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MEASURING AND MODELING THE MIXING POWER OF THE HULLED MILLET IN AN AGITATED DRUM DRYER

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In the agricultural, food, chemical and pharmaceutical industries, the mixing of granular materials often occurs. To select the mixing motors installed in the equipment, the speed of the mixer and the performance for the propulsion engine are required. The main purpose of this research was to create a discrete element simulation model capable of determining the mixing power consumption of an agitated drum dryer and to validate it with laboratory measurements.

Keywords: *agitated drum dryer, mixing, discrete element method.*

1. Introduction

In the agricultural, food, chemical and pharmaceutical industries the mixing and moving of granular materials are often encountered. The dynamics of mixing solid substances show different behaviors compared to fluid mixing, to describe these, the parameters of the mixed material and the geometric and operating parameters of the mixer (filling rate, rotational speed) are needed. There were several research to investigate this mixing process. Bridgwater, 2012 [1] collected the mixer geometries used to mix powders and granular materials and the phenomenas occuring during operations and the researches which describe them. As a result of which he found that studies of easily bulking materials without internal cohesion and hard-to-bulk materials with internal cohesion require further research. Kuo et al., 2003 [2] using Positron Emission Particle Tracking examination (PEPT), observed the behavior of a horizontal axis shovel mixer. During their measurements, the movement of the granules within the assembly was divided into three motion ranges. The active range of motion was considered around the blades. A further transient range has been defined, beyond which the inactive range is located away from the paddle, which is slowly moving away on the surface and at the bottom slowly approaching to the shovel. Their investigations were limited to particile movements

within the grain assembly, which served as a basis for analyses of later mixing quality studies. Gijón-Arreortúa & Tecante, 2015 [3] investigated the mixing of normal maize starch and icing sugar in a U-shaped horizontal axis mixer. While the former material mentioned above is insoluble in water, the latter mentioned is well soluble in the water, so that homogeneity can be well examined during mixing. The mixing power requirement and mixing time were observed at various filling rates and rotational speeds. A correlation was established with respect to the calculation of the mixing power consumption based on the physical properties and characteristic sizes of the granular materials and parameters of the mixer. It was found that the mixing power consumption is proportional to the increase in the rotational speed and filling rate. They illustrated the relationship between the effective cohesion number and the performance number, and based on the obtained curve, a correlation between the two numbers was made. Masiuk, 1987 [4] investigated the effect of the rotational speed, the filling rate and the moisture content of the mixed sand on the mixing power consumption of a double spiral band mixer. It has been found that the mixing power requirement increases linearly by increasing the mixing speed or the filling rate but decreases with increasing the moisture content. Many of the laboratory and plant tests and measurements carried out by the researchers have, in the majority of cases, produced appropriate results to determine mixing power requirements and the mixing properties of the materials. However, conducting these measurements is extremely

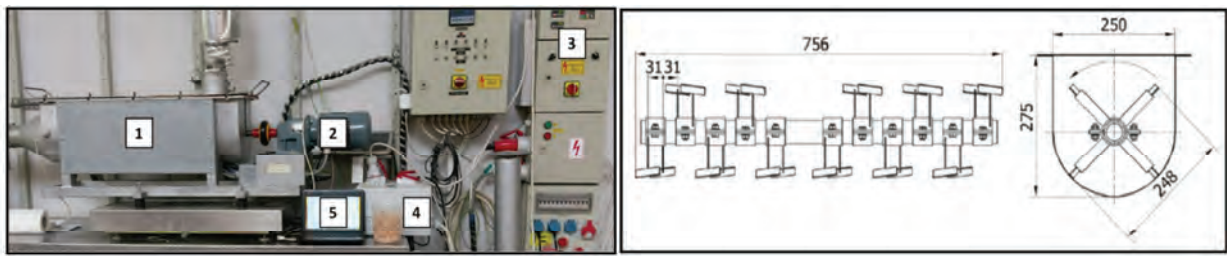


Figure 2. On the left, the laboratory agitated drum dryer (1. the drum, 2. geared electric motor, 3. frequency inverter, 4. three-phase power meter, 5. computer) and on the right side, the design of the drum and the mixer

time-consuming and only a few parameters have been observed. By Geng et al., 2009 [5] a 3D DEM model was created for simulating the operation of a horizontal axis rotary drum. In their simulations, the granules used in laboratory tests were modeled with good approximation. However, during their research, only frictional contact model was used. The effect of moisture content on cohesion in grain assembly have not been investigated.

The aim of this research is to create a simulation model of a horizontal axis drum dryer with mixing blades based on discrete element method (DEM), which is suitable for determining the mixing power requirements.

2. Material and methods

For the measurements hulled millet was used, which material characteristic size have already been determined in previous studies [6]–[8]. Before starting the measurements, it is important to prepare the material. The material assembly must be cleaned of dust, other contaminants and broken particles in order to obtain a precise characteristic size of the given material assembly.

a. Material

The hulled millet is a suitable agricultural material for the measurements, because it is small-scale (typically 1.7 ± 0.1 mm [8]), properly homogeneous, spherical, wettable and relatively cheap. In addition, the material itself is prone to arch building and has hydrophilic properties, so its moisture content greatly influences its material properties. Its real look is shown in Figure 1.



Figure 1. Hulled millet

First, the granular material have been cleansed and provided the roughly same particle size with a wind-sorting device (which selects by gravity deposition speed). It is also important to determine the moisture content because it greatly influences the specific properties of the material. The exact moisture content on wet basis was determined by a drying chamber.

b. B. Laboratory equipment and measurement method

The measurements were performed in the agitated drum dryer which can be seen on the left side of Figure 2. The electric performance of the mixing motor was measured with a special three-phase power meter at 1 s sampling intervals and recorded on a computer. The mixing of the material is carried out by a bladed mixer driven by the geared electric motor in the drum. The motor is connected to the power transmitter via the frequency inverter, which records the actual performance, from which the idling performance must be deducted. In order to determine the idle performance, the idle measurement at each speed (0.48; 0.63; 0.79; 0.95; 1.11; 1.27; 1.43; 1.58 1 / s) was

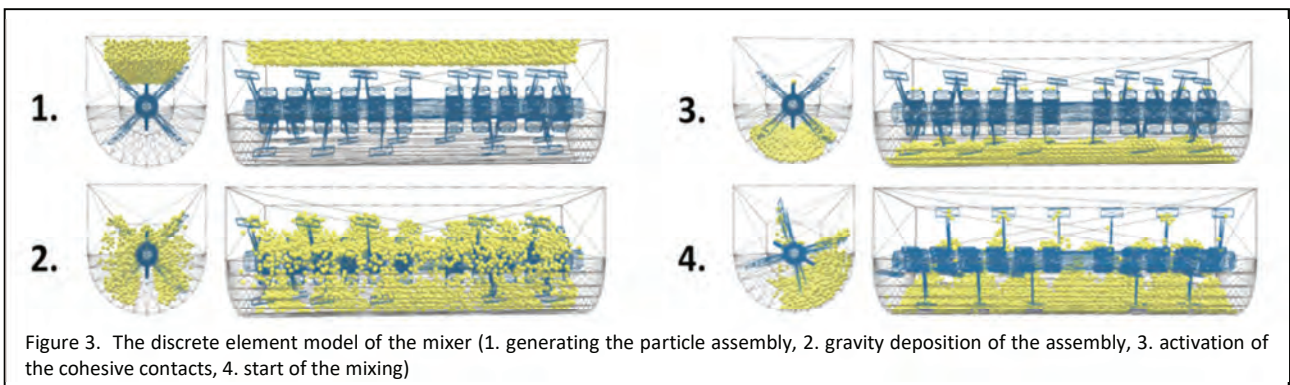


Figure 3. The discrete element model of the mixer (1. generating the particle assembly, 2. gravity deposition of the assembly, 3. activation of the cohesive contacts, 4. start of the mixing)

Table 2. The global default parameter settings of the DEM simulations

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

performed. The data per minute for a given setting was averaged. The idle performance was deducted and we considered this the mixing power requirement for the given conditions. Knowing the mixing power consumption (P) and the rotational speed (n), the mixing torque required (M) can be calculated:

$$M = \frac{P}{2\pi n} \quad (1)$$

The batch operational agitated drum dryer dimensions and arrangement are shown on the right side of Figure 2. 765 mm long, 250 mm wide and 275 mm high U-section drum that is covered by a flat plate. There are 22 mixing blades on the same axis as the drum shaft, each of which is 20 mm high, 50 mm wide and their horizontal angle is 10°.

c. Discrete element method

In this research, the Yade open source discrete element software was used in which the modeling is done in Python [9]. Several types of so-called motors, such as particle contact models, were available to describe the rheological processes between the particles (eg. frictional, cohesive and capillary, etc.). In the model we used a frictional-cohesive (CohFrictMat) contact model [10] due to the nature of the task being investigated, which is suitable for simulating the cohesion of moisture in the granular material. 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 (Fig. 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 requirement (P) can be calculated based on the Equation (1) in terms of torque (M) and rotational speed (n). Table 1 summarizes the parameters of the equipment's material used in the simulations, which were taken from the material properties of the steel [11].

Table 1. The DEM parameters of the equipment's material [11]

Density [kg/m ³]	Elasticity modulus [GPa]	Poisson ratio [1]	Friction angle [°]
7750	200	0.3	40.1

The mixing's global default parameter settings for the discrete element simulations are summarized in *Table 2*. The time step is divided by the proportional factor and it is equal to the critical time step [9] defined by Yade software.

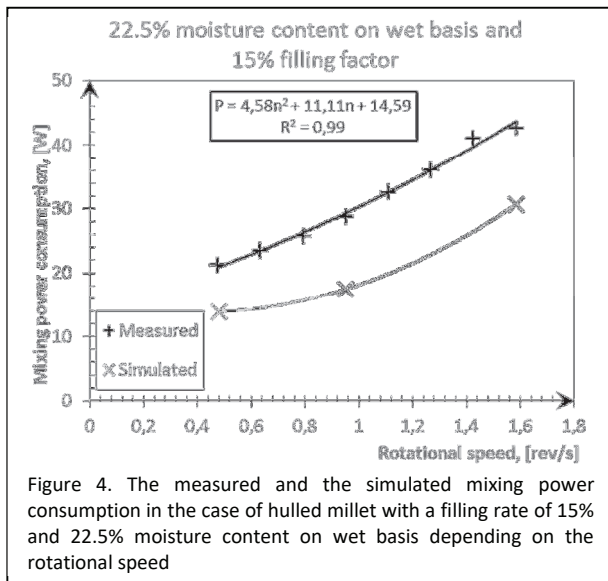
3. Measurement and simulation results

The dimensions and setting parameters of the granules used during the simulation of the mixing process are summarized in Table 3, which was determined by static measurements and simulation calibrations in previous studies [6]–[8]. 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. Thus the diameter of the particles was increased. The mixing and simulation results are shown in Figure 4. It can be stated that the simulation model of the mixer underestimated the results of the measurement. The mixing power consumption increased polynomially by increasing the rotational speed. The simulational curve showed similar characteristics to the result of the laboratory measurement.

Table 3. The parameters of the hulled millet used for the DEM simulations

Measured granule diameter [mm]	Measured moisture content (wet basis) [%]	Measured granule density [kg/m ³]	Chosen 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 [3]	20 [6]	40.3 [3]	61 [1]	0.05 [1]

*The real mean diameter of the hulled millet was 1.7 ± 0.1 mm [3].



Further calibration of the model is required, in which parameter sensitivity tests should be performed for the simulated material parameters chosen from the literature. It could be a solution to increase the elasticity modulus of the particles because it was taken from the literature [11] or slightly distorting the geometric shape of the particles, thus increasing their interdependence.

4. Conclusion

In this research, the mixing power requirement of a horizontal shaft agitated drum dryer was determined by mixing millet with a given moisture content. The mixing equipment and its operation were modelled with discrete element method, taking into account the operating parameters used during the measurement. Then simulation of the mixing was performed with material parameters determined by previous static measurements and simulational calibrations. Measured and simulated results were compared. The mixing power increased polynomially by increasing the rotational speed. The simulational curve showed similar characteristics to the result of the laboratory measurement. It has been found that the model underestimated the laboratory results. Therefore, additional calibrations are required in which parameter sensitivity tests are required to be performed on the simulational material parameters chosen from the literature.

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