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A study of the performance of a modified V-shaped solids mixer using segregating materials

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Summary

A binary free-flowing mixture made up of 30% salt and 70% non-pareil seeds was used as a mixing model. The performance of the mixer was defined in terms of relative standard deviation from the measured mean and the percent of the discharge profile within a 5% limit. The variables investigated in the present study included the leg reduction (0, 10, 20, 40 and 60%), offset angle (0, 15, 30, 45, 60, 75 and 90°), mixing time (0, 1, 5, 10, 15 and 30 min) and any combination of the afore-mentioned variables. The study confirms that the V-shaped blender can be improved upon by using an uneven leg (10–20% reduction) and an offset angle (15°). A combination of a 40% leg reduction and 75 or 90° offset angle gave the best results and that of a 0% leg reduction and 90° offset angle produced the worst results.

Introduction

At present, cylindrical and cubical-shaped blenders are not used, to any great extent, in the pharmaceutical industry because of poor crossflow along the axis and a less efficient sliding motion due to the flat surfaces in the case of the cube blender. Variations in blender geometry can significantly increase crossflow and improve the mixing action. The V-shaped blender is a good example wherein two inclined cylinders are joined to form a V shape. This is quite effective because of improved crossflow due to the incline of the cylinders on their axis and hence substantial intermixing action. However, the V-shaped blender can be further improved upon by an asymmetric design, such as an uneven leg and an offset angle. The purposes of the present study were: (a) to investigate the effect of an uneven leg and offset angle of a V-shaped blender on the mixing efficiency using segregating materials; and (b) to study the dual effect of these two asymmetric designs on the mixedness.

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Materials and Methods

Mix materials

A binary free-flowing mixture made up of 30% potassium chloride salt (15% ethylcellulose

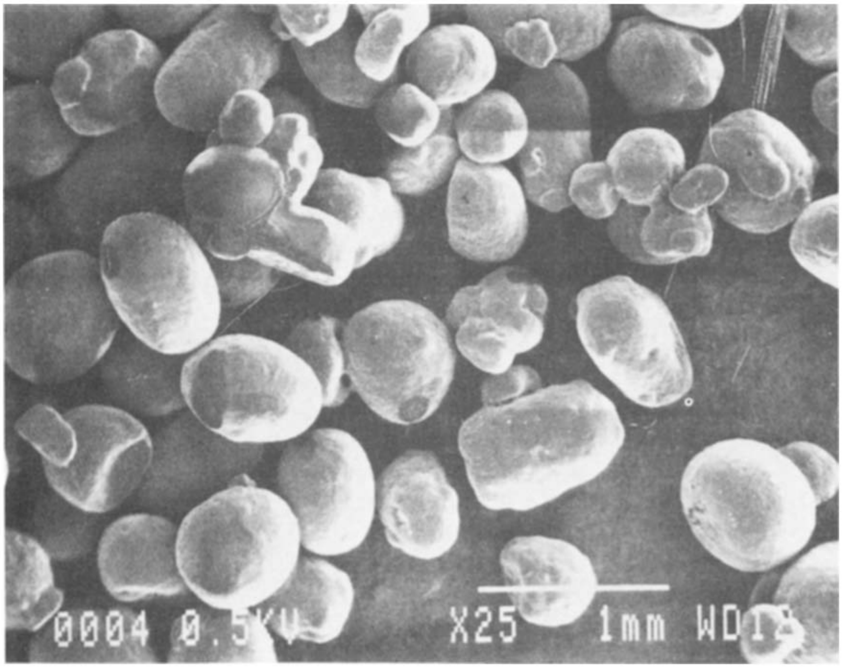

Fig. 1. The shape of ethylcellulose coated potassium chloride crystals.

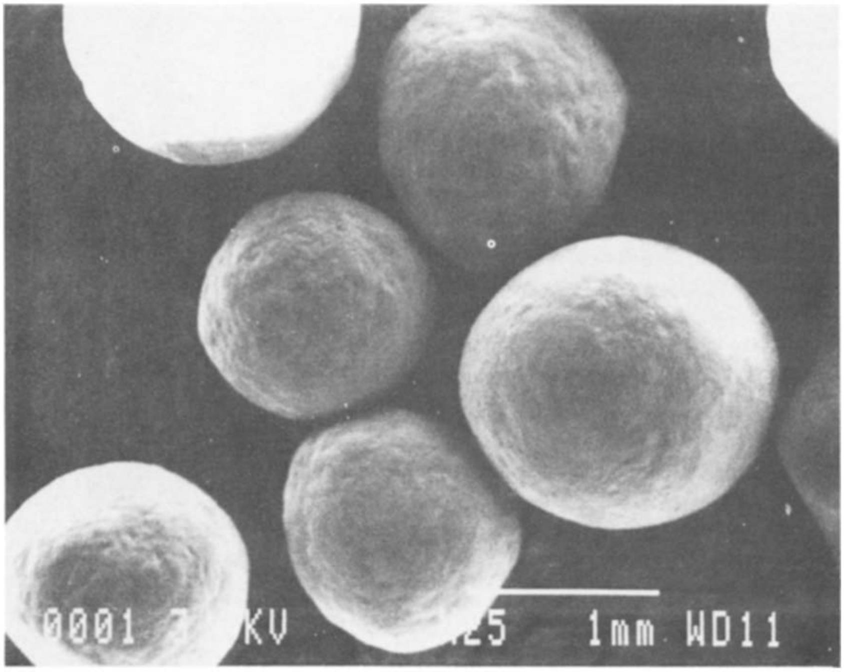

Fig. 2. The shape of Opadry yellow coated non-pareil seeds (pellets).

coated) and 70% non-pareil seeds (3% Opadry yellow coated) was chosen as the mixing model, since it has strong segregating tendencies which would accentuate any differences in the mixedness among the mixing variables. The two ingredients were coated to provide mechanical strength in order to avoid size reduction of the particles and to provide color differences to facilitate the screening procedure. The properties and micrographs of the two ingredients are given in Table 1 and Figs 1 and 2.

Procedure

A twin-shell solid-solids blender frame (Patterson Kelley Co., East Stroudsburg, PA, Model SB-8) and a half-quart stainless-steel shell (Patterson Kelley Co., Model YS-1/2) in conjunction with a specially designed yoke and a leg reduction device were used in the present study (Fig. 3). In detail, the yoke consisted of a circular band, which was designed for supporting the V-shaped blender and setting the offset angles. The leg reduction device included a round teflon plate laminated between two stainless-steel plates, a bolt and lock-nuts. The bolt was placed through a drilled hole in the lid of V-shaped blender and held in place with lock-nuts. The extent of leg reduction was adjusted by raising or lowering the bolt. The rotational speed of the mixer was fixed at 30 rpm for all of the tests. Non-pareil seeds (210 g) were loaded into the mixer as a bottom layer and potassium chloride crystals (90 g) as the top layer. The variables investigated in the present study included leg reduction (0, 10, 20, 40

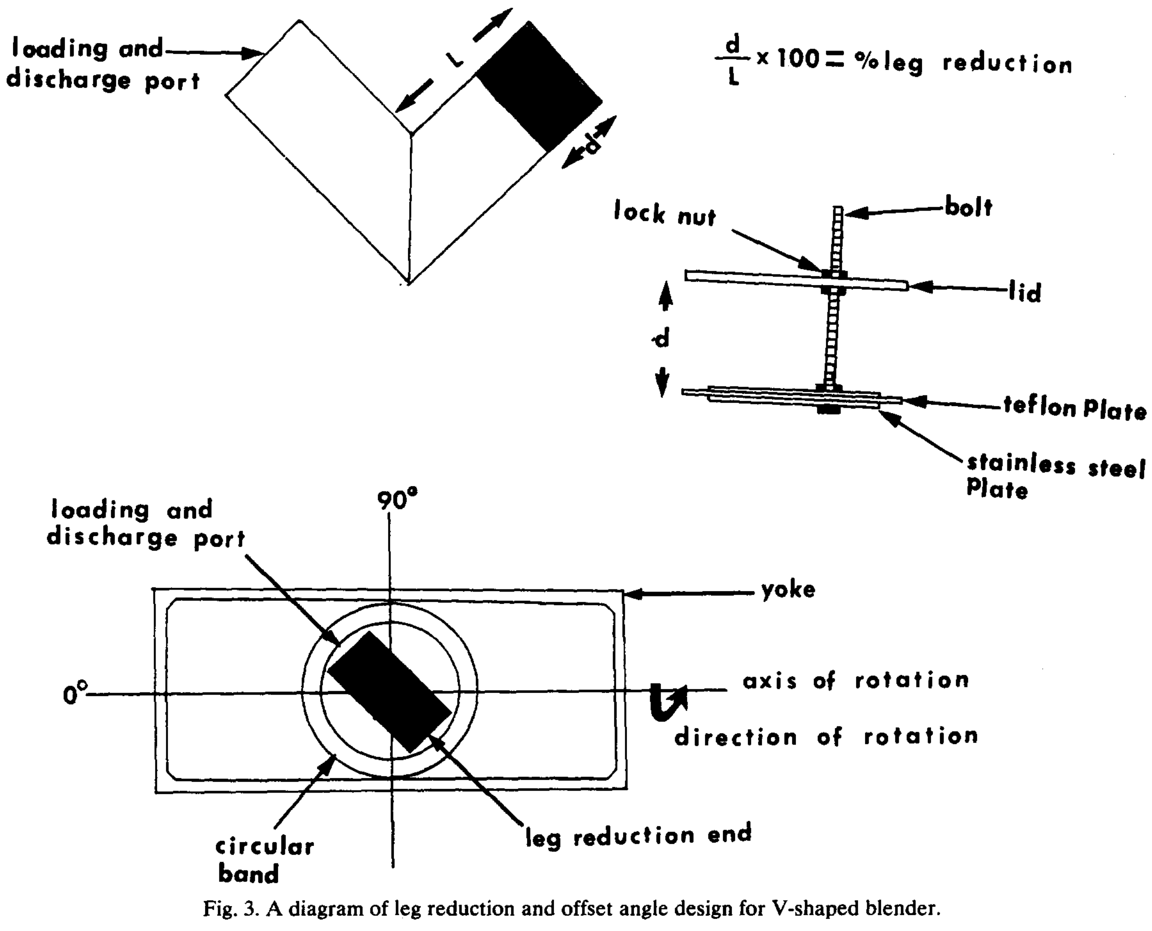

Fig. 3. A diagram of leg reduction and offset angle design for V-shaped blender.

TABLE 1

Properties of ethylcellulose coated potassium chloride crystals and Opadry yellow coated non-pareil seeds

U.S. sieve no.	Aperture size (μm)	Percentage by weight	
		Salt [a]	Pellet [b]
14	1400		12.3
16	1180		63.9
18	1000		23.8
20	850	1.0	
30	600	9.3	
35	500	24.5	
40	425	31.2	
50	300	30.2	
Pan		3.8	
Mean particle size (μm) [c]		466	1273
Bulk density (g/cm^3)		1.04	0.83
Moisture content (%) [d]		0.4	2.3
Shape		Fig. 1	Fig. 2

[a] Potassium chloride crystals coated with 15% ethyl cellulose.
[b] 14/18 mesh non-pareil seeds coated with 3% Opadry yellow.
[c] Mean particle size = summation of weight size/100. Weight size = arithmetic mean size of openings × % retained on smaller sieve.
[d] Ohaus moisture balance 200; temperature setting 105°C for 12 min.

and 60%), offset angle (0, 15, 30, 45, 60, 75 and 90°), mixing time (0, 1, 5, 10, 15 and 30 min) and any combination of the afore-mentioned variables. The mixer with preset offset angle and leg reduction was set in motion for a prescribed time and the contents discharged by hand through the discharge end to form an approx. 40 cm long and 5 cm wide pile. 20 samples of this discharge were taken consecutively by using a flat-bottom scoop. The mean weight of the sample taken was 7.5 g with a range of 6.0–9.0 g. Great care was exercised to ensure representativity of the sample. The components of each sample were separated by hand sieving to determine weight percent of non-pareil seeds (pellets).

The entire procedure including storage of the two components, mixing, sampling and screening, was performed in a humidity-controlled room (relative humidity: 65–75%) to minimize electrostatic charge build-up.

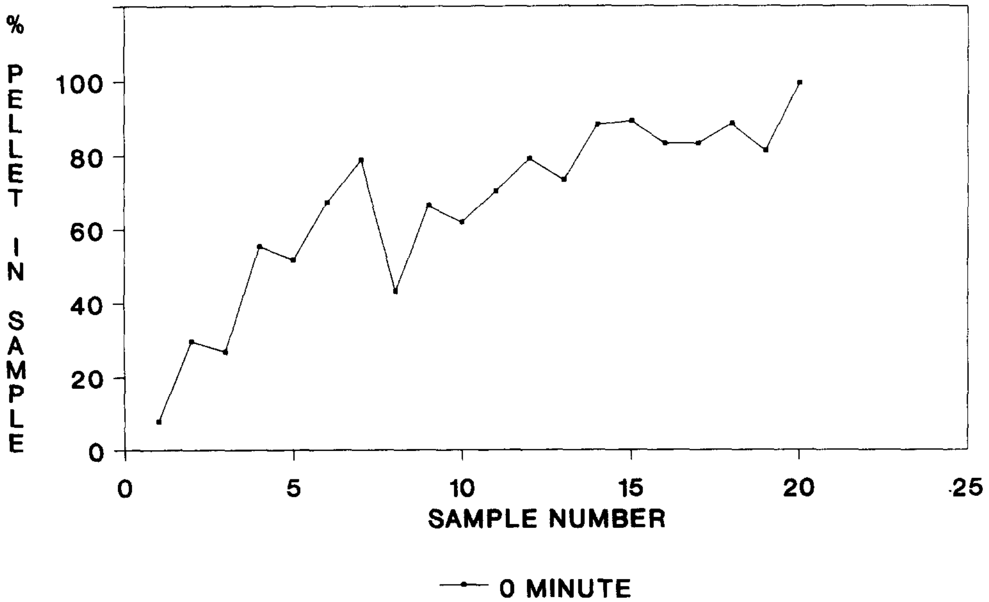

Fig. 4. Discharge profiles for no mixing. Top layer, 90 g potassium chloride; bottom layer, 210 g non-pareil seeds.

Results and Discussion

Sampling, which largely determines the validity and interpretation of the derived index, is an integral part for a quantitative assessment of mixture quality. There are two general rules of sampling (Allen, 1975):

(1) A powder mixture should be sampled during the discharge phase. In other words, sampling should be carried out when the powder mixture is in motion.

(2) To ensure the representativity of the sample, the whole stream of powder should be taken for many short increments of time.

In the present study, the sampling procedure deviated from these rules primarily because there is no dumping port at the bottom of the half-quart twin shell. However, scoop sampling did not preferentially reject one of the components based upon the following observations:

(a) The mean sample compositions for all experiments are not significantly different from the charge composition by using the *t*-test and 0.05 confidence level.

(b) Fig. 4 shows the discharge profile for no mixing. As expected, the percent of coated nonpareils (pellets) in the sample gradually increases from early to late discharge due to top-loading of the potassium chloride crystals. It appears that the discharge profile can be used to identify the location and pattern of segregation. It also demonstrated that scoop sampling in the present study did not destroy the representativity of the samples.

(c) Fig. 5 shows the reproducibility of three runs of 30 min mixing. There is a marked similarity in the discharge profiles for these three runs. This further indicates the validity of the mixing and sampling procedure. The mean relative standard deviation for these three runs was 20.6% with a standard deviation of 2.7%.

Effect of an uneven leg

The uneven leg design utilizes the different volume of two legs to achieve the unequal displacement of material which can cause a strong sideway movement of material from each leg of the blender to the other. It has been demon-

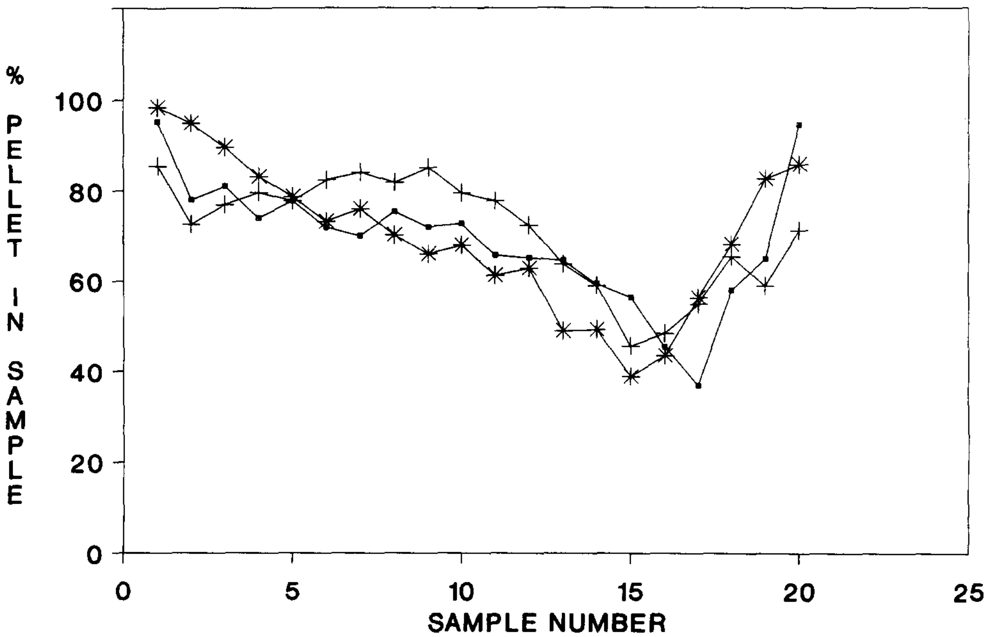

Fig. 5. Discharge profiles for three 30 min mixing runs.

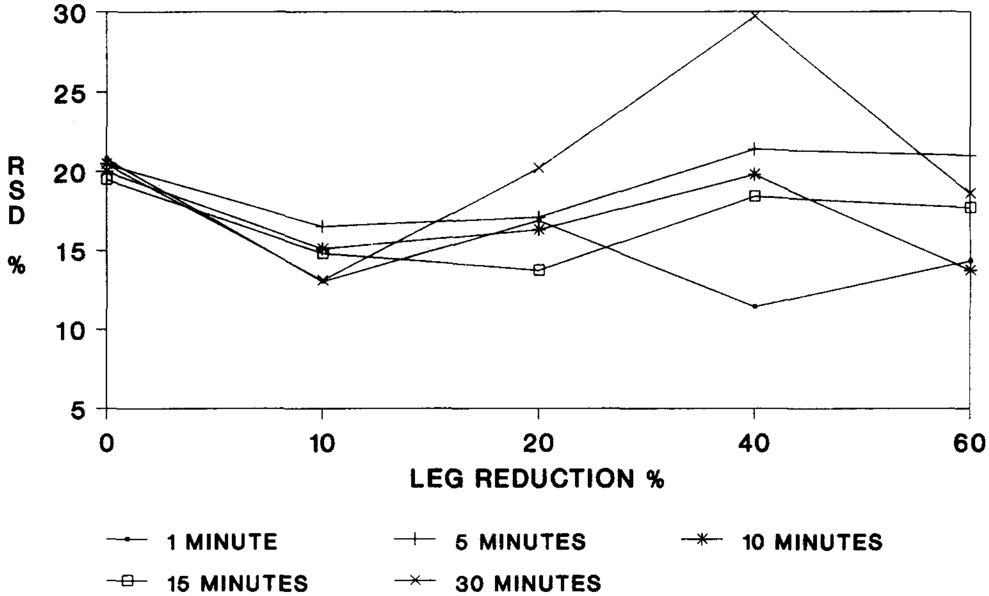

Fig. 6. Effect of leg reduction on the mixedness of various mixing times (RSD, relative standard deviation from the measured mean).

strated that uneven leg design produces a better blending performance than the V-shaped blender (Patterson-Kelley Co., 1989). The relative standard deviations from the measured means for various mixing times were plotted against various leg reduction settings, as shown in Fig. 6. There is

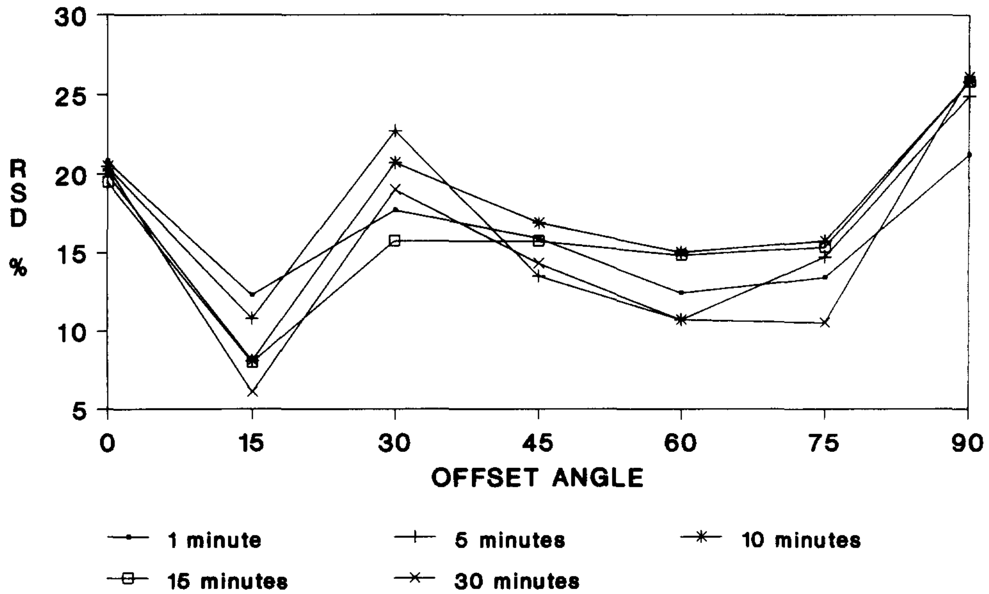

Fig. 7. Effect of offset angle on the mixedness of various mixing times (RSD, relative standard deviation from the measured mean).

a noticeable improvement of mixedness in the cases of 10 and 20% leg reduction for almost all mixing times. For 40 and 60% leg reduction, the highest efficiency can be achieved by 1 and 10 min mixing, respectively. The optimum mixture obtained by leg reduction is not achievable by a V-shaped blender. However, the leg reduction approach has two potential drawbacks: (1) greater sensitivity to the amount of loading than the V-shaped blender; and (2) decreased working space when the loading remains the same.

Effect of an offset angle

The offset angle design utilizes the different position of two legs during the rotation to achieve an unequal material displacement. Fig. 7 shows a plot of the relative standard deviations from the measured means for various mixing times against the offset angle settings. The superior quality of mixture can be obtained at 15° offset angle for all mixing times. Increasing the offset angle gradually increases the shear force and the extent of unequal displacement of materials. For example, a 90° offset angle provides the highest external force among the various angle settings. However, the majority of the binary mixture was tumbled within one leg space. Due to the insufficient exchange of materials from one leg to the other and the inefficient working space, a poor mixedness was obtained at a 90° offset angle. The different mixing performance of the various angles is the result of the interaction among the extent of unequal displacement of materials, the external force and the effective working space. A common industrial approach for effectiveness of mixing is to impose a tolerance on the mixture product and the percent of the discharge profile within the set limits was used as a measure of the mixer effectiveness (Harnby, 1967). A plot of the percent of mixtures within 5% limits against various offset angles also demonstrates that 15° is an optimal offset angle in the present mixing condition.

Dual effect of leg reduction and offset angle

Fig. 8 shows the effect of various offset angles and a 10% leg reduction on mixing effectiveness. The general trend of the profile is quite similar to that shown in Fig. 4, except for two data points, i.e., 15° and 15 min, and 75° and 5 min. However,

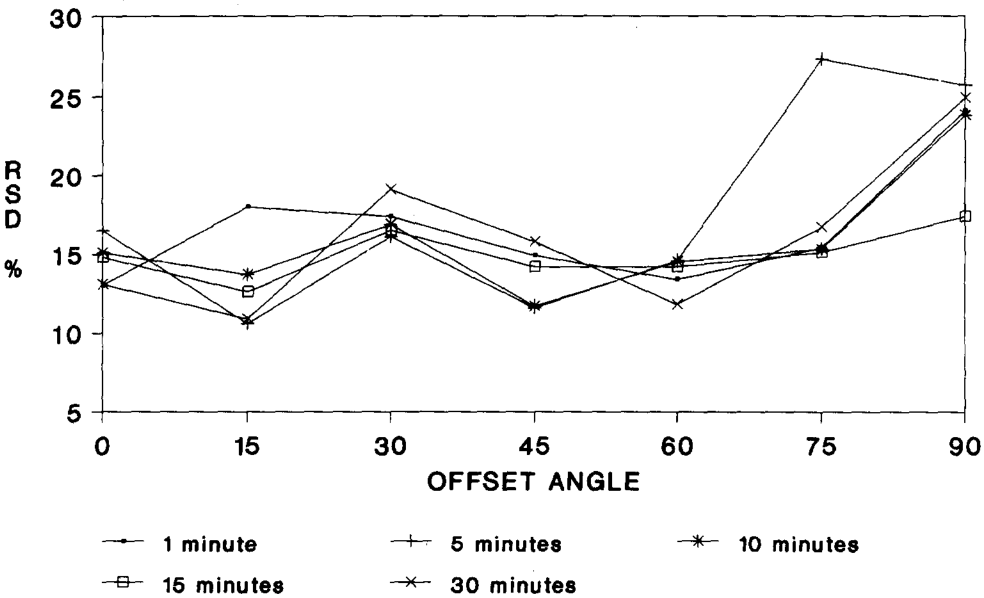

Fig. 8. Effect of various offset angles and 10% leg reduction on the mixedness of various mixing times (RSD, relative standard deviation from the measured mean).

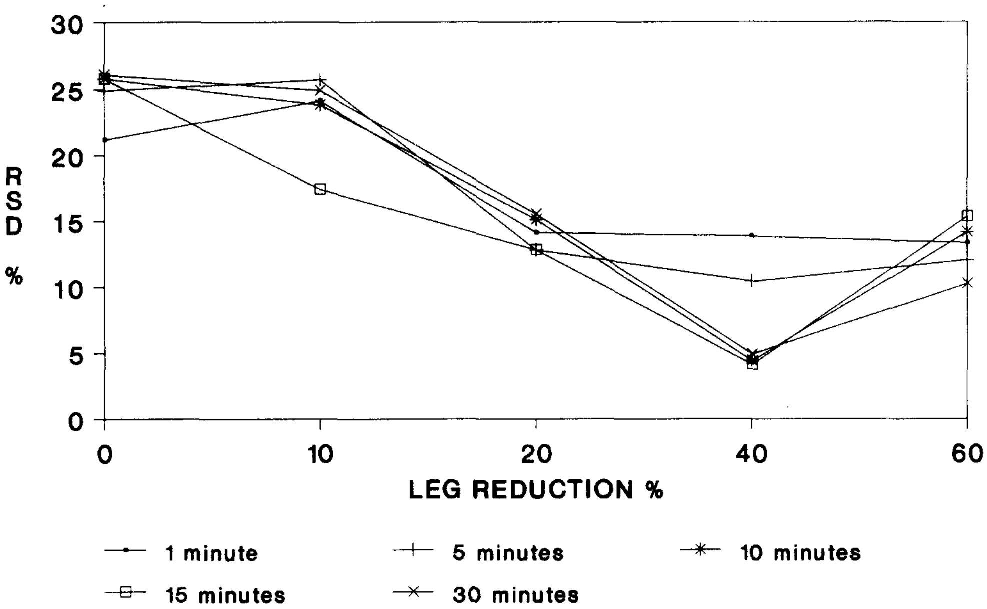

Fig. 9. Effect of various leg reductions and 90° offset angle on the mixedness of various mixing times (RSD, relative standard deviation from the measured mean).

an optimal offset angle at 15° is not that clear, compared to the 0% leg reduction (Fig. 4). 20% leg reduction severely disturbed the optimum of the unequal material displacement which was generated by mixing conditions of a 15° offset angle and 0% leg reduction. On the other hand, a 20% leg reduction can be used to restore a better distribution of materials between legs and to improve mixing efficiency in the case of a 90° offset angle. For 40% leg reduction, the highest efficiency achieved with various offset angles at either 10 or 15 min mixing time was excellent. Especially at 75 and 90° offset angles, a remarkable improvement of mixedness for almost all the mixing times can be noted. Fig. 9 shows that further shortening of the leg to 60% at a 90° offset angle setting worsens the mixedness.

Conclusions

A noticeable improvement of mixing efficiency can be obtained either by a 10 to 20% leg reduction, or by a 15° offset angle in the present mixing condition. The dual effect of leg reduction and offset angle is complicated. However, the overall effect on the extent of unequal material displacement plays a major role; different shear forces and effective working space may be minor contributory factors. A combination of 40% leg reduction and 75 or 90° offset angle gave the best results whereas that of 0% leg reduction and 90° offset angle produced the worst results. Although the improvement in mixedness can be obtained by changing the leg reduction and/or offset angle, using a V-shaped blender to mix free flowing mixtures with large differences in particle size is not generally recommended.

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