Evaluate the blend quality of powders using a simplified mixing law

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Abstract

The research presents an easy to follow approach to evaluate blend quality of particle blends which are complex in shape and vary in size. For some materials simulations with discrete modelling approaches are challenging because of size and shape constrains but also of the access to recourses and know how of practitioners in the field using blending equipment for evaluating the blend quality of their products. A significant proportion of bulk handling operations happens in agriculture and related industries e.g. producing fertilisers, handling and storing food such as beans, lentils and rice. Different materials such as mung beans, black eye beans, lentils and rice were blended in a variable speed screw blender. The blender could vary the screw speed and then results taken from experiments were analysed to quantify the blend quality. It was found that a screw speed of 120 rpm gave the highest blend "quality" defined as a50 / 50 percent mix for different materials and blending time intervals. It was also found that the sampling position in the variable speed screw blender mattered because of axial and radial segregation occurring in the blender.

1. INTRODUCTION

The agriculture and food industry handle a wide range of materials such as beans, lentils, rice and fertilisers. Taking fertilisers as an example, it can be seen that the handling of complex fertilisers is challenging because quality fluctuations could lead to excess nutrients in soils causing environmental damage or reduced yield. Quality fluctuations in the fertiliser are the consequence of segregation during the handling and storage process. Segregation occurs in storage silos during the filling process when particles with different size and shape settle in different areas of the silo which causes quality fluctuations when discharging the segregated materials. The segregated material is then re-blended by using continues mixers Lance [1].

Continuous mixers such as the variable speed screw blender compress particles in axial direction by forcing the material against a shear plane (blending plane) which influences the motion and interaction between the different particles. The motion of particles can be considered as the result of transfer of energy from the screw to the particles where momentum is transferred to the particles and the work done by the motion of the screw is changing the kinetic energy of the particles. The kinetic energy of the particles moves the particles in a direction of least resistance or action. The path of the least action taken by the particles reduces the heterogeneity of the blend in axial and radial screw direction. Heterogeneity reduction in the radial direction of the blender is limited because the radial direction is smaller compared to the axial direction which corresponds to the length of the variable speed screw blender. Heterogeneity reaches a steady state Dynamic Blending Equilibrium (DBE) which often results in a non-zero heterogeneity value because heterogeneity cannot be reduced by further blending action. The DBE is a linear time-invariant heterogeneity state of the blend which balances the forces in the system dynamically. The heterogeneity index as defined in Eqn. 1 gives the equilibrium state of the blend Ghaderi, 2003. This equilibrium state of the blend defines the "achieved mixing" which represents the reduced or eliminated variance in the feeder component and also natural fluctuations (noise component) of the material fed into the blender. In contrast, an ideal blender would have no noise component which defines the "achievable mixing" possible with an ideal blender Ghaderi [2]. Comparing the "achieved mixing" with the "achievable mixing" of the powder blend provides a measure of how "good" a material is blended and, thus, opens new interpretations for defining "quality of blends". The quality of a blend Cs is defined in Eqn. 2.

$$I_s = \left(\sum_i \frac{M_i}{M_L} \times \left[\frac{c_i - c_L}{c_L} \right]^2 \right)^{1/2} \qquad \text{(Eqn. 1)}$$

$$C_s = \frac{\text{Achieved mixing}}{\text{Achievable mixing}} = \frac{\sqrt{N_{X_i} \times N_{X_{50}}}}{N_{X_{50}}} \qquad \text{(Eqn. 2)}$$

where N_{X_i} is the sample shape of component i and $N_{X_{50}}$ is the sample shape of an ideal blend. M_i is the mass of component i in the sample with concentration c_i, M_L is the total mass in the blender and c_L is the start concentration of component i in the blend. The quality factor C_s is similar to the heterogeneity index I_s. The quality factor C_s has a value between zero and one where one represents the highest possible blending state achievable with a given blender.

2. EQUIPMENT, MATERIAL AND SAMPLING PROCESSES

2.1 Experimental set up

The mixer used for the experiments is a variable speed screw blender as shown in Fig. 1. The blender consists of a horizontal U-shaped trough of 0.48 m. The screw is powered by an electrical motor and the rotation of the screw is controlled by a frequency controller. The conversion between power input of the motor (in percent) to the revolutions per minute (rpm) of the screw at zero load is shown in Figure 2. The screw speed was measured with the Standard AT-6 TACHOMETER.

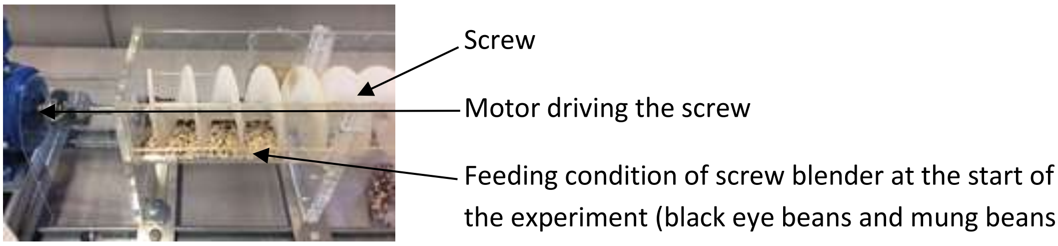

Fig. 1: Variable speed screw blender with frequency controller

2.2 Materials

A range of materials such as mung beans, black eye beans, lentils and rice were blended in the variable speed screw blender. The materials were selected because of the difference in particle size and shape as shown in Table 1. The main advantage of using large size particles such as beans is that sampling and separating the different materials e.g. using sieves after the blending provides more repeatable results.

Table 1: Materials used for the experiments and corresponding particle size ratios

	Rice	Lentils	Black Eyes Beans	Mungs Beans
particle size ratio (large to small diameter)	3.8	2.1	1.7	1.5

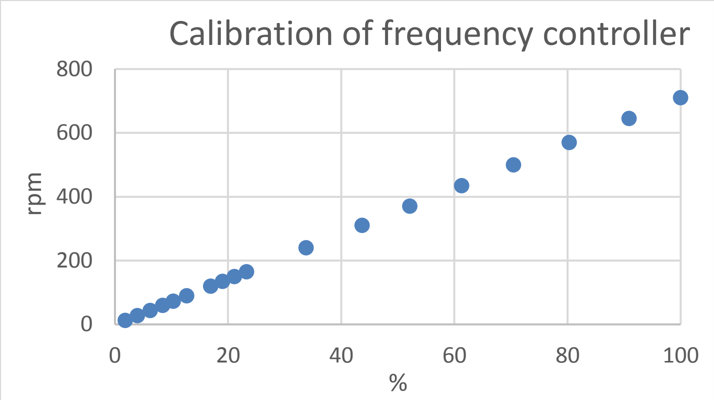

Fig. 2: Frequency controller on from 0 to 100% convert in rotational speed (rpm) measured with Standard AT-6 TACHOMETER at zero load.

Fig. 3: Placing the material (mung beans and black eye beans) in the variable speed screw blender

2.3 Experimental procedure

First, 500 g of material, e.g. 250 g of mung and 250 g of black eye beans, were placed in the variable speed screw blender as shown in Fig. 3. Then the digital frequency controller was set to the desired screw speed (rpm) and the material was mixed for a fixed time interval such as 20, 30 and 60 sec. At the end of the test, samples from three different positions (A, B and C) as shown in Fig. 4 were taken without disturbing significantly the material in the trough of the variable speed screw blender. At the end samples were sieved using a square hole sieve (e.g. 750 micron sieves which separated the mung beans and the black eye beans) and the mass and mass concentration of component i was measured using a Mettler PC 4400 balance.

3. Results

Varying the screw speed provided interesting insides into the change in blend quality of different materials. The results of the tests are shown in a radar chart. The parameters changed were blending time, screw speeds and materials blended. From Fig. 5 it can be seen that the blend quality is highest at a screw speed of 120 rpm. The data were statistically analysed and with a screw speed of 120 rpm the least standard deviation values were obtained Table A2 (Appendix).

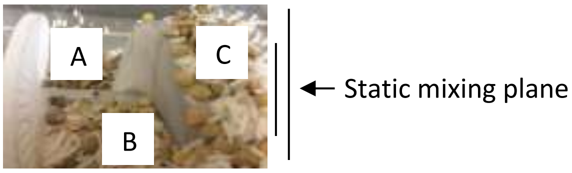

Fig. 4: Sampling the blended material (rice and lentils) near the static mixing plane at the end of the variable speed screw blender

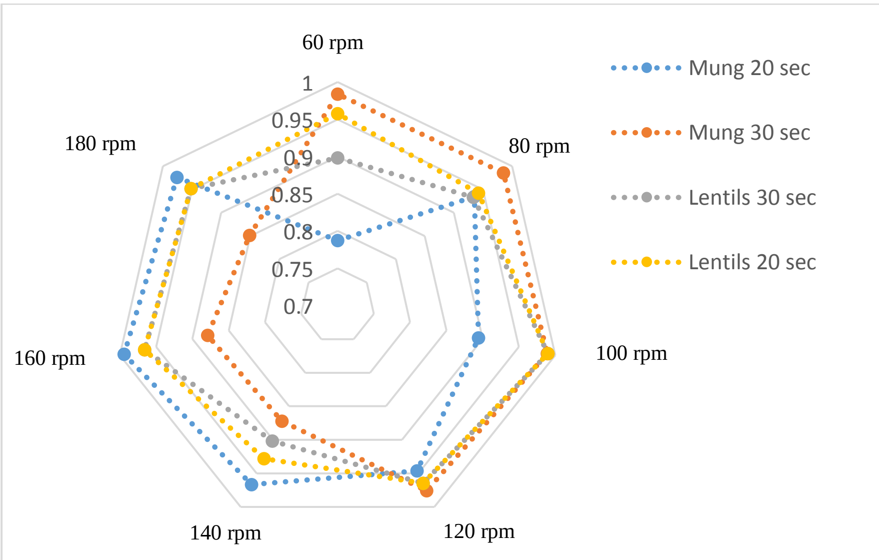

Fig. 5: Comparison of two different blends (Mung beans and black eye beans and lentils and rice) at different time intervals 20 and 30 sec.

Blending lentils and rice for 30 seconds and comparing the heterogeneity value (I_s) with the blend quality (C_s) revealed that these two values are very similar as shown in Fig. 6. From samples taken in different positions in the blender it could be seen that the heterogeneity of the blend varied across the axial direction of the blender. It was found that samples taken in position C which was closest to the static shear plane had the highest blend quality followed by section B. The lowest blend quality was obtained in position A furthest away from the shear plane as shown in Fig. 7. The difference in the blending quality between section A and C is the result of particles being pushed away from the blending plane (section C) to the centre of the screw (section A) and, thus, was not available for the blending process any more.

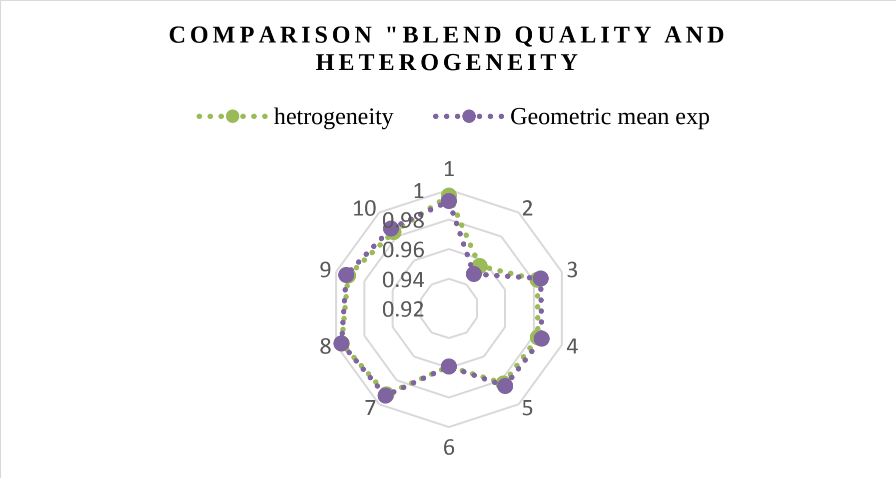

Fig. 6: Comparison of blending quality and heterogeneity value for lentils and rice (30 sec blending time)

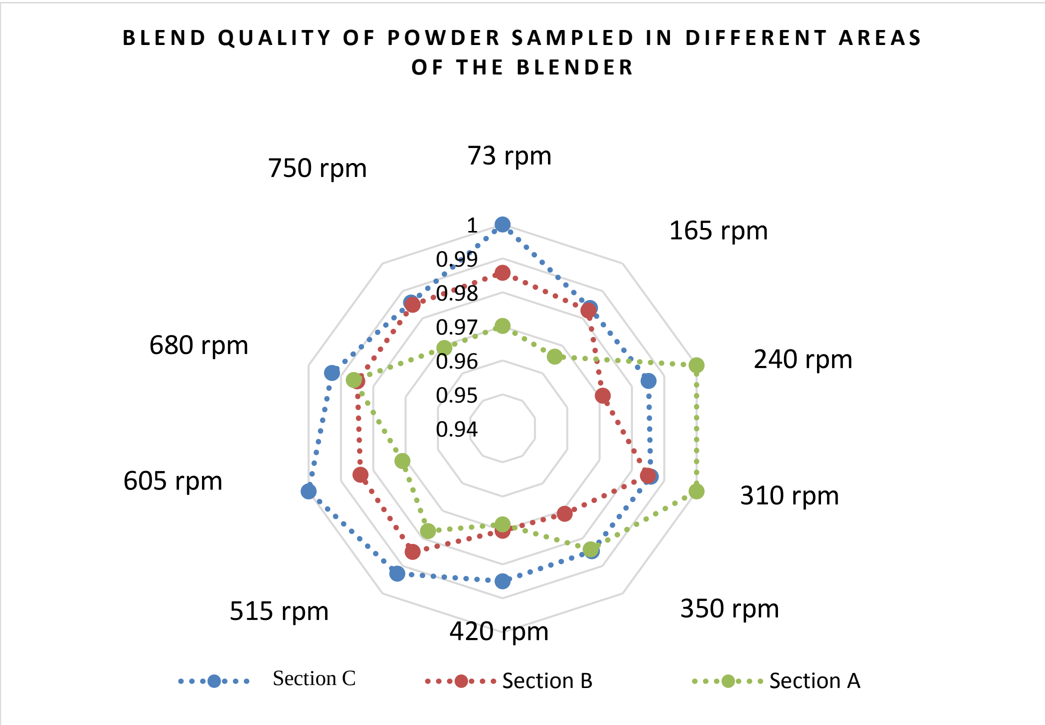

Fig. 7: Comparison of blend quality at different positions of the blender where A is furthest away from the shear plane, B is the centre position and C is closest to the shear plane

Blending mung beans and black eye beans for 30 sec indicated that the highest blend quality for this blender was obtained between 60 and 120 sec as shown in Fig. 8. Screw speeds above

120 rpm reduced the blend quality significantly because segregation occurred due to higher kinetic Energy input of the screw into the powder blend.

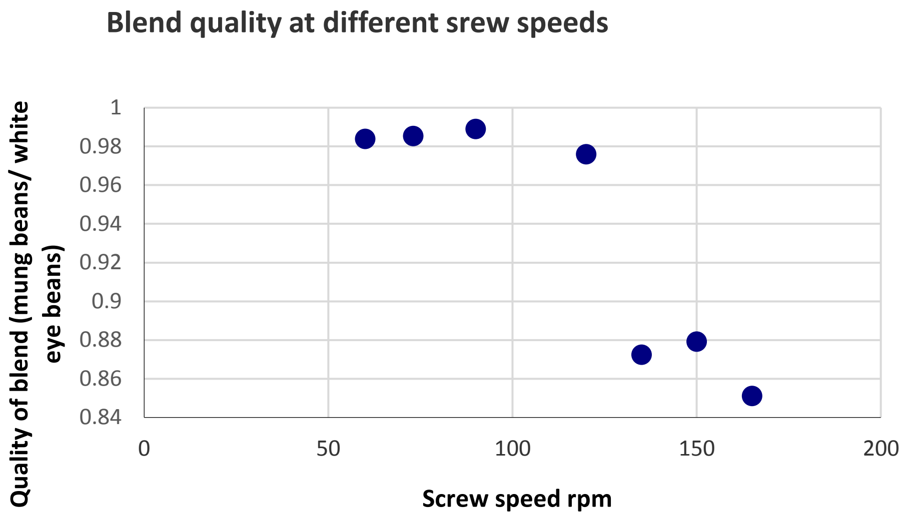

Fig. 8: Change in blend quality for Mung and black eye beans for varying screw speeds

4. Conclusion

This research has established a new blending index the "blend quality" which is an easy to use measure for practitioners to evaluate the heterogeneity of their powder blends. The heterogeneity values were similar to the values obtained for the "blend quality" index. The new index was applied to different materials and process settings such as blending time and it was found that the blend quality of lentils/ rice and mung beans/ black eye beans was highest at 120 rpm for the given blender. The position of sampling in the screw blender showed that blend quality varies across the position of the screw which is reinforcing the importance of sampling for blending processes. Sampling in industry is often not well understood and can cause operators to change process parameters on their equipment such as screw blenders which could reduce instead of increase blend quality. This was another finding of this research that increasing the screw speed does not result in an increase in blend quality but reduces the quality of the blend. More detailed work is required in the future to better understand the operational characteristics of blenders related to the restitution characteristics of different particles in the mixture by measuring the forces applied to the shear plane by means of load cell on the shear plane itself. This would then provide an indication of the dynamic forces and hence stresses in a blending system. With this type of information, it may be possible to improve the design techniques currently employed in designing blending systems.

5. References

[1] G. Lance, Handbook of solid fertiliser blending, European Fertilizer association, 2007

[2] A. GHADERI, *Characterization of Continuous Mixing of Particulate Materials,* Materials Particulate Science and Technology, 21: 1–12, 2003

Appendix

Table A1: Blending rice and lentils for 30 seconds at different screw speeds

RPM		Mean	Weighted Mean	STDEV.P	Centre Quartile 1	Median	Spread Quartile 3
60	0.957547	0.91	**0.85**	0.076	0.87	0.93	0.96
	0.983871						
	0.89823						
	0.7875						
80	0.942308	0.95	**0.94**	0.022	0.93	0.94	0.95
	0.985294						
	0.933333						
	0.934783						
100	0.989796	0.97	**0.92**	0.041	0.97	0.99	0.98
	0.988889						
	0.989796						
	0.894231						
120	0.964646	0.96	**0.96**	0.011	0.96	0.96	0.97
	0.975904						
	0.964646						
	0.946237						
140	0.927885	0.92	**0.90**	0.035	0.89	0.91	0.94
	0.87234						
	0.901869						
	0.966667						
160	0.966019	0.95	**0.91**	0.043	0.94	0.97	0.97
	0.879121						
	0.966019						
	0.994118						
180	0.951923	0.93	**0.90**	0.048	0.93	0.95	0.96
	0.851064						
	0.951923						
	0.97619						

m