDEM

Table 1: mean value of the physical properties of alfalfa seed

Parameters	Mean
Mean value (mm)	2.38±0.26
Width (mm)	1.4±0.16
Thickness (mm)	0.96±0.12
Particle size (mm)	1.58
Sphericity	0.62
Sphericity aspect ratio (*l/w)*	1.70
Length to thickness ratio (*l/t)*	2.48
Ratio (*w/t)*	1.46
Moisture content (%),d.b	0.798
True density (kg/m^3)	1231
Bulk density (kg/m^3)	976

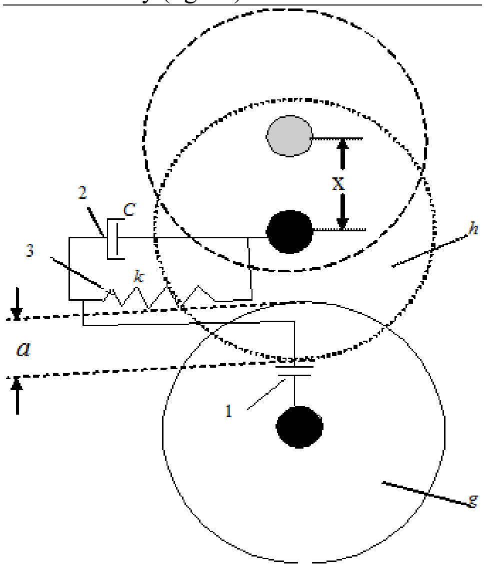


Figure 4: Scheme soft model of the contact force between spherical particles

Where: β: cell angle of release of the vertical plate plane, µis the static coefficient of friction of alfalfa seed which is 31°. The forward movement of the machine is assumed constant at different rotating speed for uniformity, therefore seed displacement can be calculated by the given speeds of machine applying formula:

$$X_s = \frac{m.v}{Q} \quad (7)$$

Where: *Xs* is the displacement of the machine, m is the overall quality of the material, Q is the mass flow rate of discharge, v is the machine speed

4. Simulation results and discussion

4.1 Influence of rotating vertical plate velocity on cells filling

Figure 5, presents the various trends of the average seed filling values with respect to the rotational velocity of the vertical plate of various cell shapes at different rotating velocities of 10, 30 and 50rpm. The (Fig. 4) indicates the seed filling average particles number per cell unit at each rotation velocity and the trends decrease as the rotating velocity of the vertical plate approaches minimum seed filling at 50rpm. The u-shape had the highest seed filling is approximately equivalent to 30% more seeds per unit cell in comparison to the triangle and v-shape cells.

Figure 2, and 3, displays the metering device structure, from the structure perspective the seed chamber, the angled flow is larger enough than the repose angle alfalfa seeds (Eq.7), allows free particle sliding on contact surface, at lower surface friction and maintaining seed particles to accumulate by the vertical plate side bottom edge, as the plate rotating the normal force moves c the seed bulk towards rotating cycle, the seed surface create an inclined trend, which seed bulk to flow back to the point where cells filling occurred (Fig. 8) shows the filling and discharge phases.

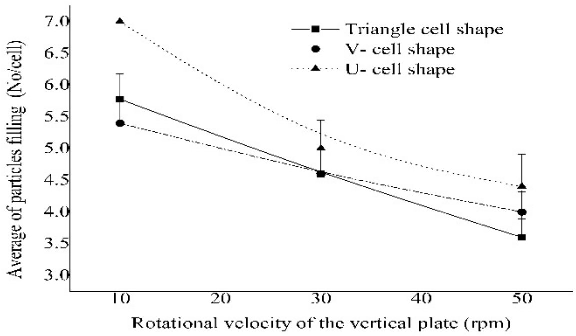
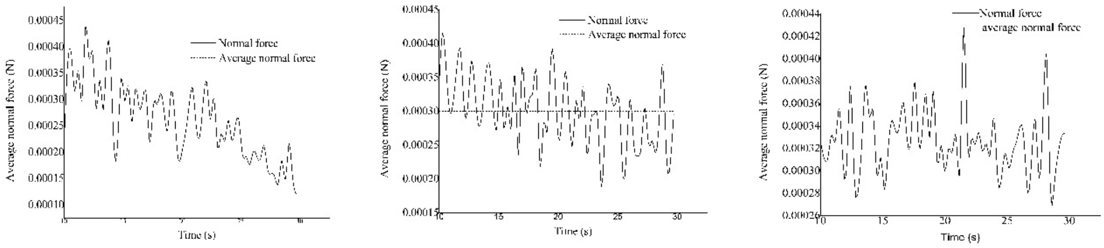


Figure 4: Average seed particles filling at a different rotating velocity of the vertical plates

4.2 Influence of rotating velocity the vertical plate on normal force and particles velocities

The average normal force of the contact between the alfalfa seed particles Figures 1 and figure 6, the average velocity of seed particles within the chamber range from 0.01s to 0.0.10s based on the rotating velocities of the vertical plate, (Fig 5). The average normal force frequency found to be irregularly with time under various rotational velocities of the vertical plate, the frequencies increases as the rotating velocity of the vertical plate increases, as well average normal force decreases when the number of seed particles within the seed chamber range from $45x10^{-5}$ N to $15x10^{-5}$N for different rotational velocities of the vertical plate. The average normal force increases significantly with a difference of with an average value of (0.0003N). (Fig.3) illustrates on alfalfa particles velocities increase as the rotating velocity of the vertical plat increases which causes seed group disturbance and seed-filling pattern, observing that higher rotational velocity the higher particle disturbance resulted in fewer seed particles accommodation cell units. Figure



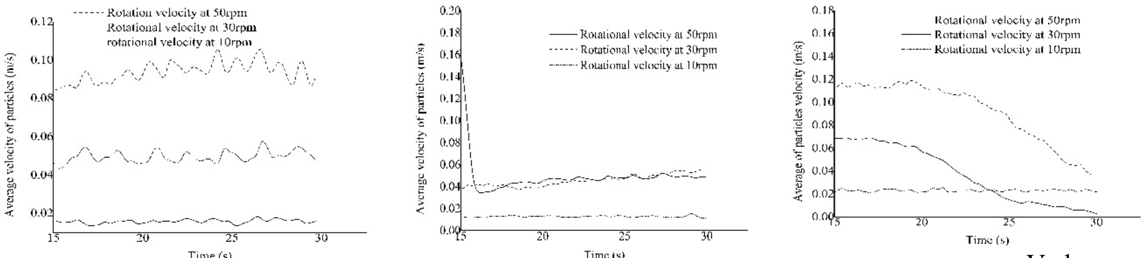
a- 50rpm b- 30rpm C= 10rpm

Figure 4: Trends of the normal force and time with respect to rotational velocities of the vertical plate

4.3 Influence of rotating velocity of the vertical plate on the mass flow rate

The loading particles area is known as an area in which the particles overlap and movement trajectory of seed in the loading area of the metering device. Less seed filling area shows higher loading efficiency and the opposite higher seed loading less efficiency, as well as the rotational velocity has an advantage influences on releasing the access seed during the rotating cycle (Fig 7)

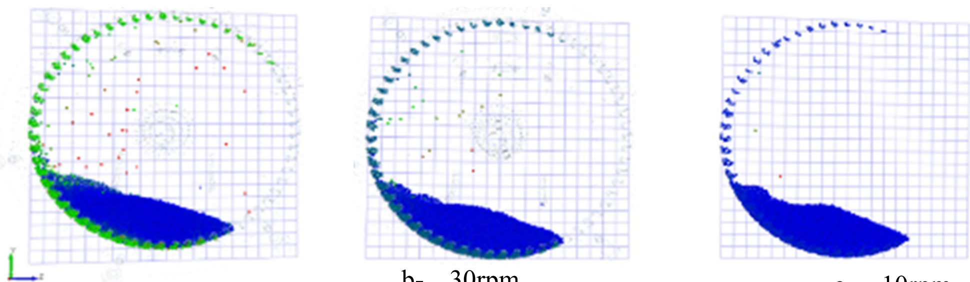
The lower and the higher rotational velocity indicate the amount of the particles released from the cell units. The rotational velocity of 50rpm shows the highest seed particles release from the cell as the vertical plate rotates, due to the initial loading time is shortening. Figure 8 indicates the displacement of the particle (mm), it is shown that larger particles displacement occurred at higher rotational velocity of the vertical plate, the particle displacements range from 250mm to 300mm, 100mm to 200mm and 100 less for the rotating velocity at 50, 30 and 10rpm, which explained the number of seeds accommodated in each cell unit. However, it has been observed that the normal force magnitudes have great influence by the availability of seed particles within the seed chamber, as it decreases with the time as a result of particles reduction based on the rotational velocity.



a- T-shape b- U-shape c- V-shape

Figure 6: Average particle velocities under influence of various rotating speed of vertical plate with respect to

the cell type



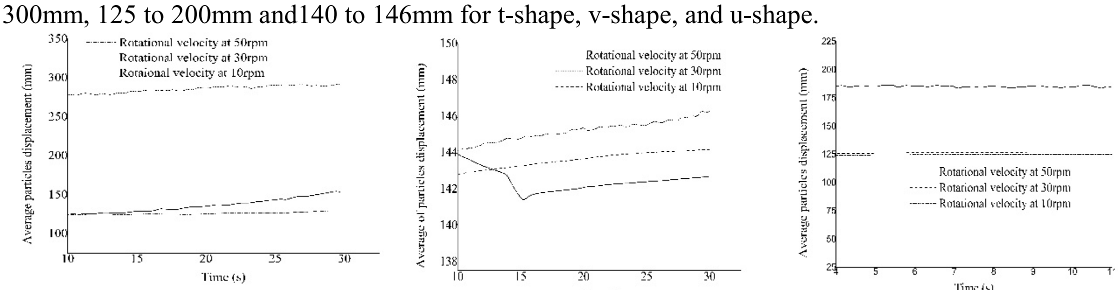
a- 50rpm   b- 30rpm   c- 10rpm

Figure 7: Particles filling, releasing and discharge process at different rotational velocities of the vertical plate

4.4 Influence of rotating velocity of the vertical plate on particles displacement

Figure 8, presents the particles displacement distance of the vertical plate types at different rotational velocities, comparing the distance trends, indicates an increase with the time, that illustrates the influence of rotation velocity, cell shape and the amount of seed in the seed chamber.

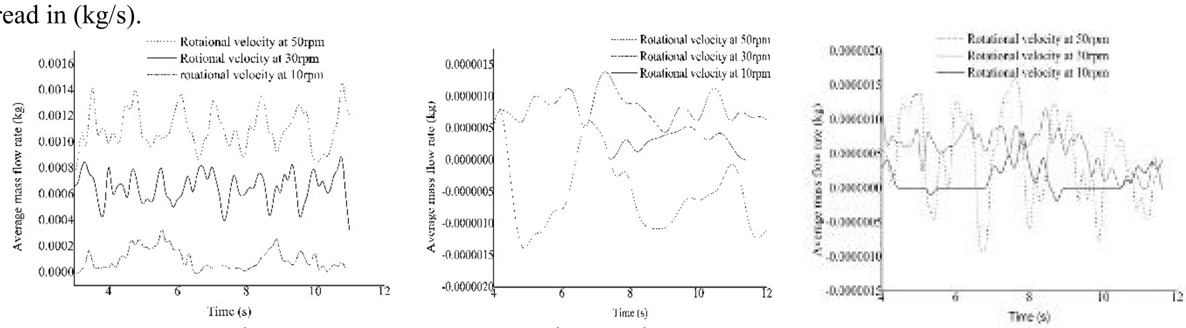
For the cell type of the u-shape shows the lower distance obtained compared to the t-shape, and the v-shape at different rotating velocities, t-shape had the largest distance values. The average values ranged from 125 to 300mm, 125 to 200mm and140 to 146mm for t-shape, v-shape, and u-shape.



a- T-shape   b- U-shape   c- V-shape

Figure 8. Particles displacement process at different rotational velocities of the vertical plate with respect to the cell shapes

The displacement trends explained the number of the particles per cell unit and releasing the frequency of the particles. From the trends results, it is observed that the t-shape and v-shape have the lowest accommodated particles in the cell and the releasing uniformity trend frequency of the mass flow rate (Fig 9), the mass flow rates are the fallen seed particles through releasing guide of the metering cell unit and passes by the mass flow sensor read in (kg/s).



a- T-shape   b- U-shape   c- V-shape

Figure 9: Particles mass flow rate under different rotational velocities of the vertical plate with respect to the cell

The sensor shows the falling frequency of the seed particles, from the observation the mass flow rates, of the t-shape, had shown better trend frequency, which illustrates the flow uniformity of the released particles compared to the v-shape and the u-shape.

5. Conclusion

This study aimed at determining a simulation of alfalfa seed flow and the contact model of particles at suggested rotating velocity of the vertical plate metering device with three different cell shapes to overpass friction force between the seeds and create smooth seed disturbance.

The designed alfalfa seed physical model would enhance the proportional seeds motion and optimize the seed filling efficiency when simulated the results indicated a higher rotational velocity of the vertical plate resulted in more seeds disturbance, reduces seed filling by enhancing seeds accessibility and fall from cells.

When considering the cell shapes, the results show that cell shape was filled in the initial placement of the filling zone, and the filling efficiency based on the accumulated mass (Kg) per unit cell. Furthermore, the T-shape had a lower seed filling and higher seeds releasing in comparison to the V-shape and U-shape cells. The lower seed filling found to be the higher filling efficiency while the higher seed filling leads to the lower filling efficiency.

The filling efficiency was significantly influenced by the rotational velocities of the vertical plate and the cell shapes. As the rotational velocity of the vertical plate exceeded 10rpm the cell unit reach the optimum which leads to less seed loading of 0.30 reduction percentages of the mass flow, therefore when the mass flow rate of the seed metering device is optimized, seed filling can be upgraded as well the cell filling efficiency alongside working velocity of the seeding machine

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