EVALUATION OF THE MIXING CAPABILITY OF A LOW-COST, SANITARY, FOOD-GRADE MIXER

By

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EVALUATION OF THE MIXING CAPABILITY

OF A LOW-COST, SANITARY,

FOOD-GRADE MIXER

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ABSTRACT: Sanitary, food-grade, commercial mixers can have a sizeable price tag. Many entrepreneurs and new businesses cannot afford to invest in commercial mixing equipment, so a low-cost version would be a great alternative. The mixing capabilities of two different mixing bowls manufactured by Kushlan Products Incorporated with a total of five different internal set-ups were evaluated in this study and compared to a commercial V-blender. A new evaluation method was developed to test mixing capability using a steel grit tracer as opposed to table salt. The mixed contents were transferred into the hopper of a vibratory feeder and samples were taken by passing cups underneath the discharge of the feeder. The steel grit tracer was collected very easily with a magnet while the salt tracer required extensive preparation for analysis in small batches. Both tracers were tested in the V-blender and one of the trials using the steel tracer out of 11 total trials between the two tracers resulted in an adequate mixture. A screening study of 8 mixing factors found that bulk media size, bin transfer of product, and sampling interval had the most significant effect on the mixing process. Ground corn was the bulk media used for most of the trials, but all-purpose flour was also tested and it mixed as well as and sometimes better than the ground corn, but it was still not good enough to be considered adequate. Adequate mixing was not obtained using any of the five bowl configurations although the closest results came from utilizing the bowl that contained two molded-in paddles and two stainless steel blades.

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CHAPTER I

INTRODUCTION

Mixing is an important part of many food processes and is defined as the combination or blending of different materials into a homogenous mass. Most recipes include steps where different food ingredients are combined to form intermediate products or a finished product. Sanitary, food-grade, commercial mixers can have a sizeable price tag. Many entrepreneurs and new businesses cannot afford to invest in commercial mixing equipment, so a low-cost version would be a great alternative.

Kushlan Products Incorporated, an innovative equipment manufacturer, recently began to produce a sanitary version of their cement mixer. Their mixing bowls have stainless steel attachment hardware and all food contact surface materials are FDA approved. They have provided a mixer with two mixing bowls to test potential food applications.

The objectives of this research are to:

- Develop a new method to test mixing capability
- Test the newly developed method on a known mixer
- Complete a screening study to improve/refine the mixing test procedure
- Test a bulk media that would be applicable to potential food applications
- Test the mixing capability of the Kushlan mixer with 5 bowl configurations

CHAPTER II

REVIEW OF LITERATURE

The process of mixing can be dated at least back to the Ancient Egyptians whose diet was very dependent on bread. They would mix the ingredients and knead the dough with their hands or feet. Although not very sanitary, it would get the job done. They made use of what they had available to them since the advanced technology around today such as an electric stand mixer with a dough hook for kneading was not anywhere near being thought of yet. In fact, electricity wasn't even discovered until around 1600 A.D. and the electric standing mixer wasn't invented until Herbert Johnson came up with the idea in 1908. Electric mixers have continued to evolve over the past century and help ease the process of mixing for many people and companies.

For a mixing process, the goal is to achieve complete mixing wherein ideally there is a uniform distribution of the products being mixed. There are several things to consider, however, when attempting to achieve this goal. First, one must consider the state of the materials being mixed (i.e. solids only, liquids only, or a combination of the two). Second, an adequate type of mixer must be selected based on the materials. Third, all factors that affect the mixing process (such as product size, batch size, mixing time, and the sampling process) must be determined and set. Last, but not least, it is important to select an appropriate procedure to evaluate the adequacy of mixing.

2.1 Materials

Kushlan Products Incorporated provided a portable mixer with two different mixing bowls to be tested (see chapter 3). The intended use of this mixer is to mix small batches of concrete, which is a combination of liquid (water) and solids (cement, sand, and gravel or small stones). For the purposes of this research, the focus will only be on mixing solids as this is one of the most difficult combinations to achieve adequate mixing. Some examples of dried food products that might be mixed if the project is successful include bakery mixes (muffin, cake, and cookie), spices, and micronutrients (such as vitamins and minerals). Liquid/solid systems will not be evaluated in this study.

2.2 Types of Mixers

Food processing of dried goods can use two different classifications of mixers: batch and continuous. Batch mixing involves loading all ingredients into a mixer followed by mixing for an established amount of time to achieve adequate mixing. The mixer is then turned off and the final mixture is emptied. "Most mixing operations in the food and agricultural industries are carried out batchwise" (Niranjan, et al., 1994). Two examples of batch mixers are tumbling mixers (like V and Y blenders) that rotate around a central axis, and agitated mixers that use paddles or plows to stir the mixture. For continuous mixing, the mixer is allowed to constantly run since the ingredients go through the mixer in one pass. Ingredients can be added at one end while the final mixed product comes out of the other end. Two examples of continuous mixers are the zig-zag mixer, which consists of three V-blenders connected together in a line, and the Acrison Model 350 blender, which "incorporates a large auger enclosing a smaller diameter but longer auger" (Harwood, et al., 1974). Based on this information, the type of mixer

provided for this research is a batch mixer that is a combination of a tumbling mixer since it uses a rotating drum and an agitated mixer since the drum includes paddles (Paul, et al., 2004).

2.2.1 Tumbling Mixers

Several research projects have been done utilizing various types of batch mixers. The double-cone blender is one example of a tumbling batch mixer. This blender consists of a cylindrical section that connects the circular ends of two cones that are the same size. The cones of the blender rotate around a horizontal axis that passes through the center of the cylindrical section and the content of the blender shifts back and forth between the cones as it does so. A V-blender is another example of a tumbling batch mixer and it is often used for solids mixing. It is named as such because it is basically two cylinders fused together in the shape of the letter "V" and it rotates around a horizontal axis that passes through both cylinders about halfway up causing the contents to segregate into the tips and then re-combine at the base. A horizontal cylinder is also a tumbling batch mixer. Table 1 lists some of the findings from individual studies of these types of mixers.

Studies also exist where comparisons were made between multiple tumbling batch mixers. Some outcomes for a few of these studies are shown Table 2. This table includes the addition of another tumbling batch mixer, the bin-blender, which basically consists of half of the double-cone blender as it has a circular plate in place of where the other cone would be attached while the horizontal axis of rotation still passes through the center of the cylindrical section that is now the top part of the blender.

Table 1: Tumbling Mixer Studies

Citation	Mixer Type	Factors Tested	Evaluation Method	Findings
Blumberg and Maritz, 1953	Horizontal Cylinder	Number of Sampling Points and Statistical Distribution of Samples	Thief Sampling and Counting of Colored Particles via Microscope	10 sampling points were sufficient and the proportion of colored particles at each point followed a normal distribution.
Hogg and Fuerstenau, 1972	Horizontal Cylinder	Fill Level and Number of Rotations	Calculation of Variance between "Samples" on a Photographed Image	A "dead spot" appeared above 50% fill. More rotations were required to achieve mixing at 50% fill than lower fill levels.
Wightmen, et al., 1996	Horizontal Cylinder	Number of Samples and Sample Size	Solidification, Slicing, and Scanning with a Video Camera followed by Image Analysis	Mixing results were greatly impacted by the number of samples. The sample size, however, was not really a factor.
Brone, et al., 1998	V-blender	Rotation Rate and Fill Level	Same as Wightmen, et al., 1996	Varying the rotation rate from 8 to 24 rpm did not affect the rate of mixing as measured by total revolutions. The rate of mixing increased when the fill level was reduced from 60% down to 40%.
Chester, et al., 1999	Double-cone Blender	Loading Pattern, Fill Level, and Number of Rotations	Computed Tomography (CT) Scanning and Image Analysis	Good axial mixing (top down) was achieved after 10 to 20 rotations, but radial mixing (side-to-side) was still poor. The 80% fill level resulted in a dead zone at the center that was not apparent at the 50% fill level.
El-Hagrasy, et al., 2006 Part 1	V-blender	Humidity, Component Concentration, Blender Speed, Particle Size, and Density	Near-Infrared (NIR) Spectroscopy	Humidity, component concentration, and blender speed affected the blending process, but only humidity and concentration impacted the particle size and density of powder mixtures.
El-Hagrasy, et al., 2006 Part 3	V-blender	Intra-shell and Inter-shell Mixing	Near-Infrared (NIR) Spectroscopy	Intra-shell (left-to-right) mixing was achieved faster than inter-shell (top, middle, or bottom) mixing. The bottom level mixed faster than the top level for inter-shell mixing.

Table 2: Comparison Studies for Tumbling Mixers

Citation	Mixer Types	Factors Tested	Evaluation Method	Findings
Kaufman, 1962	Double-cone vs. V-blenders	Fill Level, Component Concentration, Number of Rotations, and Size of V-blender	Thief Sampling and Calculation of Variance	Each variance calculation was based on 10 samples. The V-blender mixed better than the double-cone. The largest V-blender mixed faster than the two smaller ones.
Carley-Macauly and Donald, 1962 Part 1	Cylinders vs. Double-cone Blenders	Number of Samples and Rate of Mixing	Thief Sampling and Calculation of Variance	Each variance calculation was based on 40 to 60 samples made up of 40 to 60 pieces of colored sand. The primary rate of mixing occurs around the plane of rotation while the secondary rate is perpendicular to that.
Carley-Macauly and Donald, 1962 Part 2	Cylinders vs. Double-cone Blenders	Loading of the Mixer, Speed of the Mixer, and Particle Size	Thief Sampling and Calculation of Variance	The extent of mixing should be measured by the total number of revolutions instead of the speed of the mixer. A 33% fill level produced about the same rate of mixing for the two mixer types. The rate of mixing for the horizontal cylinder decreased as the fill level neared the centerline.
Carstensen and Patel, 1977	Horizontal Cylinder vs. V-blender	Non-spherical Particle Size and Concentration (Percent Weight Basis)	Sieving and Counting of Colored Particles or Spectroscopy	Concentration did not affect the blending rates. Mixing two different particle sizes led to inadequate mixing as measured by standard deviation in both mixer types.
Moakher, et al., 1999	Double-cone vs. V-blender	Particle Flow – Mixing and Segregation	3D Particle Dynamics Simulations	The double-cone blender exhibited an almost continuous flow while the V-blender had a distinct intermittent flow resulting in faster mixing, but both blenders had segregation patterns that kept appearing.
Lemieux, et al., 2007	V-blender vs. Bin-blender	Loading Profile, Fill Level, and Rotational Speed	Thief Sampling, Image Analysis, and Discrete Element Method	The V-blender mixed better than the bin blender using a right-left loading profile. The mixing time was greater for higher fill levels and less for higher rotational speeds.

Table 3: Agitated Mixer Studies

Citation	Mixer Type	Factors Tested	Evaluation Method	Findings
Cook and Hersey, 1973	Nauta Mixer	Mixing Time for Multiple Component Mixtures	Thief Sampling and Gas Liquid Chromatography	30 samples were taken for each data point. Each component mixes at different rates, but brief homogeneity occurred between 4 and 7 minutes for the four components tested.
Masiuk, 1987	Ribbon Mixer	Speed of Rotation, Loading Ratio, and Mixing Time	Thief Sampling and Calculation of Weight Concentration	For the binary mixture experiment of rotating a 4:1 sand to ionite ratio at 44.4 rpm, it took between 4 and 7 minutes to get homogeneity.
Hiseman, et al., 2002	Planetary Mixer	Speed, Fill Level, and Particle Flow	Positron Emission Particle Tracking (PEPT)	The agitator movement affected the particle flow in the center of the mixer while the planetary motion caused the particles near the wall to move upward in ascending steps. This was noticed at all speeds and fill levels.
Zhou, et al., 2004	Cylindrical Bladed Mixer	Particle Flow	"Modified" Discrete Element Method (DEM)	An area of strong recirculation occurred in front of the blades with more force between particles required at the bottom by the corner caused by a higher coefficient of sliding friction and/or a lower coefficient of rolling friction. Higher coefficients of friction gave the particles more potential energy that required more torque to stir the mixture.
Porion, et al., 2004	Turbula® Shaker-Mixer	Speed, Particle Size, and Fill Level	Magnetic Resonance Imaging (MRI)	80% was considered the maximum fill level. Segregation occurred at lower speeds. The mixer was found to work well for binary mixtures of dry particles when smaller particles of 10% or less concentration are mixed with larger particles at a high speed.
Jones, et al., 2007	Ploughshare Mixer	Rotor Frequency and Fill Level	PEPT	For batch mixing, it was determined that the fill should range from 12.5% to 25% and the rotor should operate at 4 Hz.

2.2.2 Agitated Mixers

Many types of agitated mixers are also on the market. Table 3 indicates the results of experiments with the following mixers. The Nauta mixer consists of a vertical cone containing a screw that circulates around the inside. The Ribbon mixer has two or more helical ribbon blades that are attached to two side-by-side shafts in a horizontal chamber. The planetary mixer includes a K-beater agitator that moves around two vertical axes at the same time inside a bowl. The cylindrical bladed mixer consists of a rod in the center with two flat blades attached that move in a circle around the bottom of a vertical cylinder. The Turbula® shaker-mixer has a cylindrical mixing chamber that is secured in a device using turbulent rotation, translation, and inversion. The ploughshare mixer is a cylindrical horizontal mixer in which blades attached to a rotating horizontal bar sweep around the cylinder.

2.3 Mixing Factors

Many factors need to be considered when evaluating the mixing capability of mixing equipment for solids. The *A.I.Ch.E. Standard Testing Procedure for Solids Mixing Equipment* lists the following factors: "uniformity of composition and properties or quality of mix, time required for mixing in batch equipment, ease and frequency of cleaning, need for manual cleaning, formation of dust, time required for filling and emptying, ease of filling and emptying, completeness of discharge, location of any material retained, and wear of equipment (1961)." This standard also addresses the sampling process and the factors that affect it such as sampling time, size, method, location, and number of samples, which are especially important to this research project. In addition to these factors, particle size and total amount of ingredients must also be

considered. Overfilling or under-filling the mixer can result in inadequate mixing (Herrman and Behnke, 1994).

2.3.1 Batch Mixers

For batch mixers, the mixing time required to achieve adequate mixing must be determined by experimentation since there is not yet a theoretical model that can be used to predict it (Weinekötter and Gericke, 2000). These experiments consist of running several trials of equal batch size with varied mixing times while using a common sampling process after the mixer is stopped. Experiments must be repeated for different batch sizes. Anywhere from five to up to fifteen samples should be taken after each batch. As for the sample size, the maximum amount per sample should not exceed the smallest amount of product required to meet a defined specification unless a larger sample size can't be avoided. When it comes to the sampling method, care should be taken to cause minimal disturbance to the mixed product when taking samples. At the end of the batch mixing time, sampling can be done in one of three ways: while the product is still inside the mixer, while removing the product from the mixer, or after removing the product from the mixer. For sampling locations, samples are to be randomly taken throughout the entire mixed product (A.I.Ch.E. Standard Testing Procedure for Solids Mixing Equipment, 1961).

2.3.2 Agitated Mixers

Blades that come in many different shapes and sizes can be used to induce mixing in agitated mixers. Bagster and Bridgwater studied the effects of moving a long flat blade horizontally through granular material. Some key findings were that the rake angle

and immersion (depth) of the blade were very important factors, but roughness and velocity of the blade were not for the most part (1970). Laurent, Bridgwater, and Parker looked into the effects of passing a long flat blade through a particle bed in a horizontal cylindrical shell where the blade is attached on a rotor shaft via six radial arms. The main finding was that the number of times the blade passed through the particle bed affected the patterns of particle motion the most instead of the speed of the blade. They also found that there was a somewhat stagnant zone located right below the rotating shaft (2000). Laurent and Bridgwater further tested this mixer with different geometries. With six long flat blades evenly spaced, they noticed that a circulation loop appeared beneath the shaft. After changing the geometry to four rows of short paddles spaced evenly around the shaft that consisted of two rows with five paddles on opposite sides and two rows with four paddles, the circulation loop disappeared. Also, the axial dispersion coefficient for the paddle geometry was greater for higher fill levels as opposed to the six-bladed geometry where it was smaller for higher fill levels (2002).

2.4 Segregation and Percolation

Segregation, which occurs when ingredients of different size, shape, density, or resilience separate out during mixing, is a well-known problem that occurs when mixing solids. Segregation is most prevalent when there is a difference in ingredient size. Agitation or motion causes the ingredients to change position and sometimes segregate instead of mix. Smaller ingredients can percolate or filter through spaces between larger ingredients and end up gathering in one area if not disturbed by further mixing. It is important to note that measurable segregation can still occur when there is only a slight difference in ingredient size (Harnby, et al., 1997).

2.5 Sampling and Evaluation Procedures

The last, but most certainly not least, factor to consider is how to evaluate the performance of the mixer to see if it is achieving an adequate final mixture. In order to do this, a tracer is included when initially loading the mixer. Some examples of a tracer are salt and/or whole kernel corn in the amounts of 0.5% and 5%, respectively (Lindley, 1991). Samples taken at the end of the batch mixing time are analyzed for the amount of tracer in each and this data is used to calculate a coefficient of variation (CV). A CV for an adequate mixture is no greater than 10% (Harner, et al., 1995). Relative standard deviation (RSD) is the same thing as coefficient of variation. RSD is a more commonly used term in the pharmaceutical industry (Lemieux, et al., 2007).

The type and contents of the mixer are considered when selecting the sampling method. Some sampling methods are: using a probe or thief, dividing the whole mixture into countable segments, adding a polymer to "freeze" the mixture so slices can be removed, or passing cups under an outlet stream. Evaluation procedures include, but are not limited to: counting, image analysis, spectroscopy, chemical analysis, and X-ray fluorescence. 5 to 15 samples are recommended for analysis and the total amount of mixed product removed should be less than 5% (Fan, et al., 1970). Muzzio, et al. performed an experiment that involved sampling non-cohesive granular blends via four different probes – a Globe-Pharma sampler, groove thief, end-cup sampler, and core sampler. They found that using probes could result in misleading results because inserting the probes disrupted the granular bed. The core sampler performed much better than the others by being able to collect the most samples from one insertion with the smallest variation in sample size while disrupting the granular bed the least.

In a review of segregation, Williams noted that even if an adequate mixture is obtained as defined by "equilibrium between mixing and segregation," further handling and storage of the mixture might upset this delicate balance (1976). Results of an experiment using UV spectroscopy to analyze powder blends in a V-blender showed that some segregation can still occur after obtaining sufficient mixing according to RSD calculations. One of the blends went from 3.17% up to 33.14% and then back down to 2.10% over a period of 4 minutes that occurred 6 minutes after the designated mixing end point (El-Hagrasy, et al., 2001). An experiment where sand was mixed in a tote blender, however, indicated that the mixture homogeneity stayed consistent after being transferred into a cylindrical bin as measured by RSD calculations based on core sample results (Sudah, et al., 2002).

CHAPTER III

METHODOLOGY

3.1 Mixer Description

The Kushlan portable mixer provided, Model 350W (Stafford, TX), has the specifications shown in Figure 1 below that come directly from Kushlan's *Assembly & Operating Instructions and Parts Manual for Model 350W & Model 350WSB & Model 600W* (May 2004).

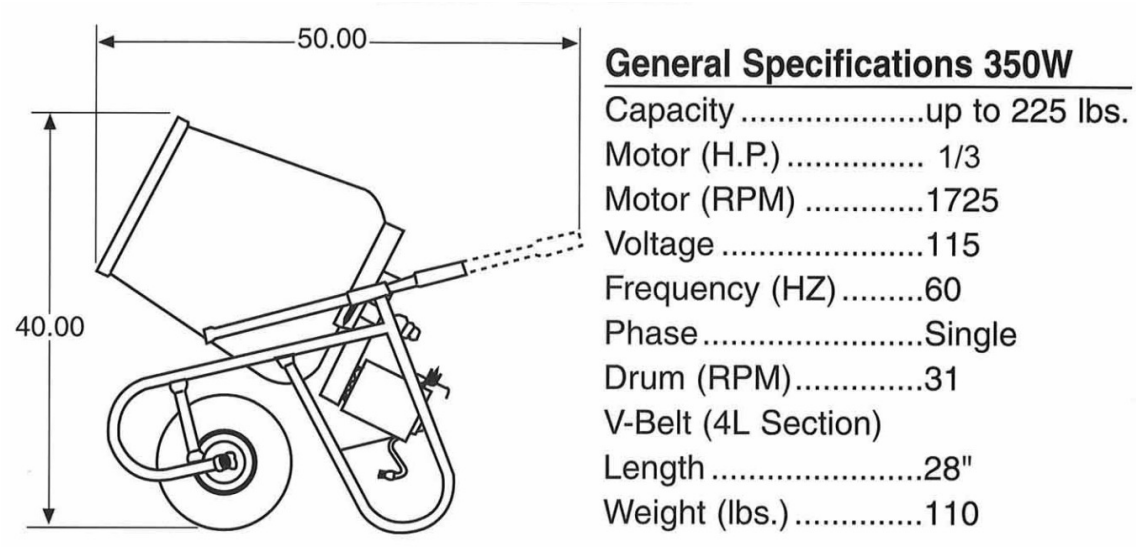

Figure 1: General Specifications for Kushlan Mixer 350W

There are currently two 3.5 cubic feet capacity drums available from the manufacturer (noted as drums 1 and 2) that attach into the portable base unit of the mixer. This explains the main reason for the two very close model numbers, 350W and 350WSB.

Model 600W comes with a drum that has 6 cubic feet of capacity, but was not tested in this research. The two provided drums were initially testes and then modified in an effort to maximize their mixing capability. Five total configurations between the two drums were tested and are explained in the following sections.

3.1.1 Drum 1

Drum 1 is the drum that comes with Model 350W. It has two molded-in plastic paddles as can be seen in Figures 2 and 3.

Figure 2: Model 350W with Molded-in Plastic Paddles (Drum 1) Side View

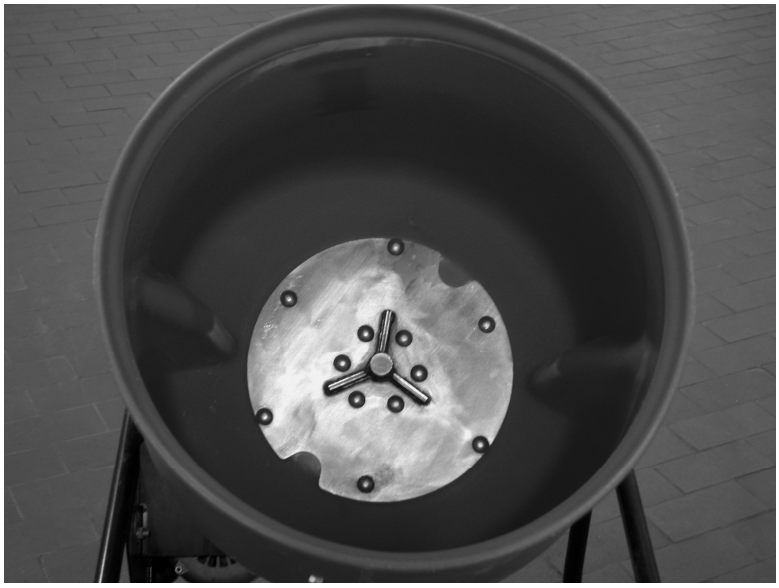

Figure 3: Model 350W with Molded-in Plastic Paddles (Drum 1) Front View

3.1.2 Drum 2

Drum 2 is the drum that comes with Model 350WSB. It has three stainless steel blades with gaps between the blade and the drum wall as depicted in Figures 4 and 5.

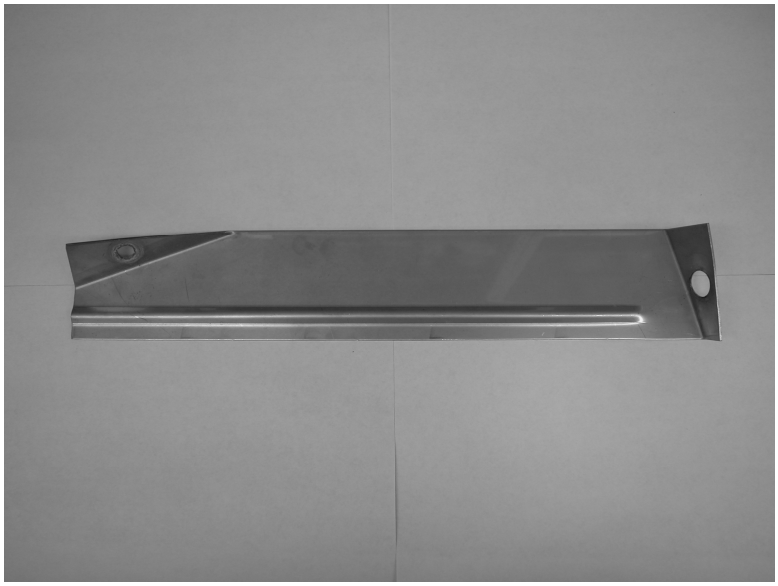

Figure 4: Model 350WSB Individual Stainless Steel Blade

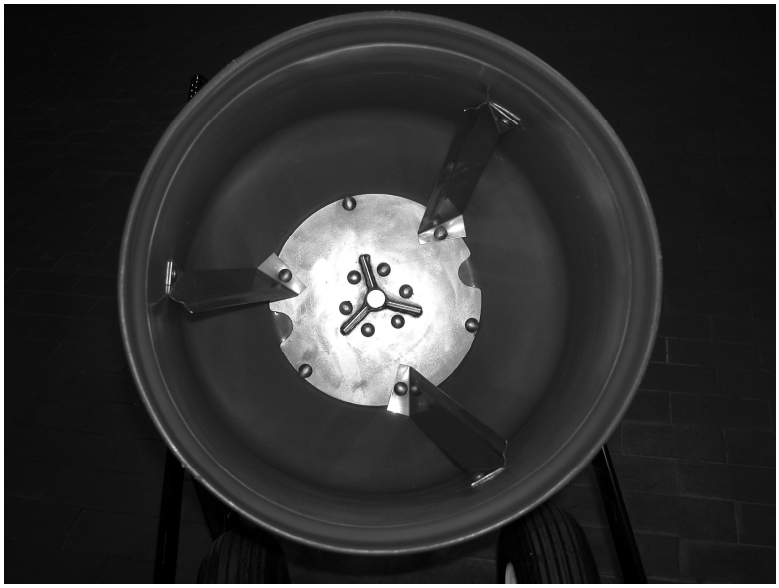

Figure 5: Model 350WSB with Stainless Steel Blades (Drum 2)

3.1.3 Drum 3

Drum 3 is a modified version of drum 1 designed to hinder circulation loops. Two of the stainless steel blades from drum 2 were added to drum 1 halfway between the molded-in plastic paddles on both sides of the drum as shown in Figure 6.

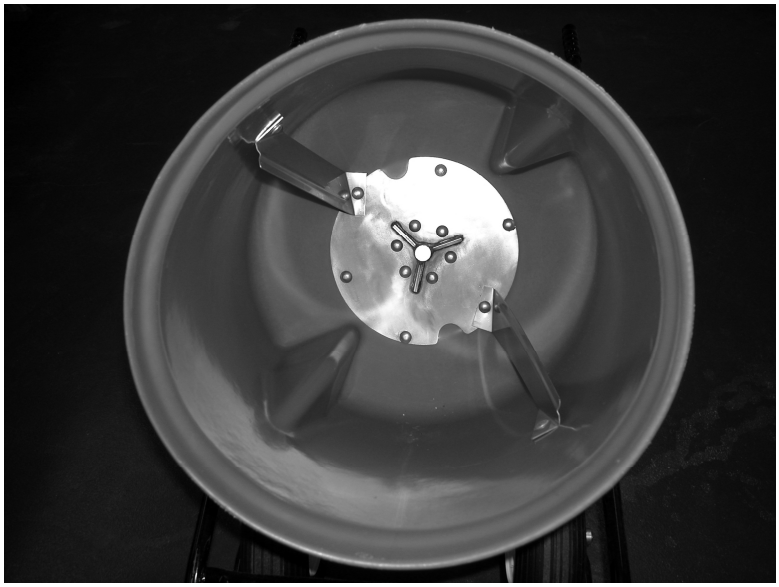

Figure 6: Combination of Molded-in Paddles and Stainless Steel Blades (Drum 3)

3.1.4 Drum 4

The remaining stainless steel blade in drum 2 was removed and three brand new stainless steel blades were made and installed in this drum to make up drum 4. The three new blades attached to the drum in the same way as the original blades at the same angle, but the new blades were lengthened to sit flush up against the side and bottom of the drum as depicted in Figure 7 in order to prevent particles from sliding underneath them.

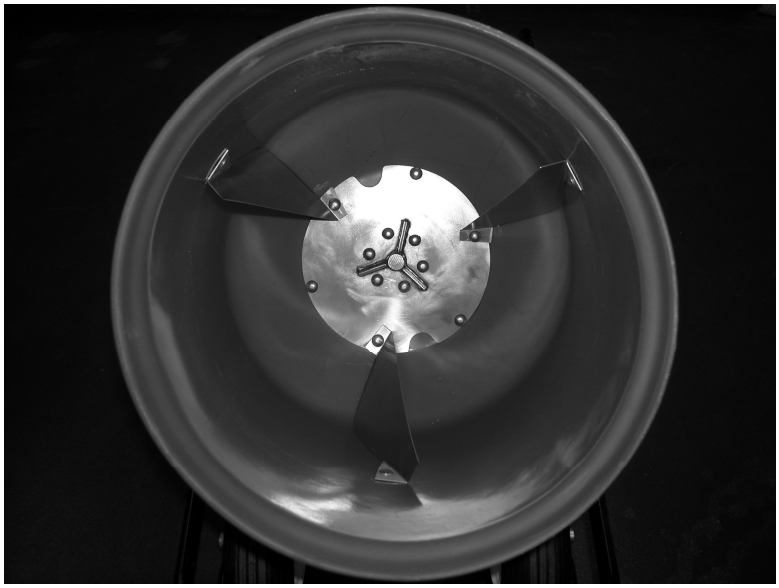

Figure 7: New Stainless Steel Blades Flush against the Side and Bottom (Drum 4)

3.1.5 Drum 5

Three more stainless steel blades were made (see Figure 8) and added to the center of drum 4 to get drum 5, which now has a total of six stainless steel blades as can be seen in Figure 9 in an effort to hinder circulation loops and segregation.

Figure 8: Individual Stainless Steel Center Blade

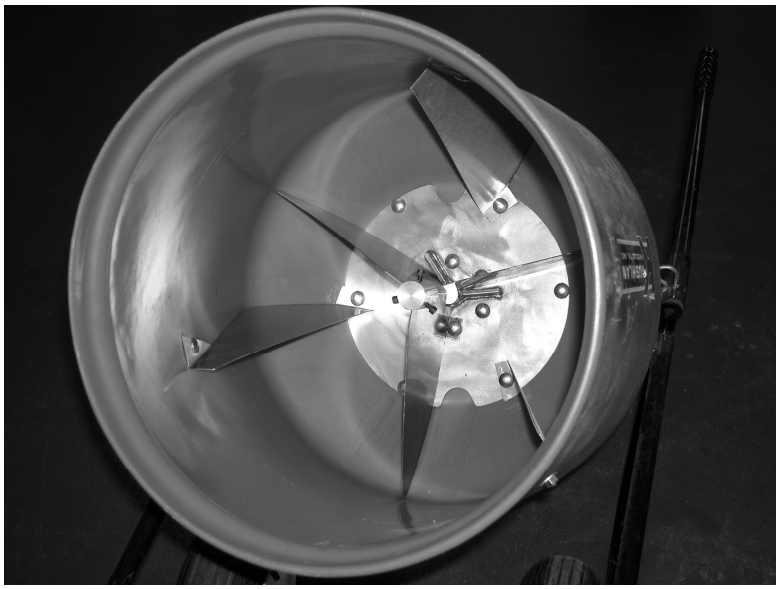

Figure 9: Six Stainless Steel Blades (Drum 5)

3.2 Methods

3.2.1 ASAE S380

ASAE S380 DEC95 is the "test procedure to measure mixing ability of portable farm batch mixers." It was the most appropriate procedure to use because of its intended application as related to this project and because of the immediate availability of the equipment required to perform the evaluation. The Kushlan mixer is a portable batch mixer with mixing ability that needs to be measured for potential food applications. Also, a grinder was available for the required base material, corn, as well as an analyzer for the salt tracer. Some modifications were made, however, to the sampling method as detailed in the following sections.

3.2.2 Magnetic Particle Tracer Substitution

The ASAE S380 procedure calls for using salt as the tracer. Analyzing the salt concentration in each sample, however, proved to be a bit difficult because it required extensive preparation, needed multiple analyses per sample in order to estimate the total amount of salt in the sample, and took a long time to evaluate since the analyzer took a while to stabilize each time. In an effort to find an alternative method to the salt concentration test, steel abrasive blasting media, SAE size no. G-25 grit, was selected as a potential substitution for the tracer because it can be easily recovered from samples using a strong electromagnet and it is the closest in size to table salt crystals. There is currently no literature available on this media having been used before for this type of application. This steel grit, which is made by freezing and shattering steel shot, was obtained from the AMASTEEL Division of Ervin Industries located in Adrian, Michigan

and Butler, Pennsylvania and will be referred to as the "shattered" steel tracer. As part of the screening study mentioned later, SAE size no. S-230 steel shot from Ervin Industries was also obtained and tested. This steel shot will be referred to as the "spherical" steel tracer. Pictures of the steel tracer are shown in Figure 10 with the shattered grit in the left photo and the spherical shot in the right photo. According to the "AMASTEEL SAE Specs" brochure found under the 'Document Library' section of the Ervin Industries website, ervinindustries.com, steel grit should have a density greater than or equal to 7.3 gm/cc while steel shot should be greater than or equal to 7 gm/cc. The density of salt (pure sodium chloride) is 2.165 gm/cc according to the Salt Institute. Since the steel media is denser than the salt, a series of tests is required directly comparing the two to see if the steel tends to segregate more when used in a commercial food mixer under similar conditions. This will be done in the V-blender trials (see section 3.2.4) using equal mixing times and sample intervals.

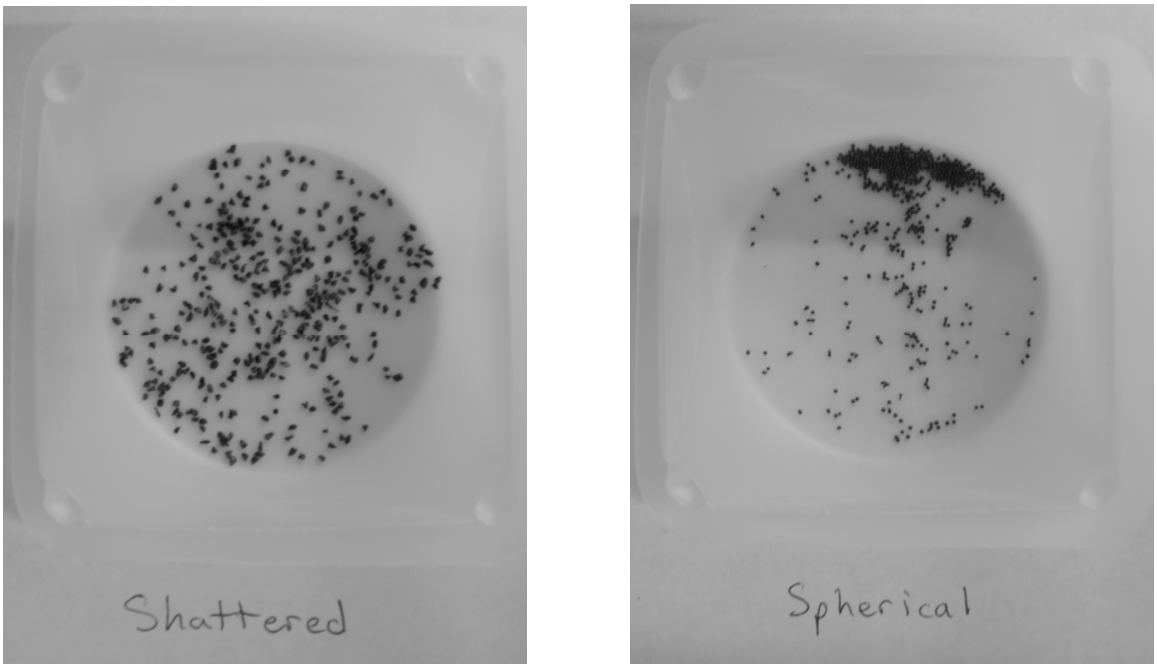

Figure 10: Steel Tracers (Actual Size)

3.2.3 Preliminary Trials

The preliminary tests used drums 1, 2, and 3 and consisted of 11 trials that are numbered as trials 1 through 11. The purpose of these trials was to experiment with the procedure and get an initial indication of how well the different drums were mixing. The general testing procedure used was:

1. Start with a clean, dry mixing bowl and ingredients at room temperature in an indoor laboratory. Grind a sufficient amount of the U.S. Grade No. 2 whole kernel corn using a hammer mill with a 3/8 inch screen.
2. Measure and add the desired amount of base material (ground corn) to the mixing bowl.
3. Measure and add the desired amount of tracer (steel abrasive media, salt, or whole kernel corn) to the approximate geometric center of the base material in the mixing bowl.
4. Operate the mixer for the specified time period, measured using a timer.
5. Once the mixer is turned off, unload it by lifting the handles to tilt the bowl down and dump the mixed contents or "product" into a plastic bin large enough to contain the entire mixture. Carefully lift the plastic bin and dump the mixture into the hopper of a vibratory feeder.
6. Operate the feeder in continuous mode (weigh scale hopper detached) and catch fifteen mixed "product" samples at designated time periods (pre-determined by how long it takes the batch size to feed completely through) by sweeping individual sample cups under the cascading product as it falls from the end of the feeder trough down into a collection bin.

7. Once all of the mixture has fed through and the feeder has been turned off, dispose of the mixture located in the collection bin and clean the mixing bowl and the vibratory feeder.
8. Depending on which tracer was used, analyze the fifteen samples for the amount of tracer in each by mining for the steel with an electromagnet, measuring the salt using a laboratory chemical procedure, or sifting through a sieve to separate out the whole kernel corn and use the resulting data to determine the coefficient of variation (CV).

For step 1 of the procedure, a Fitz®Mill Communitor (model DAS06, The Fitzpatrick Company, Elmhurst, IL) with 3/8 inch screen in place was used as depicted in Figure 11 to obtain the ground corn. The ground corn was collected and stored in a 32 gallon Rubbermaid® Brute® Container (Item No. 2632), which is visible underneath the mill in Figure 11. This container also had a snap-fit lid (Item No. 2631), which was used for sealed storage and wheel attachment (Item No. 2640), which provided mobility to and from the freezer during storage. The container of corn was removed from the freezer the day before trials were run in order for the corn to warm to room temperature.

Figure 11: Hammer Mill with 3/8 Inch Screen

For step 2, a Mettler Toledo SpeedWeigh® scale (model SW, Mettler-Toledo, Inc., Columbus, OH) was used with a tared 5 gallon plastic bucket. See Figure 12.

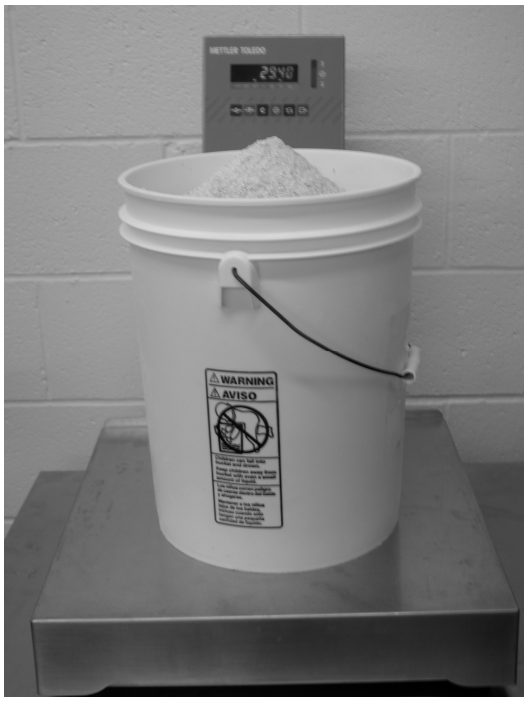

Figure 12: Weighing of Ground Corn

For step 3, tared plastic weighing boats on an electronic analytical balance (model A-160, Denver Instrument Co., Bohemia, NY) were utilized to weigh the salt and steel tracers and a tared 1000 mL plastic beaker on the Mettler Toledo scale was utilized to weigh the whole kernel corn tracer. The tracer was placed in the approximate geometric center of the base material in the mixing bowl as shown in Figure 13.

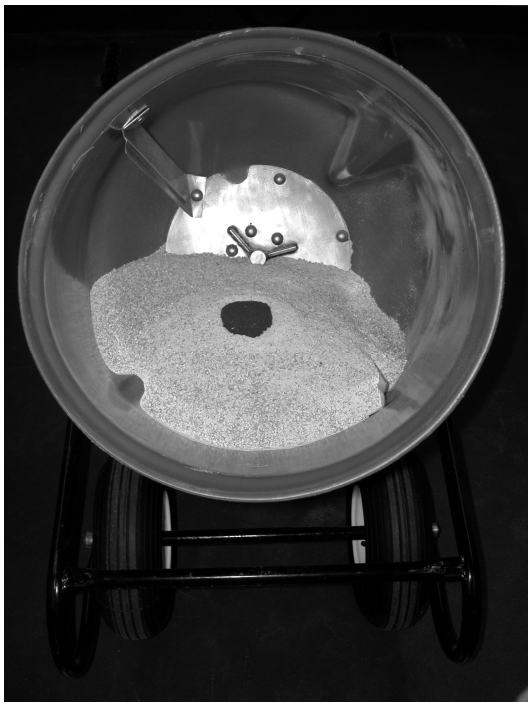

Figure 13: Loading of Mixing Bowl

For step 4, the mixing time was measured using a West Bend® electronic timer (Cat. No. 40035, The West Bend Company, West Bend, WI).

For step 5, the mixer was unloaded by dumping the mixed product into a plastic ToteAll 2000® bin (Koch Supplies, Inc., Kansas City, MO) as can be seen in Figure 14.

Figure 14: Dumping of Mixed Product from the Drum into the Plastic Bin

The mixture was then dumped into the hopper of the vibratory feeder (model ME109, Actionpac Scales & Automation, Ventura, CA) as depicted in Figure 15. The hopper slide gate was attached and in the down position throughout the preliminary trials.

Figure 15: Dumping of Mixed Product from the Plastic Bin into the Hopper

For step 6 of all the preliminary trials, the hopper vibration mechanism (attached to the back side of the hopper) was unplugged during the use of the feeder. Samples were taken in 6 oz polystyrene clear jars (Item No. 70220, US Plastic Corporation, Lima, OH) by holding them one at a time under the narrow end of the chute that is attached below the feeder trough (shown in Figure 16) and is narrow enough to completely catch the cascading sample stream at designated times until the jars were slightly more than brim-full. The jars came with white polypropylene screw caps. After each sample, the excess mixture that was collected above the brim of each cup was quickly scraped off by passing the cap flat across the brim. The cap was then screwed on and the sample set aside. The remaining mixture that was not collected during sampling was allowed to drop into a 20 gallon plastic bin that is also shown at the bottom of Figure 16.

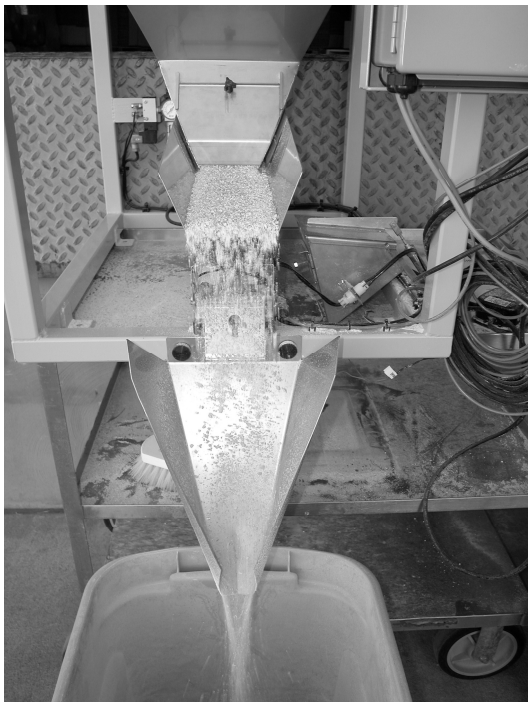

Figure 16: Feeding of Mixed Product for Sampling

For step 7, the mixing bowl was cleaned by tilting it over a drain and spraying the interior with hot tap water (greater than 130°F) for two minutes at approximately three

gallons per minute. The bowl was left inverted to air dry. The vibratory feeder was cleaned by brushing out particles with a paint brush.

For step 8, each sample was spread one at a time onto a white, ribbed, plastic tray by gently shaking it out of the plastic jar. After that, a strong electromagnet (12 VDC, 5.6 Watt, 2 inch diameter, Part number 5698k116, McMaster Carr, Elmhurst, IL) was used to collect the steel grit tracer from each sample. The steel collection procedure involved six separate passes of the electromagnet over and through the sample. First, the electromagnet was passed over the entire sample keeping it about an eighth of an inch above the sample. Figure 17 shows the steel collected on the magnet as a result.

Figure 17: Tracer Collected on Electromagnet during First Pass

For the second pass, the electromagnet was held at a slight angle with one side touching the sample and moved it down each row between the ribs of the tray in a circular motion. For the third pass, with one side still touching the sample, the electromagnet was run down the entire length of the tray a couple of times between each set of ribs including the

short section between the edge of the tray and the outside rib changing the angle of the magnet after each run. After the third pass, a repeat of the first pass was performed holding the electromagnet above the sample while sweeping it down the tray. For the fifth pass, the electromagnet was moved back and forth through the sample parallel to the ribs of the tray. For the sixth and final pass, the first pass was repeated one last time. There should be very few, if any, pieces of steel tracer collected at this point. The tracer collected on the electromagnet was removed and placed in a tared plastic weighing boat after each pass. Occasionally small pieces of corn and/or corn dust collected on the electromagnet along with the steel tracer. When this happened, it was brushed off with a gloved finger while the electromagnet was still on allowing the electromagnet to keep hold of the steel tracer. The total tracer collected for each sample was weighed on the same A-160 electronic analytical balance that was used in step 3.

For all of the preliminary trials, both the whole kernel corn and steel tracers were used. The steel tracer used was the shattered grit. The whole kernel corn tracer, however, was only included as a back-up option for mixture analysis (per the recommendation of ASAE S380 when using a salt tracer) in case there was a problem initially with our process of using the steel tracer. The steel tracer was easily recovered from the samples, though, so the whole kernel corn tracer was not analyzed. The drum type, mixing time, and total mix used were varied as listed in Table 4.

Table 4: Mixing Variables for Preliminary Trials

Trial	Drum	Mixing Time (min)	Total Mix (lbs)
1	1	5	60
2	1	10	30
3	2	10	30
4	2	20	30
5	2	20	30
6	2	20	60
7	2	20	60
8	2	20	60
9	3	10	30
10	3	20	30
11	3	5	30

The total mix used included the tracer. For example, 60 lbs of total mix consisted of 3 lbs (5 wt%) of whole kernel corn, 0.3 lb (0.5 wt%) of steel tracer (136.1 g), and 56.7 lbs of ground corn (weighed in two buckets). These amounts were divided in half when 30 lbs of total mix was required. Before sampling times were determined, the hopper was loaded with ground corn from two brim-full 5 gallon buckets just like the one shown in Figure 12. This was the equivalent of 60 lbs of ground corn. It took approximately 140 seconds for this amount to go through the feeder. Based on this, samples were taken every 9 seconds when feeding 60 lbs of total mixture and every 5 seconds when feeding 30 lbs. The time was monitored using the same electronic timer mentioned in step 4 of the detailed procedure explanation.

3.2.4 V-blender Trials

The V-blender was the commercial food mixer selected to use as a standard for testing the general procedure for comparison to the Kushlan mixer and for testing the difference between using the recommended salt tracer versus the steel tracer. The V-blender tests consisted of 11 trials using the P-K Blend Master® Lab Blender (intensifier

model, Patterson-Kelley Co., East Stroudsburg, PA) with a 16 quart capacity "V" shaped shell made of Type 316 stainless steel that is depicted in Figure 18. According to the owner's manual, the shell rotates at approximately 25 RPM. These trials are numbered as trials 12 through 22.

Figure 18: Patterson-Kelley V-Blender used in Trials 12 through 22

Four things were varied during these trials: the tracer type, tracer amount, mixing time, and sample interval as shown in Table 5. The sample intervals are designated by the letters x, y, and z where x indicates samples were taken every 12 seconds, y indicates samples were taken every 10 seconds, and z indicates samples were taken every 8 seconds with the first sample being taken 15 seconds after starting the feeder. Due to the capacity of the V-blender, all trials were performed with 20 lbs of total mix. It took 4 minutes and 25 seconds for 19.6 lbs of ground corn to go through the feeder. The steel tracer used was the shattered grit and the salt tracer used came from a 26 oz container of Morton® Salt (Plain Table Salt, Morton International, Inc., Morton Salt, Chicago, IL).

Table 5: Mixing Variables for V-blender Trials

Trial	Tracer Type	Tracer Amount (wt%)	Mixing Time (min)	Sample Interval
12	Steel	0.5	5	x
13	Steel	0.5	5	y
14	Steel	0.5	5	z
15	Steel	2.0	2	x
16	Steel	2.0	8	x
17	Salt	2.0	5	x
18	Steel	2.0	2	y
19	Steel	2.0	8	y
20	Salt	2.0	5	y
21	Steel	2.0	2	z
22	Steel	2.0	8	z

The following modifications were made to the detailed procedure discussed in section 3.2.3. After adding the ground corn into the V-blender in step 3 by dumping it as equally as possible into both top ends, the tracer was added on top of the corn in the center of the "V" located just beneath the top of the weld joint on the inside. For emptying the blender in step 5, the blender was stopped at the end of the mixing time with the bottom of the "V" at an angle of 45° below horizontal because there wasn't enough space between the bottom of the blender (when in the vertical position) and the cart it was mounted on (see Figure 25) to fit a collection container. The empty and clean 5 gallon plastic bucket initially used to weigh the corn in step 2 was placed beneath the bottom of the blender to collect the mixed product as it fell out after the bottom latch was opened.

For the salt tracer analysis in trials 17 and 20, Orion procedure no. 205 was followed, which is the procedure for finding "salt in canned vegetables." Blending was not required since the salt was intentionally added as the tracer to the solid mixture and thus didn't have to be extracted from the corn. The procedure was run three times for each sample and the results were averaged and used to calculate the CV.

3.2.5 Screening Study

The next step was to determine what variables or factors have the greatest effect on the mixing and evaluation processes so that they can be optimized. This was done by performing a fully saturated screening test of mixing factors. An 8 trial design with two levels for seven factors was chosen, which is the set-up recommended by Paul Funkenbusch (2005). The seven factors, labeled A through G, along with their descriptions and two levels (where -1 = 'low' and 1 = 'high') are listed below in Table 6.

Table 6: Factor Descriptions and Associated Levels

Factor	Description	Level	
		-1	1
A	Mixer Drum	Drum 4	Drum 3
B	Mixing Time	5 min	10 min
C	Steel Tracer Amount	0.5 wt%	2 wt%
D	Bulk Media Size	1/4" screen	3/8" screen
E	Bin Transfer	Yes	No
F	Steel Tracer Shape	Shattered	Spherical
G	Sample Interval	Shortest	Normal

All trials were performed with 30 lbs of total mix. The bulk media used was ground corn made with the indicated screen size. Bin transfer refers to the process mentioned in step 5 of section 4.1 and "no" means the mixture was dumped directly from the drum into the hopper at the end of the mixing time. These trials are numbered as trials 23 through 30.

It took 6 minutes and 30 seconds for 29.4 lbs of ground corn (the amount required when using 2 wt% of steel tracer) to go through the feeder. For the sampling interval, "shortest" refers to taking samples every 10 seconds and "normal" refers to every 15 seconds with the first sample being taken 15 seconds after the feeder was started in both cases. The level of each of the seven factors for a given trial was set according to the array shown in Table 7. For example, trial 23 utilized drum 4, had a mixing time of 5

minutes for 0.5 wt% of the spherical steel tracer added to corn that was ground to 1/4", excluded the bin transfer, and had samples taken from the feeder using the "normal" interval of every 15 seconds. Each trial was performed only once.

Table 7: 8 Trial Array for the 7 Factors

Trial	Factor						
	A	B	C	D	E	F	G
23	-1	-1	-1	-1	1	1	1
24	-1	-1	1	1	-1	-1	1
25	-1	1	-1	1	-1	1	-1
26	-1	1	1	-1	1	-1	-1
27	1	-1	-1	1	1	-1	-1
28	1	-1	1	-1	-1	1	-1
29	1	1	-1	-1	-1	-1	1
30	1	1	1	1	1	1	1

3.2.6 Bulk Media Study

After the screening study, a different bulk media was tested to see how it would affect the mixing capability. All-purpose flour was chosen because of its smaller particle size and possible application due to its usual inclusion in bakery mixes. This study consisted of 11 trials divided into two parts: 5 trials (2 corn & 3 flour) for part 1 and 6 trials (3 corn & 3 flour) for part 2. See Table 8 for the factor settings of the two parts. These trials are numbered as trials 31 through 41.

Table 8: Factor Settings for Bulk Media Study

	Part I	Part II
Mixer Drum	Drum 3	Drum 5
Mixing Time	10 min	10 min
Steel Tracer Amount	0.5 wt%	0.5 wt%
Ground Corn Size	1/4"	1/4"
Bin Transfer	Yes	Yes
Steel Tracer Shape	Shattered	Shattered
Sample Interval	Normal	Normal*

*Extended for flour trials

The flour used came from 25 lb. bags of the Great Value brand marketed by Wal-Mart Stores, Inc. All trials were performed with 30 lbs of total mix. It took around 7 minutes for 29.85 lbs of ground corn to go through the feeder and 6 minutes and 30 seconds for the same amount of flour. The vibrator was required to move the flour through the feeder because the small particles would clump together and get stuck in the hopper without it. Also, the adjustable plate attached to the bottom of the hopper was removed for the flour trials. Figure 19 shows the hopper with and without this plate.

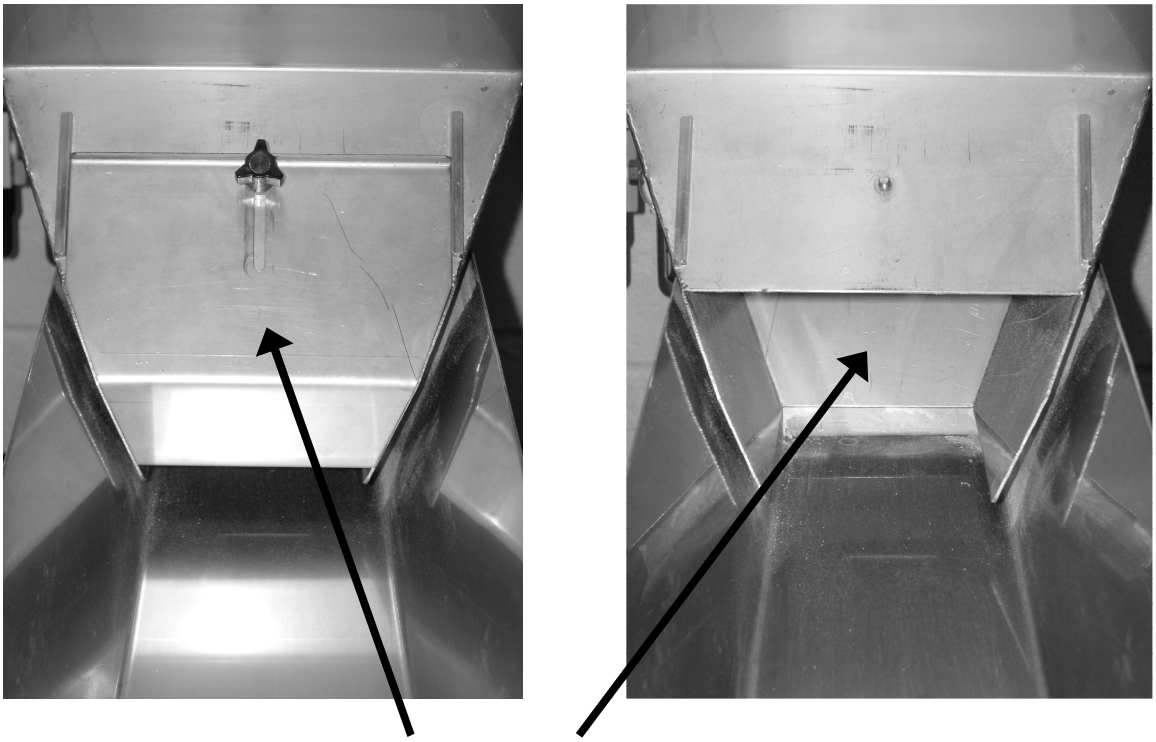

Figure 19: Hopper with and without the adjustable plate attached

For the sampling interval, "normal" still refers to every 15 seconds. This sampling interval was used for both the corn and flour trials.

For part 2, two things were changed: the mixing drum and sample interval. First, the mixer drum was switched from drum 3 to drum 5 for both the corn and flour trials in order to test one more drum configuration. Second, for only the flour trials, the sample interval was adjusted to every 27 seconds with the first sample being taken 15 seconds

after the feeder was started in order to get a more representative sampling of the entire batch of mixed product. The sample interval for the corn trials was left at every 15 seconds to be able to directly compare the results of utilizing drum 5 versus drum 3. The bulk media study was the last set of trials for this research project.

CHAPTER IV

RESULTS AND DISCUSSION

4.1 Preliminary Trials

The CVs obtained for the preliminary trials via the sample calculation in Appendix A ranged from 21.02% to 136.71% as noted in Table 9. The raw data for these trials and all other trials in this research project can be found in Appendix B. Two of the three highest CVs at 136.71% for trial 1 and 63.68% for trial 2 were obtained using drum 1, which with the two molded plastic paddles and no stainless steel blades appeared to have more of a tendency to segregate the ground corn and tracer rather than mix it.

Table 9: Mixing Results for Preliminary Trials

Trial	Drum	Mixing Time (min)	Total Mix (lbs)	CV (%)
1	1	5	60	136.71
2	1	10	30	63.68
3	2	10	30	30.30
4	2	20	30	39.69
5	2	20	30	53.55
6	2	20	60	54.91
7	2	20	60	35.61
8	2	20	60	37.40
9	3	10	30	21.02
10	3	20	30	103.97
11	3	5	30	27.69

The other really high CV of 103.97% was obtained in trial 10 using drum 3. This appears to be the result of over-mixing that lead to segregation as the mixing time for this trial was the highest used at 20 minutes. When shorter mixing times of 10 minutes for trial 9

and 5 minutes for trial 11 were used, the CVs obtained were much lower at 21.02% and 27.69%, respectively. Figures 20 and 21 show segregation of the smaller corn particles and steel tracer in the top left region of drum 3 at the end of the mixing time for trial 10.

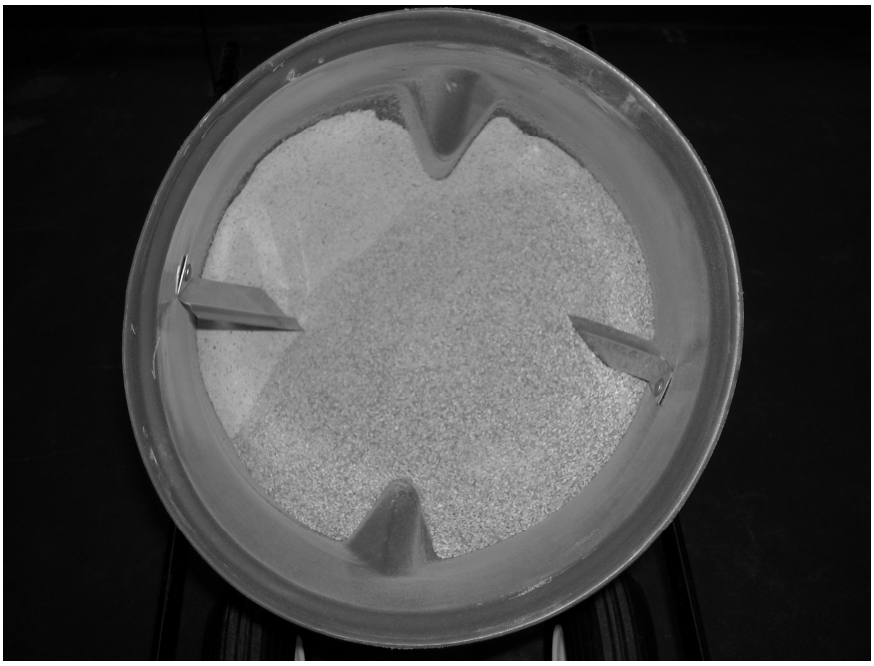

Figure 20: Significant Segregation of Smaller Particles in Drum 3

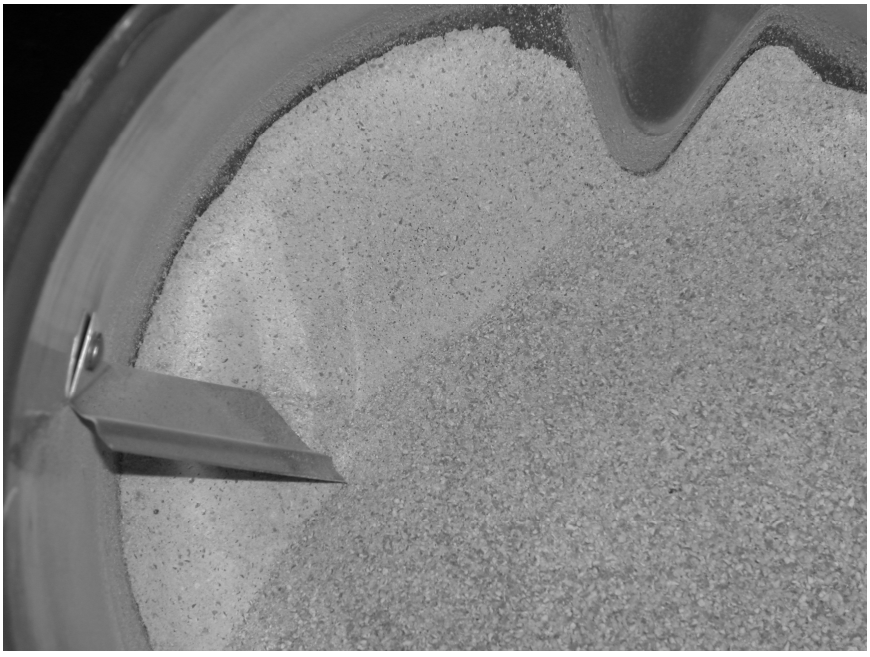

Figure 21: Close-up View of Segregation in Drum 3

The smallest range in CVs for the three drums tested was for drum 2, which went from 30.30% to 54.91%. While experimenting with drum 2, some trials were repeated using the exact same variables. For trials 4 and 5, 30 lbs of ingredients were mixed for 20 minutes in drum 2, but the CV increased from 39.69% for trial 4 to 53.55% for trial 5 indicating that the ingredients didn't mix as well the second time. For trials 6 through 8, the batch size was doubled to 60 lbs of ingredients and mixed for 20 minutes in drum 2. For trial 6, the CV obtained was 54.91%, but for trials 7 and 8 the CV decreased to 35.61% and 37.40%, respectively. These results indicate that better mixing occurred in trials 7 and 8, but not enough to be adequate since the CVs were still above 10%.

For the three drums tested so far, only one common variable trial was performed, which was mixing 30 lbs for 10 minutes. This was trial 2 for drum 1, trial 3 for drum 2, and trial 9 for drum 3. A graph of the sample results obtained can be seen in Figure 22.

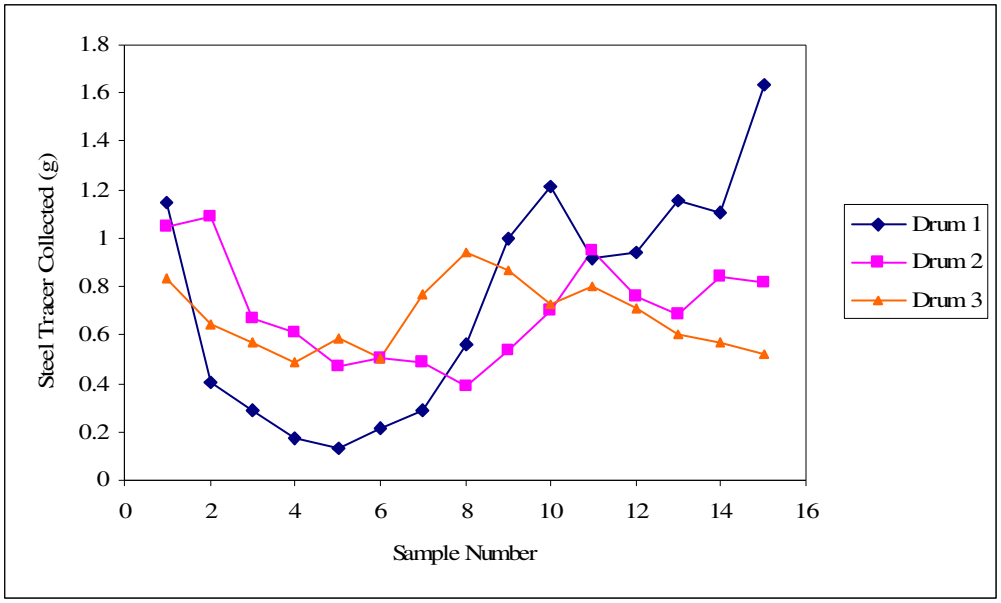

Figure 22: Sample Results after Mixing 30 lbs for 10 Minutes

Drum 1 had the largest range of steel tracer collected, which went from 0.1326g to 1.6358g as shown by the big fluctuation in the line on the graph and this resulted in a

high CV. A graph of samples taken from a well-mixed batch would be fairly close to a straight line. The steel tracer collected for drum 2 ranged from 0.3918g to 1.0888g and for drum 3 ranged from 0.4891g to 0.9418g.

4.2 V-blender Trials

The CVs obtained using the V-blender to test the general procedure and two types of tracers ranged from 8.94% to 64.91% as noted in Table 10 below.

Table 10: Mixing Results for V-blender Trials

Trial	Tracer Type	Tracer Amount	Mixing Time	Sample Interval	CV (%)
12	Steel	0.5	5	x	29.60
13	Steel	0.5	5	y	20.61
14	Steel	0.5	5	z	13.63
15	Steel	2.0	2	x	28.46*
16	Steel	2.0	8	x	31.89*
17	Salt	2.0	5	x	64.91*
18	Steel	2.0	2	y	33.30
19	Steel	2.0	8	y	14.69
20	Salt	2.0	5	y	48.07
21	Steel	2.0	2	z	15.67
22	Steel	2.0	8	z	8.94

*CV based on 12 samples instead of 15

The two highest CVs at 64.91% for trial 17 and 48.07% for trial 20 were obtained using the originally recommended salt tracer. The salt concentration for each run was recorded two minutes after the electrodes were placed in the solution. The CV for trial 17 was based on 12 samples since the product mixture went through the feeder before 15 samples could be taken, but 12 samples is still an adequate number to use to determine the CV. This was also the case for trials 15 and 16 using the steel tracer as they were performed on the same day. The average salt concentration of the three runs tested per sample (5 grams of sample per run) ranged from 0.165% to 0.964% as shown in Figure 23.

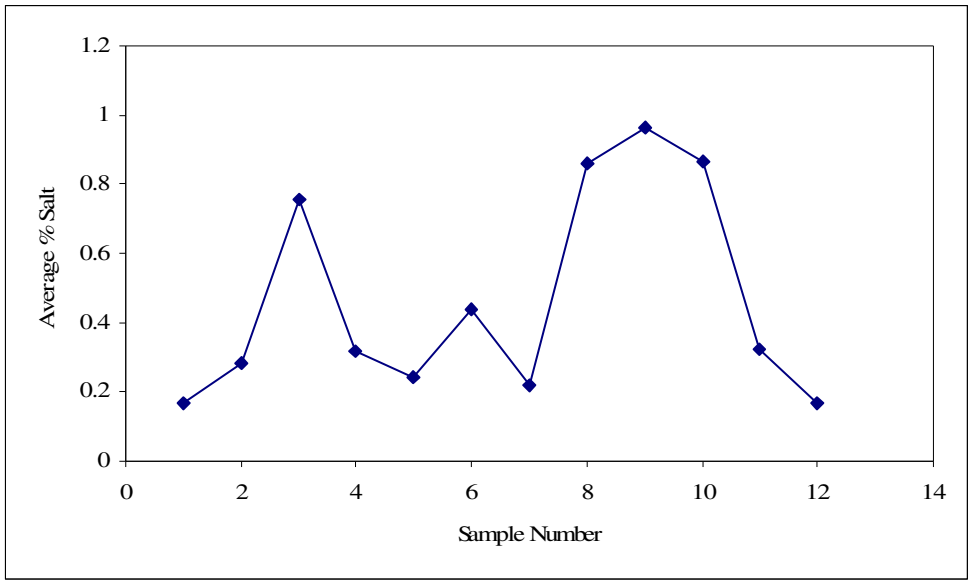

Figure 23: Salt Tracer Sample Results from Trial 17

The multiple peaks and valleys of the line on the graph indicate the variation that led to the high CV for this trial. One thing that could have led to this variation is the small sample size of 5 grams used for each run, which meant that only 15 grams of the whole sample was analyzed for the salt content. The total weight of each sample generally fell in the range between 60 and 70 grams. Thus, for trial 20 a total of 20 grams of sample was analyzed per run, which would give higher salt concentrations, but also a more accurate indication of the salt content in the whole sample and hopefully less variation. The average salt concentration of the three runs tested per sample (using 20 grams of sample per run) for trial 20 varied from 2.60% to 12.4% as shown in Figure 24, but the accepted range of the analyzer only accurately measures concentrations up to 5%. Despite this fact, further testing using the salt tracer was not performed due to the lengthy evaluation process involved.

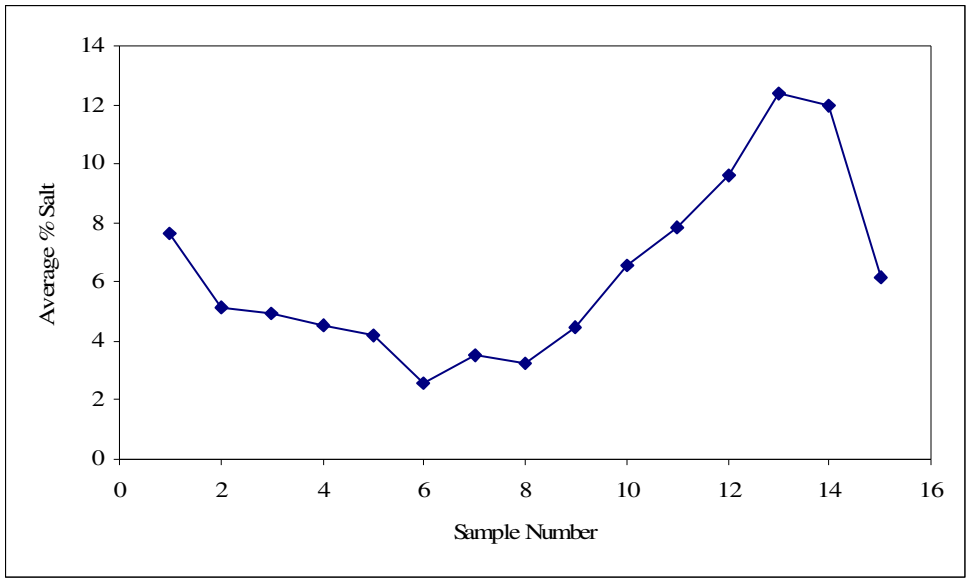

Figure 24: Salt Tracer Sample Results from Trial 20

The other nine trials all used the steel tracer. The first three trials were the only trials that included the lower tracer amount of 0.5% by weight. The mixing time was held constant at 5 minutes while the sample interval was varied according to the scheme mentioned above. With each repetition and shorter sample interval, the CV decreased. The CV started at 29.60% for trial 12, went down to 20.61% for trial 13 and ended at 13.63% for trial 14.

For trials 15, 18, and 21, the tracer amount was raised to 2.0% by weight and the mixing time was reduced to 2 minutes while once again varying the sample interval. The CV for trial 15 was 28.46%, but instead of decreasing for each repetition like before, the CV for the second attempt (trial 18) went up some to 33.30% even though the last attempt (trial 21) went down to 15.67%. Since less mixing was occurring due to the lower mixing time, the CVs for these three trials were slightly higher than those of the first three trials.

For trials 16, 19, and 22, the tracer amount was kept at 2.0% by weight and the mixing time was increased to 8 minutes while still varying the sample interval. Once again the trend of decreasing CVs was noticed with each repetition and shorter sample interval. The highest CV this time around was 31.89% for trial 16. The CV decreased to 14.69% for trial 19. The lowest CV of 8.94% was obtained for trial 22, which was the first time adequate mixing was achieved since the CV was not above 10%. Figure 25 shows the sample results for the three trials where we used a sample interval of every 8 seconds. The shorter sample interval could be leading to less variation in the results.

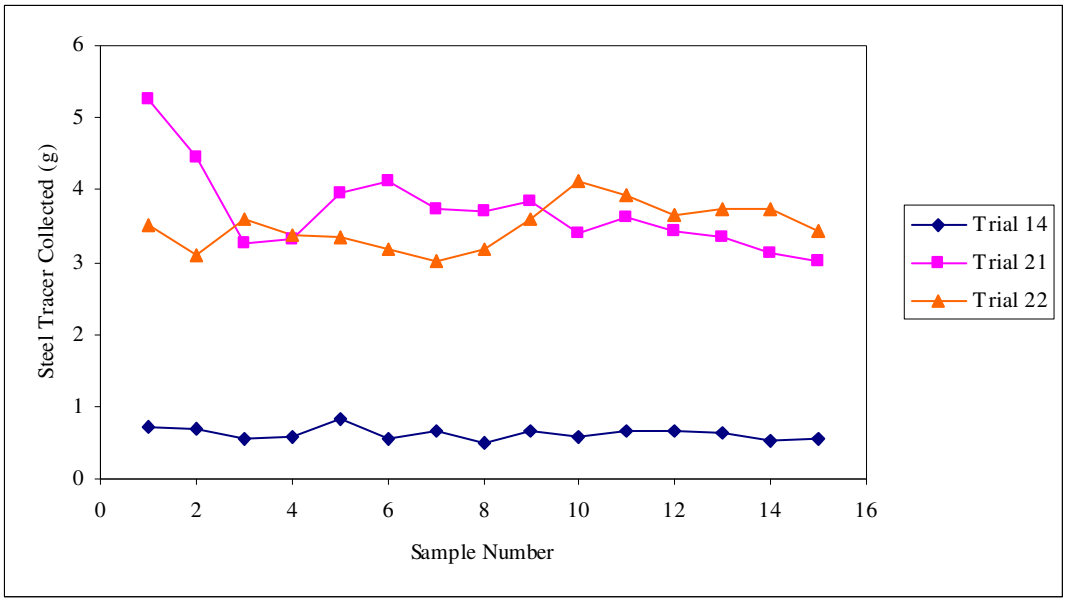

Figure 25: Sample Results from Sampling every 8 seconds

The line for trial 14 is significantly lower on the graph than the other two due to the smaller amount of tracer added at the beginning of the trial (0.5% vs. 2.0% by weight), thus resulting in less being collected in the samples. These three trials had the lowest CVs for the three mixing times evaluated. The line for trial 22 shows the results of an adequate mixture.

4.3 Screening Study

The screening study CVs obtained ranged from 15.09% to 52.40%. See Table 11. Refer back to Tables 6 and 7 on pages 32 and 33 to see the factor levels and specific settings for each trial.

Table 11: Mixing Results for Screening Study

Trial	CV (%)
23	18.03
24	26.36
25	33.69
26	37.14
27	52.40
28	18.48
29	15.09
30	38.98

The sample results for the 8 trials are shown in two separate figures based on the level of factor C, the steel tracer amount. Figure 26 shows the sample results for the odd-numbered trials that used 0.5 wt% while Figure 27 shows the sample results for the even-numbered trials that used 2.0 wt%. The lowest CVs obtained were 15.09% for trial 29 and 18.03% for trial 23, as indicated by the "flatter" lines for their respective sample results both shown in Figure 26. Adequate mixing was not achieved since the CVs were above 10%, but this wasn't the main purpose of the screening study. The main purpose was to determine which factors had the greatest effect on the CV to help determine a standard procedure for future testing. After the V-blender trials, though, it was noted that the shorter sample interval could be leading to less variation in the results. From the screening study, though, it is evident that this is not always the case as trials 25 through 28 had the shorter sample interval setting that resulted in a larger average CV of 35.43% when compared to 24.62% for the remaining four trials.

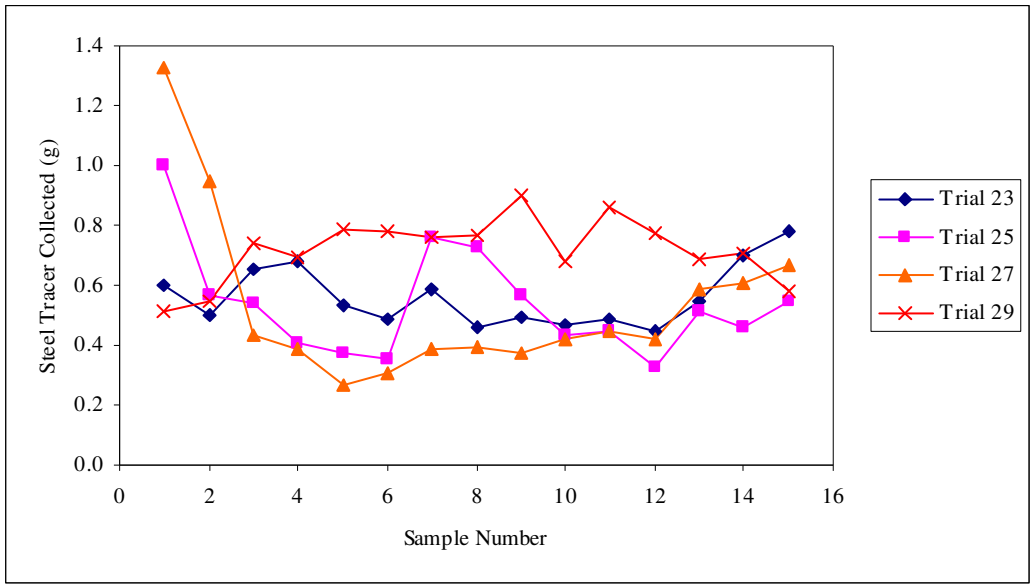

Figure 26: Sample Results for Odd-Numbered Screening Study Trials

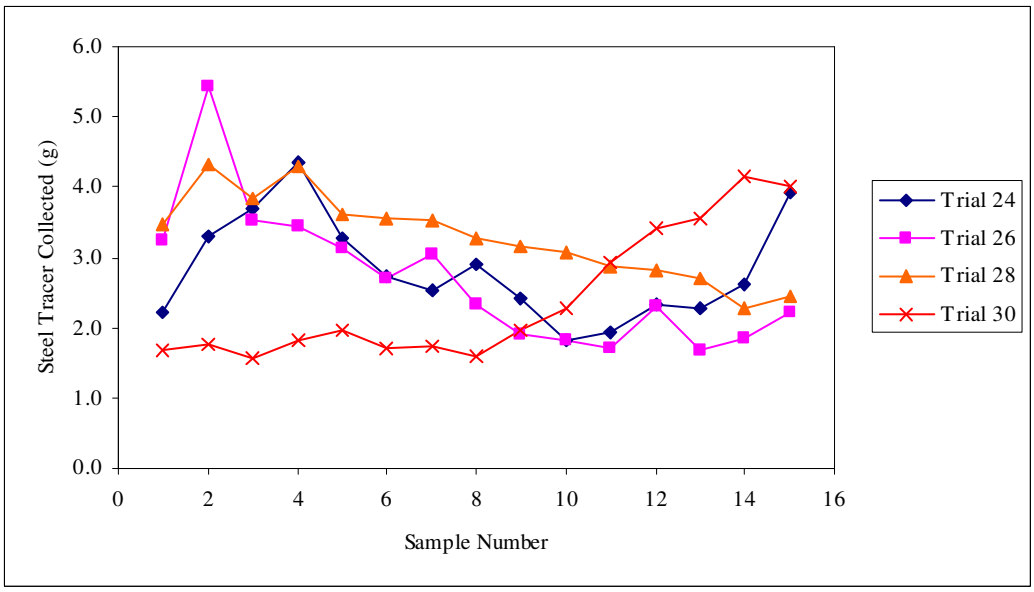

Figure 27: Sample Results for Even-Numbered Screening Study Trials

The calculated factor effects are listed in Table 12. Higher values, regardless of sign, indicate larger effects. The sign corresponds to the factor level with the greater effect. The three factors with the greatest CV effect were factor D (bulk media size) at 15.6713, factor E (bin transfer) at 13.2336, and factor G (sample interval) at -10.8125.

Table 12: Screening Study Factor Effects

Factor	Description	CV Effect
A	Mixer Drum	2.4354
B	Mixing Time	2.4074
C	Steel Tracer Amount	0.4397
D	Bulk Media Size	15.6713
E	Bin Transfer	13.2336
F	Steel Tracer Shape	-5.4537
G	Sample Interval	-10.8125

In order to establish a consistent procedure that can be used when trying to minimize the CV, these three factors need to be set at the level with the opposite sign of their effect. This corresponds with using the smaller bulk media size, including the bin transfer, and sampling at the normal interval as indicated back in Table 6. Trial 29 utilized these three settings and resulted in the lowest CV of 15.09% for the screening study.

4.3 Bulk Media Study

The factor settings for this study are listed back in Table 8 on page 33. The CVs obtained for part 1 of this study were 11.92% and 18.98% for the two corn trials and ranged from 10.14% to 24.36% for the three flour trials all in drum 3. See Table 13.

Table 13: Mixing Results for Bulk Media Study Part 1 in Drum 3

Trial	Media	CV (%)
31	Corn	11.92
32	Corn	18.98
33	Flour	24.36
34	Flour	11.39
35	Flour	10.14

The sample results for part 1 are shown in two separate figures based on the bulk media used. Figure 28 shows the sample results for the two corn trials in addition to trial 29 from the screening study while Figure 29 shows the sample results for the three flour trials. The smoother lines with less distinguished peaks and valleys correspond to the

lower CVs. The plot for trial 29 of the screening study representing a CV of 15.09% is mostly between the plots for trials 31 and 32 as expected based on their respective CV values. The plot for trial 35 in Figure 29 shows the best trial with the Kushlan mixer to this point resulting in a CV of 10.14%, which is just barely above the maximum of 10%.

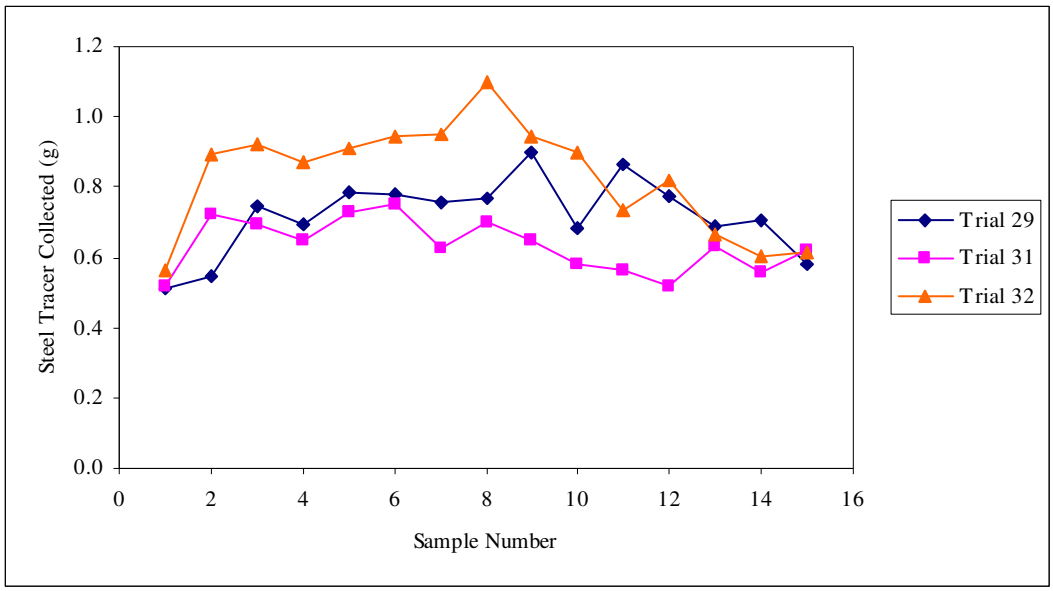

Figure 28: Sample Results for Bulk Media Part 1 Corn Trials in Drum 3

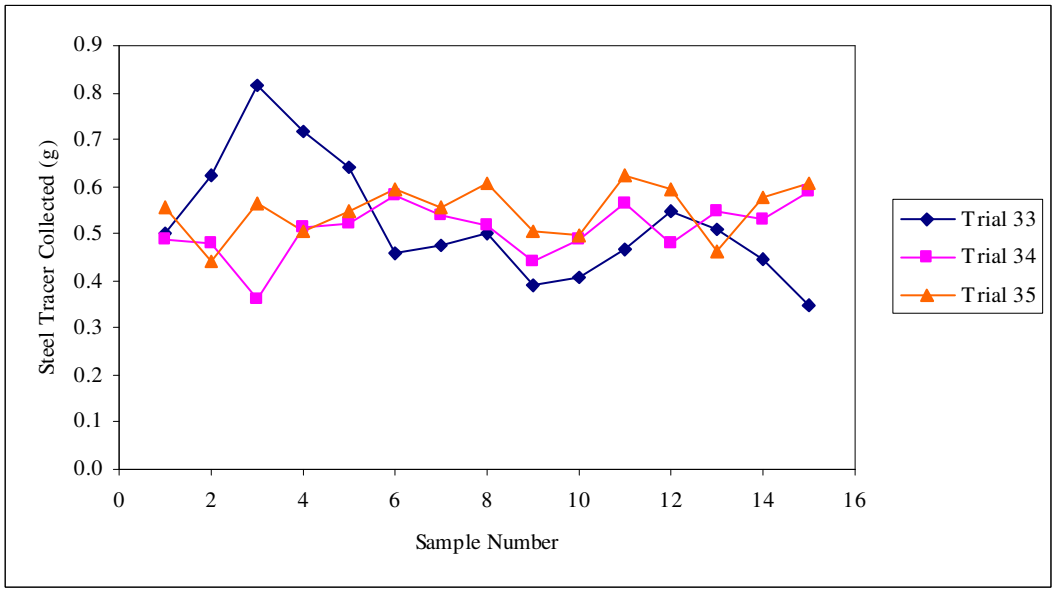

Figure 29: Sample Results for Bulk Media Part 1 Flour Trials in Drum 3

The CVs obtained for part 2 in drum 5 ranged from 17.54% to 46.66% for the three corn trials and from 63.30% to 89.13% for the three flour trials. See Table 14.

Table 14: Mixing Results for Bulk Media Study Part 2 in Drum 5

Trial	Media	CV (%)
36	Corn	26.72
37	Corn	46.66
38	Corn	17.54
39	Flour	72.53*
40	Flour	89.13*
41	Flour	63.30*

*CV based on 14 samples

The CVs for the three flour trials were based on 14 samples since the product mixture went through the feeder before 15 samples could be taken, but 14 samples is still an adequate number to use to determine the CV. The sample results for part 2 are also shown in two separate figures based on the bulk media used. Figure 30 shows the sample results for the three corn trials while Figure 31 shows the sample results for the three flour trials. Both figures show the higher variation obtained in part 2.

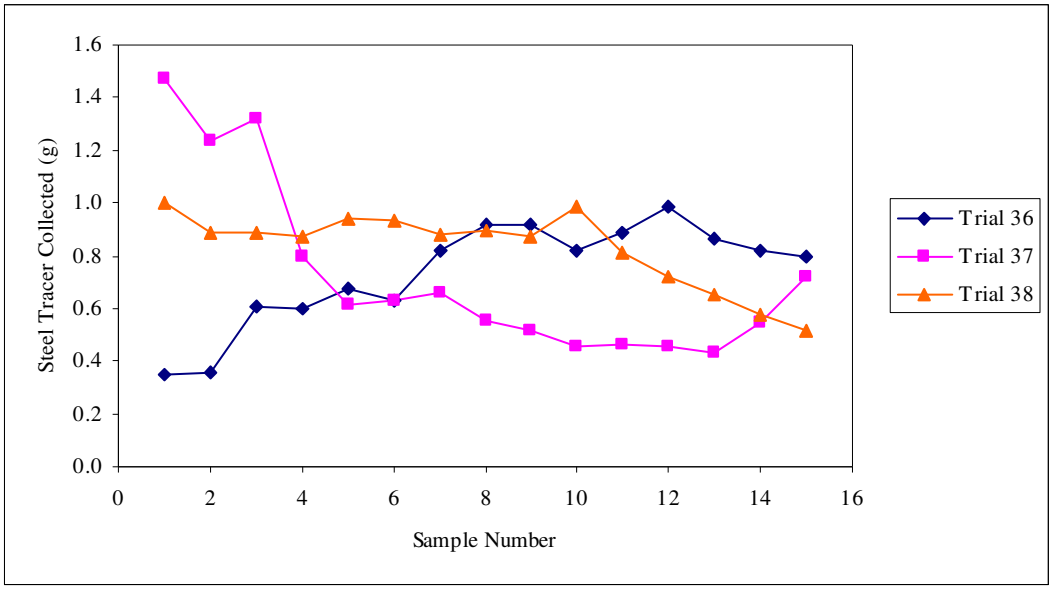

Figure 30: Sample Results for Bulk Media Part 2 Corn Trials in Drum 5

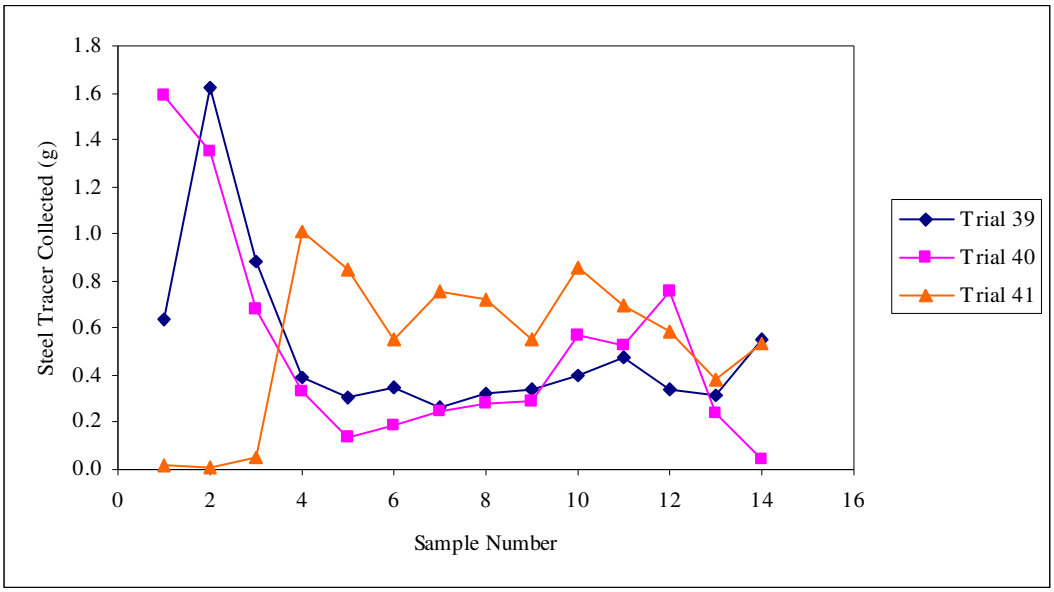

Figure 31: Sample Results for Bulk Media Part 2 Flour Trials in Drum 5

A direct comparison can be made between the corn trials of both parts because they had the same factor settings with the exception of the drum configuration used. Part 1 had lower CV values indicating that drum 3 is better than drum 5 as drum 5 appears to be segregating the mixture more than mixing it. Looking at the results of the flour trials for both parts and ignoring the extended sampling time used in part 2, the part 1 CV values are much lower once again in favor of drum 3 although still inadequate. The fact that the vibratory feeder was used for the flour trials could have also led to higher CV values particularly during part 2 where drum 5 was used.

CHAPTER V

CONCLUSIONS

- A new method was developed to test mixing capability using a steel grit tracer that was used in place of salt in 39 of the 41 total trials.
- The new method was tested using a commercially accepted V-blender, but only one adequate mixture with a CV lower than 10% was achieved (8.94% for Trial 22) out of the nine trials that utilized the steel tracer. The steel tracer, however, was much easier to collect/measure than the salt tracer used twice.
- The 8 screening study trials helped identify 3 factors with key effects and their appropriate settings, which were to use the smaller bulk media size, include the bin transfer, and sample every 15 seconds, in order to minimize variation and improve the method.
- When used as the bulk media, the all-purpose flour, mixed as well as and sometimes better than the ground corn in drum 3 although adequate mixing was still not achieved in any of the 11 bulk media trials.
- Mixing was deemed inadequate for all 5 of the bowl configurations that were tested in 30 of the trials, but drum 3 was the most promising configuration because the lowest CV of all drums (10.14% for Trial 35) was obtained using this drum and resulted in multiple CVs between 10% and 20%.

CHAPTER VI

FUTURE WORK

It is unclear whether the issues leading to inadequate mixing are the result of procedural problems related to the feeder, tracer selected, or variability inherent to the configuration of the mixer being used at the time since several trials were not repeated with the exact same factor settings. There were a few trials where the mixed product ran through the feeder before all of the samples could be taken despite the fact that each batch size used for each bulk media product was tested three times for the amount of time it took to feed completely through with the results being averaged. Perhaps this should have been done on the same day that trials were run every time since the trials were not all done on the same day. There was also the possibility that segregation occurred in the feeder trough as the mixed product fed through. This could be tested via image analysis by taking pictures of the product as it feeds through and tracking the position of individual steel tracer pieces from the hopper outlet to the end of the trough where the product falls into the chute when corn is used as the bulk media since the steel tracer pieces can be seen easily.

Another thing to consider is that the difference between the density of the salt and steel, which could lead to a segregation issue at any point in the process since the steel is heavier. The whole kernel corn tracer was added in the early trials, but not measured.

This particular tracer presents an opportunity to test whether or not the tracer type makes a difference. The whole kernel corn could be used by itself and the contents of the mixed product in the drum could be scooped out from front to back in approximately equal amounts via a scooping device that the tracer and product wouldn't slip under. This could be followed by performing a sieve analysis of each sample for comparison in order to evaluate the mixture as a whole.

Only two salt trials were performed using the V-blender, but neither one accurately measured the total concentration of salt in each of the 15 samples because the first one was based on a fraction of each sample and the second one had several readings that were greater than maximum allowed for the analyzer even though the whole sample was measured. Thus, further testing utilizing the V-blender with the salt tracer is needed where the 15 samples are each accurately and fully analyzed for salt concentration. The portion size of the sample that gets analyzed needs to be below the maximum allowed for the analyzer. The remaining portions of each sample need to be analyzed separately until the whole sample has been analyzed.

After a sampling and evaluation method is confirmed to work using the V-blender or some other commercially accepted mixer by obtaining repeatable results (at least 5 times) of adequate mixing using the same factor settings, the method can be used for further experiments with the Kushlan mixer starting with drum 3. If drum 3 still does not produce acceptable results, then further modifications could be made to the mixing bowls by trying other blade designs. For example, some center blades for drum 5 that extend a bit further up the sidewall of the drum could be developed. Second, holes could be cut in the current blades of drum 5 to allow some of the product to pass through them during

mixing. Also, slowing the rotation speed of the mixer could be tested in an effort to prevent segregation and percolation that might help obtain adequate mixing in drum 3. One other possibility is evaluating the mixer for different applications such as applying coatings to food products like putting chocolate on peanuts or pretzels.

REFERENCES

A.I.Ch.E. Standard Testing Procedure for Solids Mixing Equipment. 1961. American Institute of Chemical Engineers. New York, NY.

ASAE S380: Test Procedure to Measure Mixing Ability of Portable Farm Batch Mixers. 1975. American Society of Agricultural Engineers. St. Joseph, MI.

Bagster, D. F., and J. Bridgwater. 1970. The Flow of Granular Material over a Moving Blade. *Powder Technology*. 3: 323-338.

Bellis, Mary. "History of Electricity." *About.com*. Web. 11 Nov. 2011. <http://inventors.about.com/cs/inventorsalphabet/a/electricity.htm>.

Blumberg, R., and J. S. Maritz. 1953. Mixing of Solid Particles. *Chemical Engineering Science*. 2: 240-246.

Brone, Dean, Albert Alexander, and F. J. Muzzio. 1998. Quantitative Characterization of Mixing of Dry Powders in V-Blenders. *AIChE Journal*. 44: 271-278

Carley-Macauly, K. W., and M. B. Donald. 1964. The Mixing of Solids in Tumbling Mixers–I. *Chemical Engineering Science*. 17: 493-506.

Carley-Macauly, K. W., and M. B. Donald. 1964. The Mixing of Solids in Tumbling Mixers–II. *Chemical Engineering Science*. 19: 191-199.

Carstensen, J. T., and M. R. Patel. 1977. Blending of Irregularly Shaped Particles. *Powder Technology*. 17: 273-282.

Chester, Arthur W., Jocelyn A. Kowalski, Mary E. Coles, Ernest L. Muegge, Fernando J. Muzzio, and Dean Brone. 1999. Mixing Dynamics in Catalyst Impregnation in Double-Cone Blenders. *Powder Technology*. 102: 85-94.

Cook, P., and J. A. Hersey. 1974. Evaluation of a Nauta Mixer for Preparing a Multicomponent Mixture. *Powder Technology*. 9: 257-261.

El-Hagrasy, Arwa S., Frank D'Amico, and James K. Drennen III. 2006. A Process Analytical Technology Approach to Near-Infrared Process Control of Pharmaceutical Powder Blending. Part I: D-Optimal Design for Characterization of Powder Mixing and Preliminary Spectral Data Evaluation. *Journal of Pharmaceutical Sciences*. 95: 392-406.

El-Hagrasy, Arwa S., and James K. Drennen III. 2006. A Process Analytical Technology Approach to Near-Infrared Process Control of Pharmaceutical Powder Blending. Part III: Quantitative Near-Infrared Calibration for Prediction of Blend Homogeneity and Characterization of Powder Mixing Kinetics. *Journal of Pharmaceutical Sciences*. 95: 422-434.

El-Hagrasy, Arwa S., Hannah R. Morris, Frank D'Amico, Robert A. Lodder, and James K. Drennen III. 2001. Near-Infrared Spectroscopy and Imaging for the Monitoring of Powder Blend Homogeneity. *Journal of Pharmaceutical Sciences*. 90: 1298-1307.

Fan, L. T., S. J. Chen, and C. A. Watson. 1970. Solids Mixing. *Industrial and Engineering Chemistry*. 62: 53-69.

"Food of the Ancient Egyptians." *Tripod.com*. Web. 11 Nov. 2011. <http://egyptianfood.tripod.com/>.

Funkenbusch, Paul D. 2005. *Practical Guide to Designed Experiments*. New York, NY: Marcel Dekker.

Harnby, N., M. F. Edwards, and A. W. Nienow. 1997. *Mixing In the Process Industries*. 2nd ed. Oxford, England: Butterworth-Heinemann.

Harner, Joseph P. III, Keith Behnke, and Tim Herrman. 1995. *Rotating Drum Mixers*. MF-2053. Manhattan, KS: Kansas State University Agricultural Experiment Station and Cooperative Extension Service.

Harwood, Colin F, Kenneth Walanski, Erdmann Luebcke, and Carl Swanstrom. 1975. The Performance of Continuous Mixers for Dry Powders. *Powder Technology*. 11: 289-296.

Herrman, Tim, and Keith Behnke. 1994. *Testing Mixer Performance*. MF-1172. Manhattan, KS: Kansas State University Agricultural Experiment Station and Cooperative Extension Service.

Hiseman, M. J. P., B. F. C. Laurent, J. Bridgwater, D. I. Wilson, D. J. Parker, N. North, and D. R. Merrifield. 2002. Granular Flow in a Planetary Mixer. *Trans IChemE*. 80: 432-440.

Hogg, R., and D. W. Fuerstenau. 1972. Transverse Mixing in Rotating Cylinders. *Powder Technology*. 6: 132-148.

Jones, J. R., D. J. Parker, and J. Bridgwater. 2007. Axial Mixing in a Ploughshare Mixer. *Powder Technology*. 178: 73-86.

Kaufman, Arnold. 1962. Mixing of Solids: Experiments with Tumbling Blenders. *I. & E. C. Fundamentals.* 1: 104-106.

Laurent, B. F. C., and J. Bridgwater. 2002. Influence of Agitator Design on Powder Flow. *Chemical Engineering Science.* 57: 3781-3793.

Laurent, B. F. C., J. Bridgwater, and D. J. Parker. 2000. Motion in a Particle Bed Agitated by a Single Blade. *AIChE Journal.* 46: 1723-1734.

Lemieux, M., F. Bertrand, J. Chaouki, and P. Gosselin. 2007. Comparative Study of the Mixing of Free-flowing Particles in a V-blender and a Bin-blender. *Chemical Engineering Science.* 62: 1783-1802.

Lindley, J. A. 1991. Mixing Processes for Agricultural and Food Materials: 3. Powders And Particulates. *J. agric. Engng Res.* 49: 1-19.

Masiuk, S. 1987. Power Consumption, Mixing Time and Attrition Action for Solid Mixing in a Ribbon Mixer. *Powder Technology*. 51: 217-229.

Moakher, Maher, T. Shinbrot, and F. J. Muzzio. 2000. Experimentally Validated Computations of Flow, Mixing and Segregation of Non-cohesive Grains in 3D Tumbling Blenders. *Powder Technology*. 109: 58-71.

"Mixer History – Invention of the Mixer." *The Great Idea Finder*. Web. 11 Nov. 2011. <http://www.ideafinder.com/history/inventions/mixers.htm>.

Muzzio, F. J., C. L. Goodridge, A. Alexander, P. Arratia, H. Yang, O. Sudah and G. Mergen. 2003. Sampling and Characterization of Pharmaceutical Powders and Granular Blends. *Internationl Journal of Pharmaceutics*. 250: 51-64.

Niranjan, K., D. L. O. Smith, C. D. Rielly, J. A. Lindley, and V. R. Phillips. 1994. Mixing Processes for Agricultural and Food Materials: Part 5, Review of Mixer Types. *J. agric. Engng Res.* 59: 145-161.

Orion Application Information Procedure No. 205: Salt in Canned Vegetables. 1980. Orion Research Incorporated. Cambridge, MA.

Paul, Edward L., Victor A. Atiemo-Obeng, and Suzanne M. Kresta. 2004. *Handbook of Industrial Mixing: Science and Practice*. Hoboken, New Jersey: John Wiley & Sons, Inc.

Porion, Patrice, Nathalie Sommier, Anne-Marie Faugére, and Pierre Evesque. 2004. Dynamics of Size Segregation and Mixing of Granular Materials in a 3D-blender by NMR Imaging Investigation. *Powder Technology*. 141: 55-68.

Sudah, O. S., D. Coffin-Beach, and F. J. Muzzio. 2002. Effects of Blender Rotational Speed and Discharge on the Homogeneity of Cohesive and Free-Flowing Mixtures. *Internationl Journal of Pharmaceutics*. 247: 57-68.

Weinekötter, Ralf, and Hermann Gericke. 2000. *Mixing of Solids*. Dordrecht, The Netherlands: Kluwer Academic Publishers.

Wightman, Carolyn, Fernando J. Muzzio, and Joseph Wilder. 1996. A Quantitative Image Analysis Method for Characterizing Mixtures of Granular Materials. *Powder Technology*. 89: 165-176.

Williams, J. C. 1976. The Segregation of Particulate Materials. A Review. *Powder Technology*. 15: 245-251.

Zhou, Y. C., A. B. Yu, R. L. Stewart, and J. Bridgwater. 2004. Microdynamic Analysis of the Particle Flow in a Cylindrical Bladed Mixer. *Chemical Engineering Science*. 59: 1343-1364.

APPENDICES

APPENDIX A

SAMPLE CV CALCULATION FROM ASAE S380

Sample no.	Value of sample, *X*	Value of (*X*-*M*)^2
1	0.590	0.000784
2	0.560	0.000004
3	0.625	0.003969
4	0.560	0.000004
5	0.560	0.000004
6	0.560	0.000004
7	0.530	0.001024
8	0.590	0.000784
9	0.560	0.000004
10	0.530	0.001024
11	0.560	0.000004
12	0.520	0.001764
13	0.570	0.000064
14	0.560	0.000004
15	0.560	0.000004

$$\sum X = 8.435$$

$$\sum (X - M)^2 = 0.009445$$

$$M = \frac{\sum X}{n} = \frac{8.435}{15} = 0.562$$

$$S^2 = \frac{\sum (X - M)^2}{n - 1} = \frac{0.009445}{14} = 0.0006746$$

$$S = 0.026$$

$$CV = \frac{S}{M} \times 100 = \frac{0.026}{0.562} \times 100 = 4.63\%$$

where
n = number of samples
X = percent of tracer in sample
M = mean value of samples, X
S = one standard deviation
CV = coefficient of variation

APPENDIX B

RAW DATA

B.1 Preliminary Trials

All samples represent the steel shot (tracer) collected and are measured in grams.

Sample #	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5	Trial 7	Trial 6
1	0.033	1.1503	1.0492	0.8464	0.1122	0.0744	0.0485
2	0.2069	0.4006	1.0888	0.7284	0.2434	0.3408	0.1271
3	0.1313	0.2899	0.6651	0.3418	0.3016	0.6015	0.2102
4	0.0625	0.1715	0.6144	0.2914	0.3344	0.9779	0.2998
5	0.0649	0.1326	0.4719	0.2265	0.4785	1.0383	0.4223
6	0.0616	0.2184	0.5058	0.3062	0.5242	0.9171	1.1569
7	0.0346	0.2893	0.4832	0.5624	0.5242	0.8737	0.8945
8	1.5078	0.5628	0.3918	0.5801	0.8538	0.8952	0.8046
9	1.15	0.9974	0.5392	0.6675	0.8715	0.7566	0.8494
10	2.5	1.2098	0.6992	0.7431	1.0546	0.8062	1.0935
11	0.8486	0.9183	0.9465	0.8323	1.2504	0.8282	1.0342
12	0.6759	0.9384	0.7592	0.8079	1.1912	0.5904	1.1044
13	0.3918	1.1576	0.6867	1.0434	1.1779	0.6633	1.2197
14	0.1057	1.1069	0.8411	0.9858	0.7938	0.6375	1.0296
15	0.073	1.6358	0.8152	0.7864	0.6571	0.6218	0.7855

Sample #	Trial 8	Trial 9	Trial 10	Trial 11
1	0.1163	0.8303	0.3586	0.5768
2	0.2492	0.6407	0.1732	0.5476
3	0.5551	0.5672	0.0897	0.5040
4	0.9548	0.4891	0.0420	0.5819
5	0.9866	0.5890	0.0973	0.4377
6	1.0291	0.5068	0.0739	0.5859
7	1.0719	0.7665	0.1508	0.6013
8	0.9032	0.9418	0.2511	0.5959
9	0.8827	0.8701	0.5745	0.7371
10	0.6584	0.7290	0.7381	0.9973
11	0.6325	0.7999	1.2511	0.8952
12	0.7403	0.7126	1.6103	1.0704
13	0.6751	0.6034	1.2723	0.9055
14	0.7159	0.5731	1.4734	0.7182
15	0.7187	0.5242	2.4364	0.5923

B.2 V-blender Trials

B.2.1 Steel Tracer Trials

All samples represent the steel shot (tracer) collected and are measured in grams.

Sample #	Trial 12	Trial 13	Trial 14	Trial 15	Trial 16
1	0.9234	0.8518	0.7212	4.5037	4.6496
2	0.6649	0.6944	0.6994	2.8318	3.2238
3	0.3562	0.6642	0.5508	2.8205	3.9552
4	0.3357	0.5632	0.5920	2.9273	4.2160
5	0.4017	0.6058	0.8181	3.0282	3.5727
6	0.6743	0.7043	0.5495	2.4856	3.0325
7	0.7745	0.6750	0.6646	2.3321	2.4671
8	0.8621	0.7161	0.5009	2.2579	2.5903
9	0.9122	0.7589	0.6547	2.8600	2.2409
10	0.8845	0.7639	0.5733	2.8934	2.0594
11	0.7959	0.8504	0.6636	2.7128	2.6410
12	0.7012	0.8347	0.6595	1.0458	1.3993
13	0.5865	0.8873	0.6273	-----	-----
14	0.5004	0.5069	0.5366	-----	-----
15	0.7713	0.3612	0.5482	-----	-----

Sample #	Trial 18	Trial 19	Trial 21	Trial 22
1	3.8299	2.8854	5.2666	3.4981
2	5.4556	3.9250	4.4619	3.0972
3	5.2432	3.6412	3.2697	3.5899
4	3.6638	3.7749	3.3265	3.3688
5	3.5457	4.3484	3.9517	3.3457
6	4.0978	3.9507	4.1280	3.1818
7	3.5373	4.2141	3.7292	3.0261
8	3.5004	3.5513	3.7141	3.1703
9	3.0011	3.2077	3.8421	3.5894
10	2.6175	3.1455	3.4128	4.1276
11	2.5070	3.0318	3.6107	3.9315
12	2.2595	2.9196	3.4280	3.6555
13	1.9499	3.0221	3.3374	3.7360
14	2.0605	3.1111	3.1253	3.7231
15	2.0593	2.8716	3.0130	3.4309

B.2.2 Salt Tracer Trials

All measurements are salt percentage unless noted otherwise.

Trial 17				
Sample #	Run 1	Run 2	Run 3	Avg % Salt
1	0.128	0.108	0.262	0.166
2	0.115	0.155	0.582	0.284
3	1.08	0.672	0.513	0.755
4	0.707	0.186	0.067	0.32
5	0.276	0.244	0.215	0.245
6	0.348	0.677	0.298	0.441
7	0.195	0.298	0.164	0.219
8	1.4	0.558	0.616	0.858
9	1.04	0.772	1.08	0.964
10	1.12	0.528	0.956	0.868
11	0.361	0.207	0.404	0.324
12	0.277	0.101	0.117	0.165
13	-----	-----	-----	-----
14	-----	-----	-----	-----
15	-----	-----	-----	-----

Trial 20				
Sample #	Run 1	Run 2	Run 3	Avg % Salt
1	5.82	4.41	12.7	7.64
2	5.25	2.93	7.28	5.15
3	3.55	5.03	6.28	4.95
4	3.33	3.01	7.35	4.56
5	2.01	3.12	7.38	4.17
6	0.967	2.49	4.33	2.60
7	1.66	3.16	5.79	3.54
8	2.95	2.74	4.04	3.24
9	1.97	6.05	5.34	4.45
10	5.05	5.97	8.62	6.55
11	6.01	6.15	11.4	7.85
12	8.73	8.81	11.3	9.61
13	12.9	11.9	12.4	12.4
14	11.8	9.25	14.8	12.0
15	4.29	6.59	7.49	6.12

B.3 Screening Study

All samples represent the steel shot (tracer) collected and are measured in grams.

Sample #	Trial 23	Trial 24	Trial 25	Trial 26
1	0.5983	2.2215	1.0026	3.2277
2	0.5027	3.2970	0.5652	5.4322
3	0.6515	3.6886	0.5376	3.5156
4	0.6804	4.3575	0.4053	3.4438
5	0.5316	3.2662	0.3721	3.1365
6	0.4835	2.7174	0.3558	2.7015
7	0.5855	2.5247	0.7620	3.0379
8	0.4578	2.8899	0.7255	2.3224
9	0.4964	2.4261	0.5694	1.9010
10	0.4636	1.8258	0.4317	1.8338
11	0.4888	1.9476	0.4479	1.7163
12	0.4499	2.3273	0.3237	2.2961
13	0.5472	2.2676	0.5133	1.6792
14	0.7000	2.6163	0.4578	1.8461
15	0.7781	3.9327	0.5440	2.2080

Sample #	Trial 27	Trial 28	Trial 29	Trial 30
1	1.3295	3.4713	0.5109	1.6885
2	0.9480	4.3306	0.5434	1.7639
3	0.4318	3.8410	0.7422	1.5538
4	0.3876	4.2821	0.6923	1.8231
5	0.2674	3.6139	0.7836	1.9514
6	0.3061	3.5478	0.7811	1.6936
7	0.3880	3.5282	0.7590	1.7239
8	0.3947	3.2600	0.7685	1.5835
9	0.3723	3.1480	0.8977	1.9622
10	0.4202	3.0804	0.6818	2.2683
11	0.4466	2.8645	0.8631	2.9340
12	0.4185	2.8273	0.7736	3.4164
13	0.5864	2.7133	0.6872	3.5555
14	0.6069	2.2887	0.7077	4.1487
15	0.6644	2.4378	0.5818	4.0142

B.4 Bulk Media Study

All samples represent the steel shot (tracer) collected and are measured in grams.

Sample #	Trial 31	Trial 32	Trial 33	Trial 34	Trial 35	Trial 36	Trial 37
1	0.5163	0.5605	0.5017	0.4890	0.5541	0.3455	1.4678
2	0.7240	0.8912	0.6235	0.4785	0.4422	0.3534	1.2349
3	0.6959	0.9201	0.8149	0.3604	0.5639	0.6066	1.3205
4	0.6458	0.8723	0.7170	0.5118	0.5050	0.6023	0.8000
5	0.7269	0.9094	0.6431	0.5213	0.5465	0.6757	0.6131
6	0.7529	0.9455	0.4564	0.5819	0.5944	0.6326	0.6293
7	0.6273	0.9500	0.4746	0.5376	0.5573	0.8215	0.6592
8	0.6991	1.0973	0.5015	0.5192	0.6084	0.9181	0.5564
9	0.6464	0.9427	0.3889	0.4397	0.5038	0.9178	0.5126
10	0.5775	0.8958	0.4063	0.4868	0.4966	0.8209	0.4587
11	0.5657	0.7336	0.4662	0.5640	0.6226	0.8906	0.4615
12	0.5193	0.8189	0.5458	0.4794	0.5952	0.9882	0.4580
13	0.6307	0.6644	0.5114	0.5458	0.4613	0.8624	0.4323
14	0.5592	0.6011	0.4450	0.5289	0.5793	0.8200	0.5482
15	0.6216	0.6122	0.3479	0.5881	0.6057	0.7928	0.7169

Sample #	Trial 38	Trial 39	Trial 40	Trial 41
1	0.9983	0.6335	1.5881	0.0147
2	0.8909	1.6192	1.3506	0.0058
3	0.8847	0.8861	0.6768	0.0480
4	0.8730	0.3931	0.3334	1.0075
5	0.9386	0.3024	0.1385	0.8476
6	0.9295	0.3503	0.1877	0.5549
7	0.8834	0.2607	0.2452	0.7521
8	0.8935	0.3189	0.2843	0.7254
9	0.8731	0.3407	0.2900	0.5533
10	0.9842	0.4006	0.5689	0.8602
11	0.8100	0.4772	0.5300	0.6973
12	0.7236	0.3380	0.7571	0.5878
13	0.6521	0.3148	0.2374	0.3840
14	0.5758	0.5550	0.0404	0.5379
15	0.5191	-----	-----	-----

VITA

Joseph Daniel Kovar

Candidate for the Degree of

Master of Science

Thesis: EVALUATION OF THE MIXING CAPABILITY OF A LOW-COST, SANITARY, FOOD-GRADE MIXER

Major Field: Biosystems Engineering

Biographical:

Education:

Graduated with honors and received Bachelor of Science in Chemical Engineering from The University of Tulsa, Tulsa, Oklahoma in May, 2004.

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Process Engineering Intern at Sunoco, Inc., Tulsa, OK, June 2004 to October 2004.

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Associate Engineer at SGS, Bartlesville, OK, August 2006 to September 2009 and November 2009 to January 2010.

Contract Inspector at Innovative Inspection Solutions, LLC, Collinsville, OK, January 2010 to present.

Professional Memberships:

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