Mixing Power Consumption for Hulled Millet in an Agitated Drum Dryer with Discrete Element Method

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Abstract*— There are several technologies in the agricultural, food, chemical and pharmaceutical industries for mixing granular materials. In these processes the homogenization of the particle fractions or the prevention of arch building process play very important roles. To select appropriate mixers' motors installed in certain devices, it is necessary to specify the rotational speed of the mixer and the power requirement of the propulsion engine. This selection is a difficult task nowadays for mechanical engineers without measurement or an appropriate method for the estimation of power requirement. In researches available in the literature, the determination of the mixing power requirement is solely analytical and only for devices of universal design and geometry, in the case of mixing of certain substances. The main purpose of this research is to improve a simulation model for determining the power requirement of an agitated drum dryer, which can be generally used for modeling the mixing process of granular materials with various moisture content. In this study, laboratory measurements were made by mixing hulled millet and the results were approximated by the simulations based on discrete element method (DEM). In order to give an exact estimation of the power requirement of a given mixer, accurate geometry of the drum dryer and the appropriate micromechanical and physical parameters of the discrete particle assembly are required. In laboratory tests, the mixing power requirements of the agitated drum dryer were measured at various rotational speeds (0.48 ÷ 1.58 rev/s) using hulled millet with different moisture contents on wet basis (9.6 ÷ 29.5%) with different drum loading factors (5 ÷ 25%). Based on results it can be stated that the mixing power requirement is greatly influenced by the moisture content of the granular material and the rotational speed of the agitator. The preliminary DEM simulations and parameter sensitivity studies revealed which micromechanical parameters of the contact model should be changed in order to simulate the power requirements with good approximation.

Keywords- hulled millet; agitated drum dryer; moisture content; mixing; discrete element method

I. INTRODUCTION

In the agricultural, food, chemical and pharmaceutical industries the mixing of granular materials is often encountered, and it can be carried out in e.g., agitated drum dryers and basic material homogenizer rotary drums. In order to achieve the appropriate drying speed, and in the case of homogenization, to select the time of operation to achieve a uniform particle distribution, it is necessary to strive for the proper setting of the mixer's rotational speed. However, mixing may result in deterioration, breakage, or fragmentation of the grains, which should also be taken into account when choosing mixer design and operating parameters, including the speed of rotation. The measuring equipment required for the laboratory tests of the mixing process is costly and the measurements carried out on them are time consuming and labor intensive, so the simulation of mixing is becoming increasingly important today. To describe the mixing of the set, the mechanical properties of the materials used in the operation and the geometric parameters of the granules and the mixing apparatus are also required.

Bridgwater [1] collected the mixer geometries used to mix powders and granular materials and the phenomena occurring during operations and the researches which describe them. As a result, he found that studies of easily bulking materials without internal cohesion and hard-to-bulk materials with internal cohesion require further research. In an experiment with a horizontal shaft drum dryer, the migration of the particles was investigated between regions of the blades [1]. Between the volumes of the paddle-suspension elements, it was observed the amount of tracer-bound particles passed through the volume bounded by the other two paddle suspension elements. It was considered an event when a particle with a tracer passed through another volume. During the investigations, movements within the grain aggregation were high-lighted, but the internal displacements of the different humidity and cohesion sets have not been studied. Furthermore, the power required for mixing was not analyzed, but rather the quality of mixing was in focus.

Alchikh-Sulaiman et al. [2] analyzed the mixing of mono-disperse, bidisperse, tridisperse, and polydisperse granules in a drum dryer using discrete element method, which simulation results were compared with laboratory measurements. With the validated calculation model, the effects of drum rotation speed, grain size and initial filling rate on mixing quality were investigated. The Hertz-Mindlin contact model was used in the simulations, but the modeling of cohesive granular assemblies and the effect of the grain size were not dealt with.

Researches found in the literature have shown that a more precise description of mixing in the drum dryers requires further research and a small number of researchers have studied the effect of moisture content of agricultural granular

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materials on mixing power consumption. Thus, the aim of this research was to create a DEM model that is suitable for simulating the measured mixing power requirement results achieved with a laboratory agitate.

II. MATERIAL AND METHODS

Before the measurements were started, the test material has been prepared. The grains were cleansed from the dust, broken particles, and other contaminants and to achieve the desired moisture content they were pre-moistened.

A. Material

During the measurements, the hulled millet (Figure 1) was used. It is an appropriate agricultural material for measurements, because it has low granule size deviation, hydrophilic, properly homogeneous material structure with close to regular spherical geometry, wettable multiple times and relatively inexpensive.

Figure 1. Hulled millet

First the material was cleaned with a wind-separating device and an assembly of nearly the same particle size distribution was created. A rotating drum uniquely prepared for homogenous wet-ting of the material was used. Approximately 12 dm^3 of millet and the desired volume of water was loaded in the drum and agitated for 5 hours at predetermined intervals. To determine the resulting moisture content, a small sample was placed in a drying oven at 105 °C for 24 hours and the initial and final mass of the material was weighed. The geometric dimensions of the hulled millet were determined by sieve analysis. Based on measurements, it could be stated that the characteristic size of hulled millet (equivalent to regular sphere diameter) was ~ 1.8 mm.

B. Laboratory equipment and measurement method

The measurements of the mixing power consumption were performed on a horizontal axial agitated drum dryer. The electric power input by the mixing motor was measured with a special three phase Datcon PQRM5100-31 type meter at 1 s sampling intervals and recorded on a computer.

The intermittently operated agitated drum dryer consists of a 756 mm long, 250 mm wide and 275 mm U-shaped drum shown in Figure 2, which is covered by a flat plate. On the axis of the drum shaft, there are 22 mixing blades, each 20 mm high, 50 mm wide, and the horizontal angle of the plates is 10 degrees. The speed of the mixer can be adjusted in a wide range (0÷95 1/min) with a frequency inverter. The measurement started by filling the pre-moistened granular material into the drum. The volume of the drum is 47.4 dm3. After loading the material, the device was covered with a flat plate and then the engine was started at a given speed while the electrical power input was measured. At a given filling rate, with the given moisture content, the mixing speeds during the measurements were as follows: 0:48; 0.63; 0.79; 0.95; 1:11; 1:27; 1:43; 1.58 rev/s. Approximately the mixer was operated for one minute at a given speed, then it was turned to a higher speed, so all the cases were measured. The mixing power was recorded by the performance transmitter, from which the idle power was deducted.

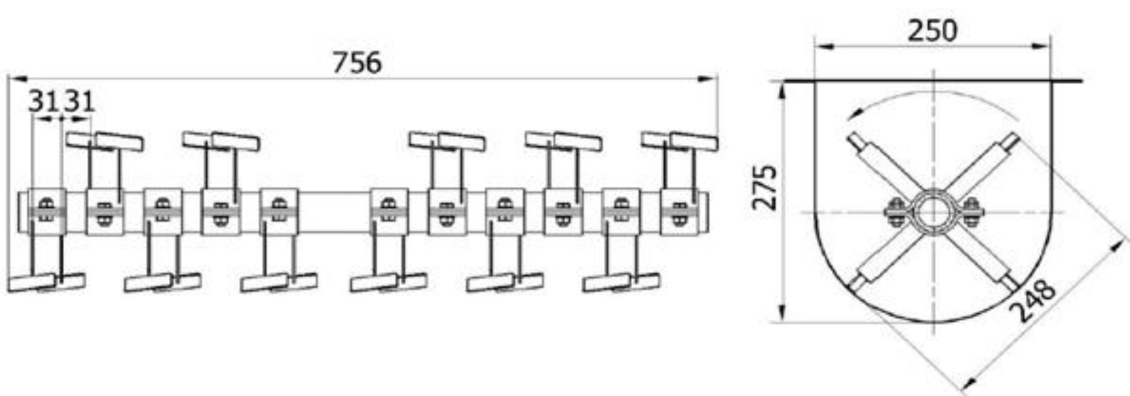

Figure 2. The design and dimensions of the mixer and the drum

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TABLE I. THE PARAMETERS OF THE HULLED MILLET UTILIZED FOR THE DEM SIMULATIONS

Chosen granule diameter [mm]	Measured moisture content (wet basis) [%]	Measured granule density [kg/m^3]	Calibrated elasticity modulus [MPa]	Measured internal friction angle [°]	Calibrated strengths of the cohesion [kPa]	Calibrated dimensionless strengths of the cohesion [1]
10±1*	22.5	2092 [6]	2000	40.3 [6]	61 [7]	0.05 [7]

* The real mean diameter of the hulled millet was 1.8 mm [6].

In order to determine the nullperformance, null measurements were performed at each speed. The data per minute for a given setting was averaged and the idle power consumption was deducted from it which was considered to be the mixing power consumption for the given conditions.

C. Discrete element method

In this research, the Yade [3] open source discrete element software was used in which the modeling is done in Python. Several types of so-called motors, such as particle con-tact models, were available to describe the rheological processes

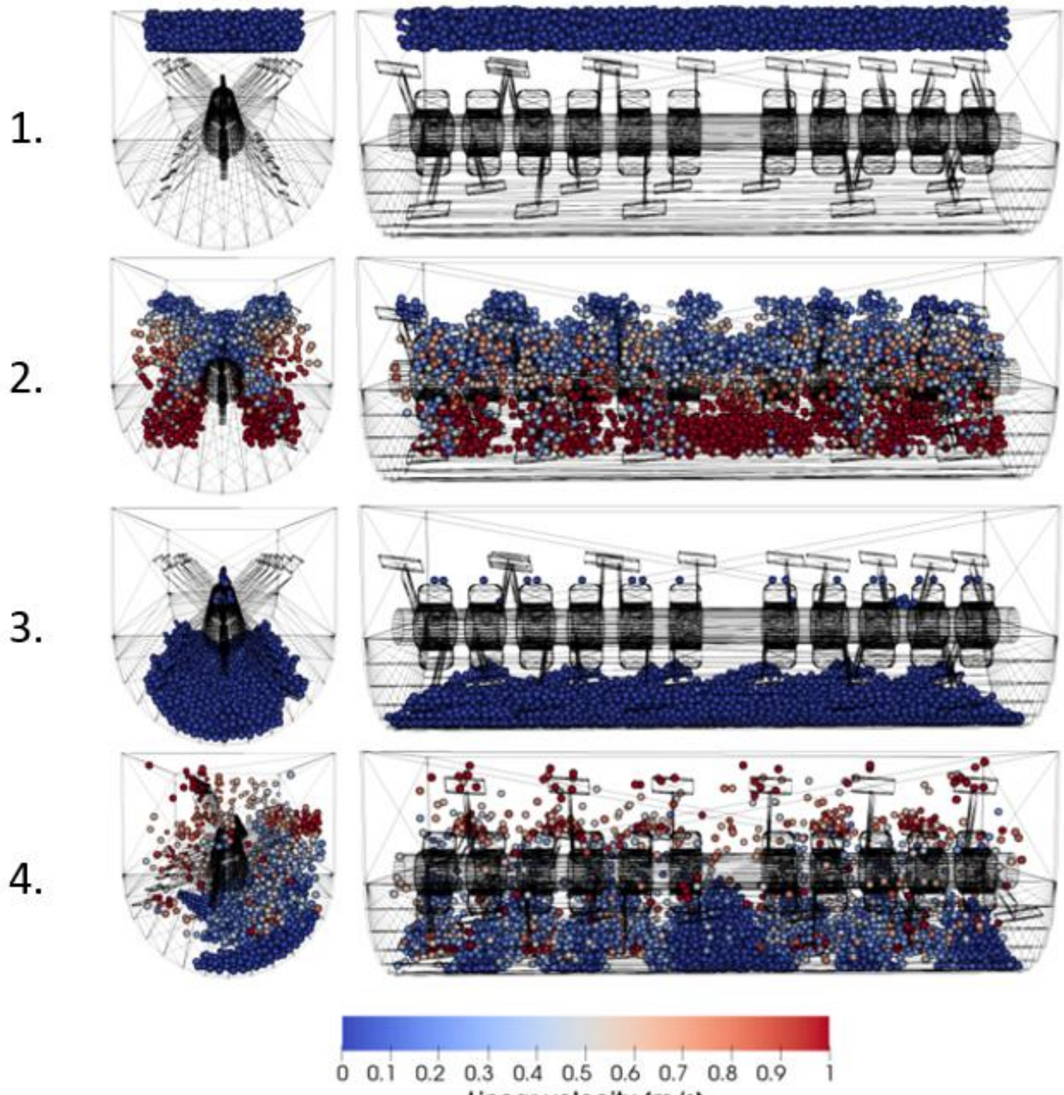

Figure 3. The discrete element model of the agitated drum dryer (1. generating the particle assembly, 2. gravity deposition of the assembly, 3. activation of the cohesive contacts, 4. start of the mixing)

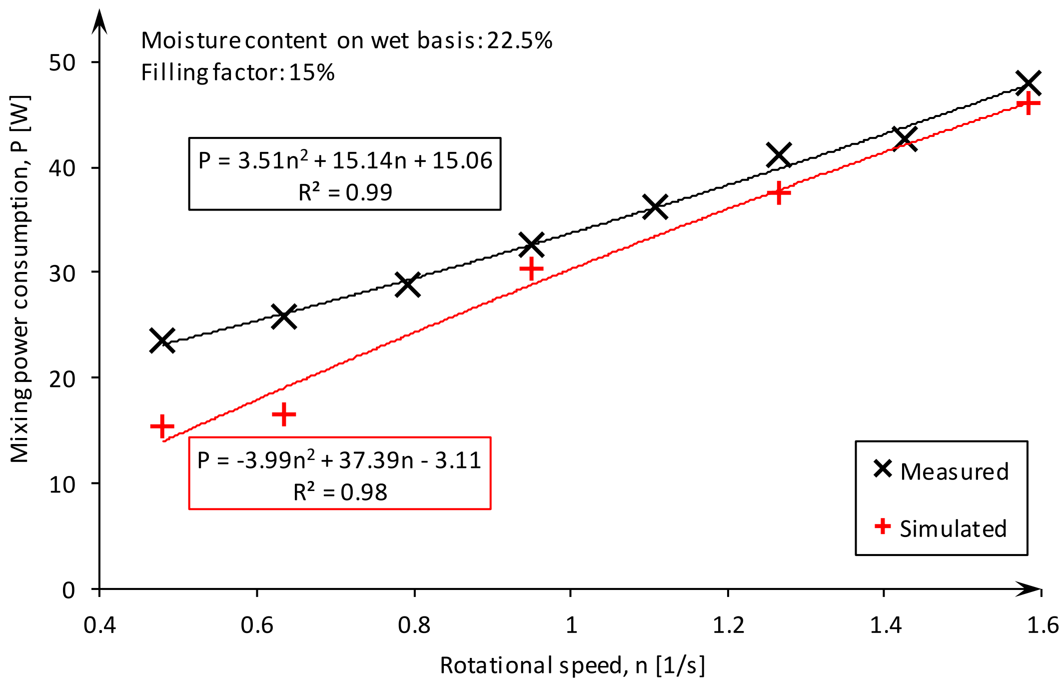

Figure 4. The measured and the simulated mixing power consumption in the case of hulled millet with a filling rate of 15% and 22.5% moisture content on wet basis depending on the rotational speed

between the particles (eg. frictional, cohesive and capillary, etc.). In the model the frictional-cohesive (CohFrictMat) contact model was utilized [4] due to the nature of the task being investigated, which is suitable for simulating the cohesion due to moisture in the granular material. Table II summarizes the parameters of the equipment's material used in the simulations, which were taken from the material properties of the steel [5].

TABLE II. THE DEM PARAMETERS OF THE EQUIPMENT'S MATERIAL [5]

Density [kg/m³]	Young's modulus [GPa]	Poisson's ratio [1]	Friction angle [°]
7750	200	0.3	40.1

The description of the connections between the drum and the particles was defined only by frictional relations. The mixing's global parameter settings for the discrete element simulations are summarized in Table III.

TABLE III. THE GLOBAL PARAMETERS OF THE DEM SIMULATIONS

Fill factor [%]	Global damping [1]	Number of particles [pcs]	Coefficient of critical time step [1]	Time step [s]
15	0	3713	0.7	$3.58 \cdot 10^{-5}$

The time step is divided by the proportional factor and it is equal to the critical time step defined by Yade software [3]. All other global parameters were left in the default setting.

III. RESULTS

The dimensions and setting parameters of the granules utilized during the simulation of the mixing process are summarized in Table I, which was determined by static measurements and simulation calibrations in previous studies [6]–[8]. In the present study the Young's modulus of the particles were modified in order to bring the simulated results closer to the real measured ones.

Because of the small size of millet grains, during the simulations, hundreds of thousands of particles would be needed, which the software could not handle with the available computing capacity at the appropriate simulation time. Thus the diameter of the particles was increased. The first stage of the simulation is to generate the particles with the filling rate (Figure 3/1). Then the gravity deposition of the assembly starts (Figure 3/2). It lasts until the magnitude of the unbalance force ratio drops below 0.001 (Figure 3/3). During the next phase, cohesion relationships between the particles will be activated, which will be re-activated each time for every new particle contact. Finally, at a given rotational speed, the mixing starts (Figure 3/4). The sampling of the torque applied to the axis was performed at every second for 30 seconds by the discrete element software.

The mixing power consumption can be calculated in terms of torque and rotational speed. Out-standing simulation performance data from the particles hitched by the mixing blades and walls of the drum were excluded during the

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TABLE IV. RELATIVE ERRORS OF MEASURED AND SIMULATED MIXING POWER CONSUMPTIONS

Rotational speed, [rev/s]	**Mixing power consumption, [W]**		**Relative Error, [%]**
	Measured	***Simulated***	
0.48	23.46	15.3	34.8
0.63	25.82	16.5	36.1
0.95	32.58	30.32	6.9
1.27	41.09	37.51	8.7
1.58	48.02	46.04	4.1

evaluation. Typically, these values were 0W and above 100W. The measurement and simulation results of the mixing are shown in Figure 4, where polynomial function can be applied to the obtained values.

It can be stated that the results of the simulation model of the mixer underestimated the measured power requirements at lower rotational speeds (0.48; 0.63; 0.79 rev/s), while at higher rotational speeds (0.95; 1.11; 1.43; 1.58 rev/s) the simulated results approached them appropriately. The reason for this is probably the fact that at lower rotational speeds mass transport is typical, while at higher rotational speeds impulse transport is common. Table IV summarizes the relative errors of the mixing power consumptions obtained by the measurements and the simulations.

Further calibration of the simulation model is required, in which parameter sensitivity tests have to be performed. Density correction due to porous volume change may be a solution in increasing particle size. In this case, while it is not advisable to change the density of the material by varying the particle sizes during mixing of different granular assemblies together, it is indispensable to simulate the mixing power consumption in order to mix the same mass as during the actual measurements. In addition, slight distortion of the geometric shape of the particles can also be a solution for the simulations of mixing power consumption at low rotational speeds, as using a more intersecting form of grain particles than the ball, the movable mass can be increased.

IV. CONCLUSION

In this research, the mixing power consumption of a horizontal axis agitated drum dryer was determined by laboratory measurements of the mixed moisture-containing hulled millet. With discrete element method the mixing apparatus and its operation were modeled taking into account the operating parameters used during the measurement. Simulation of the mixing was carried out by means of previous measured material parameters and simulational calibrations, and by modifying the modulus of elasticity of the particles. The results of the measurements and the simulations were compared. The mixing power consumption increased polynomial by increasing the rotational speed. It was found that the mixer's simulation model underestimated the measurement results at lower rotational speeds (0.48; 0.63; 0.79 rev/s) while at the higher rotational speeds (0.95; 1.11; 1.43; 1.58 rev/s) they approached them reasonably due to the former being mainly mass transport, and the latter being mainly impulsive transport. Further calibrations are required in which parameter sensitivity tests are performed in the granular assembly to give a more accurate description of the mass transport phenomenon due to the mixing. In the DEM model, the greater relative errors measured at lower rotational speeds could be solved by taking into consideration the changes in the porous volume due to the increase in the particle size, and the slight distortion of the geometric shape of the particles

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REFERENCES

[1] J. Bridgwater, "Mixing of powders and granular materials by mechanical means—A perspective," *Particuology*, vol. 10, no. 4, pp. 397–427, 2012.

[2] B. Alchikh-Sulaiman, M. Alian, F. Ein-Mozaffari, A. Lohi, and S. R. Upreti, "Using the discrete element method to assess the mixing of polydisperse solid particles in a rotary drum," *Particuology*, vol. 25, pp. 133–142, Apr. 2016.

[3] V. Šmilauer *et al.*, "Dem formulation. In Yade Documentation 2nd ed.," *Yade Proj.*, p. 37, 2015.

[4] F. Bourrier, F. Kneib, B. Chareyre, and T. Fourcaud, "Discrete modeling of granular soils reinforcement by plant roots," *Ecol. Eng.*, vol. 61, no. Part C, pp. 646–657, 2013.

[5] J. Horabik and M. Molenda, "Parameters and contact models for DEM simulations of agricultural granular materials: A review," *Biosyst. Eng.*, vol. 147, no. Supplement C, pp. 206–225, Jul. 2016.

[6] D. Horváth, "Statikus berendezésekben mozgó szemcsés anyaghalmaz modellezése," presented at the Tudományos Diákköri Konferencia, Budapesti Műszaki és Gazdaságtudományi Egyetem, 2017.

[7] T. Poós, D. Horváth, and K. Tamás, "The compare of angles of repose with discrete element method and measurement," in *8th International Scientific Conference*, Trebinje, Bosnia-Herzegovina, 2017, pp. 65–70.

[8] T. Poós, D. Horváth, and K. Tamás, "Modeling the movement of the granular material in a static equipment with discrete element method," presented at the International Scientific Conference on Advances in Mechanical Engineering (ISCAME 2017), Debrecen, Hungary, 2017.