Solid-Solid Mixing with Static Mixers

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Original scientific paper
Received: March 24, 2001
Accepted: December 7, 2001

Static mixers are in-line devices, which consist of motionless mixing elements, inserted in the given length of the pipe. Homogenization is attained by using the flow energy of the material to be mixed. The mixing effect depends on the continuous separation, distribution, and reunion of particles in the stream of material. There are various element designs available for mixing liquids and they are widely spread for use in industry. For mixing solids there is hardly any industrial usage of static mixer types, therefore, various experiments with solids have been done. The number of elements and their shape required in any application depend on the complexity of the mixing process, more elements being necessary for more complex tasks.

Three different types of static mixers were investigated in this paper. The material used was quartz sand of different granulation which was mixed in different mixture ratios. With quartz sand, only the particle size was different, which allowed us to study the countenance of the mixer type and its length to get the best quality mixture, especially when one of the components was in excess.

Static mixers have the advantage over other mixers because they are cheaper for use (loss of energy expenses), and they are very easy to install and to clean. To prove their efficiency and to show which of the types used yielded the highest homogeneity, standard statistical methods (standard deviation, variation and mixing indexes) were used as statistical descriptors of the particular mixture. The dynamics of mixing were tested by continuous sampling, and by the flowability of the material for different mixture types. The results of experiments were mathematically calculated to obtain the necessary data for each specific design. The length of the pipe, the shape and the number of mixing elements, were determined by the mixture quality for each specific mixture type.

Key words:
Solid-solid mixing, static mixers, mixing elements

Introduction

The mixing of free-flowing particular solids is a common processing operation largely used in a variety of industries. Its applications can be found in the manufacture of pharmaceuticals, animal feed and in food industry[1].

Due to the complex nature and high number of parameters involved in the process, the mechanism of mixing is still far from being clear. For each mixing method a characteristic mechanism determines the rate and the attainable degree of mixing. The mixing quality, i.e. the degree of homogeneity is especially important when a relatively small amount of an active ingredient is to be distributed in a large quantity of bulk solids or powders[2].

Longitudinal and transversal distribution of components to be mixed can be achieved in static mixers by means of moving elements. In static mixers[3] homogenization is attained by means of motionless elements using the flow energy of the powder. Guiding elements fitted in the pipeline, through which the flow is continuous, produce a mixing action by repeatedly splitting up and rearranging the product stream. Thanks to this reproducible function, which follows a geometrical pattern, the energy requirements of static mixer are small. The shear forces imposed are generally low, so that during the processing the product is not damaged[4].

These mixers frequently consist of similar elements which twist the spatial distribution of the product and which are placed one behind the other in a pipe channel. The mixing effect depends upon the continuous separation, distribution, and reuniting of the stream of material. *Boss* and co-workers[3] have studied the mixing in a tube containing static mixer elements, but the data have not provided sufficient parameters to reveal the mixing mechanism, since it is a one-dimensional concentration distribution. In another paper[5] a two-dimensional mode has been used to study the funnel flow from one bin into another, and a change in the two- dimensional concentration patterns. The results clearly indicate that the mechanism of mixing is highly influenced by the flow properties of the bulk material through the flow mechanism.

Homogenization is attained by means of motionless elements by using the flow energy of the mixed material[6]. By these elements homogenous products are achieved without moving agitators. Free-flowing particles systems with differences in size and density are highly segregating. Differences in the physical properties expedite the mixing and demixing, and it becomes practically impossible to foresee the point of the best homogeneity. In many cases such differences cannot be avoided.

Powders are usually characterized at two levels: one by individual particles and the other by a powder in bulk. Although it is self-evident that the bulk properties are primarily influenced by the particle properties, the relationship between the two is not as simple and it involves external factors. The material from which the particles are made and the process by which they are formed mainly determine the physical characteristics[7] of individual particles. The shape variations in powders[8] are enormous and they range from extreme degrees of irregularity to an approximate sphericity or well-defined crystalline shapes. The bulk properties of fine powders, always interdependent, are determined by, both, physico-chemical properties of the material, geometry, size and surface characteristics of the individual particles, and the history of the system as a whole. Many powders are known to be cohesive, which means that their attractive interparticle forces are significantly high, relative to the particles own mass. Moisture sorption is associated with increased cohesiveness, mainly due to interparticle liquid bridges. Some powders[9], especially those containing a soluble component, tend to agglomerate spontaneously when exposed to moist atmosphere or elevated storage temperature.

Despite a few superficial similarities in the flowability of liquids and powders, there is a large difference in the physical characteristics[10]. The flow rate of powders is practically independent of the height above the aperture if the powder head is more than about two and a half times of the aperture diameter. Powders can appreciably resist shear stresses. Once compacted, under their own mass or by external pressure, they can form mechanically stable structures. Therefore, even under a small pressure, many powders may cause serious flow problems. Another problem dealing with powders is segregation which occurs when particles of different properties are distributed preferentially in different parts of the bed. The main differences responsible for the segregation are differences in the particle size, density shape and resilience[11]. The segregation process generally occurs when free flowing powders, with a significant range between the particles size, are exposed to some kind of a mechanical motion. The aim of the present work is to reveal the efficiency of different static mixers for free-flowing particles. The use of statistical methods, like standard deviation, variance and mixing index as statistical description of particulate mixtures, has been discussed. The purpose of the statistics is to provide measures for the extent of subjectivity that enters into the investigator conclusion. The main aim was to establish the general relations between the flow and the mixing characteristics in different types of steady state mixer tubes. In blending and mixing of a different kind of the particular matter, one should be concerned with three extensive aspects. The first is the type of the mixer selected or designed and the mode of its operation, the second is the characterization of the state of the resulting mixture, and the third is the rate and the mechanism of the mixing process.

Materials and methodes

The performance of three different mixing elements has been studied.

The mixing degree has been investigated with a typical apparatus for longitudinal mixing, consisting of a static mixer, feeder and a receiver. Different mixing elements have been inserted into a PVC tube (Figure 1):

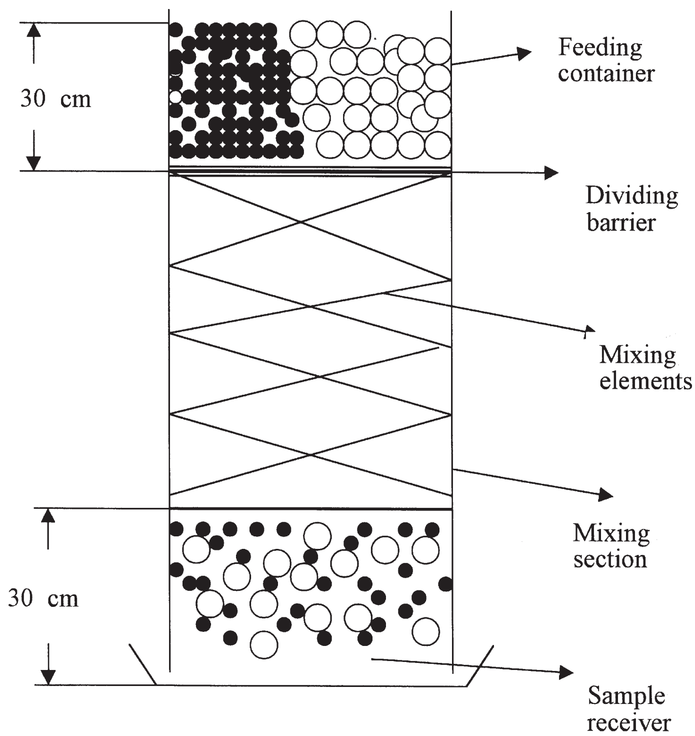


Fig. 1 – *Basic shape of static mixer*

– Kenics type 180° elements
– Komacs type element
– Sulzer SMX type elements

There is a twist of 180° in each element of a Kenics mixer and right-hand and left-hand elements are arranged alternately in a tube. The design consists of a series of mixing elements, each having a short helix of one and half tube diameters in length.

In Komacs type mixer the elements are placed point counter point. Unlimited material supply is put into the feeder section and that of free outlet forms the postmixing tube; a dense sliding particle bed takes place above the mixing elements[1].

The purpose of Sulzer SMX type of lamellar mixing elements is to split the material into individual streams that meet other streams as they flow transversely through the element. Each element mixes principally in two dimensions and the elements are aligned at 90° to their neighbors to enable a three-dimensional mixing.

The experiments were carried out with quartz sand, which is a non-cohesive free flowing material (Table 1) with particles that differed in size, distribution and bulk density. Prior to use all the materials were sieved, so that the components of different granulometric sizes could be obtained. The study was designed to focus on the mixer performances. Mixtures were designed with the components of different particle size, of different material ratios, and with a large excess of one of the components. After the material had been mixed, the samples were analyzed. A continuous sampling, paying attention to the main rules of sampling, tested the dynamics of mixing. The powder was sampled when in motion and the whole of the stream was taken for many short periods of time (between 15 and 25 seconds depending on mixer type).

Experiments with the same material combinations were accomplished using all three different types of mixing elements (Table 2).

Mixtures were made of two components combined in different ratios, shown in Table 1. Samples were put into the container placed above the mixing tube. A gate valve (Figure 2) controlled the particles flowing from the upper vessel into the mixer tube. Nominal volume of this vessel was 0,6 m^3, which was enough to run the experiments under steady state conditions.

The valve being opened, the material flowed through the pipe and over the mixing elements. The material flow of each sample was measured for each of the mixing element type (Figure 3).

The samples were collected in the containers passing under the mixer. Samples were analyzed by two different methods. The first method was granulometric, sieving and weighing. First, the whole sample was weighed, than sieved, and then one of the components was weighed separately. "Sympatec Helos Vectra" laser particle analyzer performed the second method. Data obtained in this way were calculated and treated statistically[12] and the results were presented graphically. Mixing efficiency was measured by the standard deviation of the minor component with respect to the bulk stream at the mixer exit. Both methods gave the same results.

The most important problem in solid mixing is to evalulate homogeneity of a mixture or the degree of mixedness[13]. The results have been analyzed by using parametric statistics.

A mixture can be defined as homogeneous if any sample of the mixture has the same composition and properties as any other[11]. Powder sampling[14] is an important procedure that determines the quality of the mixture. The sample of a powder should represent the powder quality of the mixture. The sample size must be adapted to the dimensions of the powder material. The distribution of the powder material in the mixture

Table 1 – *Conditions of different quartz sand particles*

Quartz sand	Diameter mm	Bulk density kg m^{-3}	Ratio of components			
A	< 0.1	1337.18	1:3	3:1	1:9	9:1
B	0.1 – 0.2	1436.70	1:3	3:1	1:9	9:1
C	0.25 – 0.4	1493.58	1:3	3:1	1:9	9:1
D	0.4 – 0.8	1620.72	1:3	3:1	1:9	9:1

Table 2 – *Quantities of three examined static mixers*

Mixer type	Lenght of tube m	Diameter of tube m	Number of elements in the tube	Hight/width ration of the tube	Width of the element m
Sulzer type	0.210	0.028	5	7.5	0.028
SMX type	0.175	0.018	5	9.7	0.023
Kenics type	0.250	0.030	3	8.3	0.028

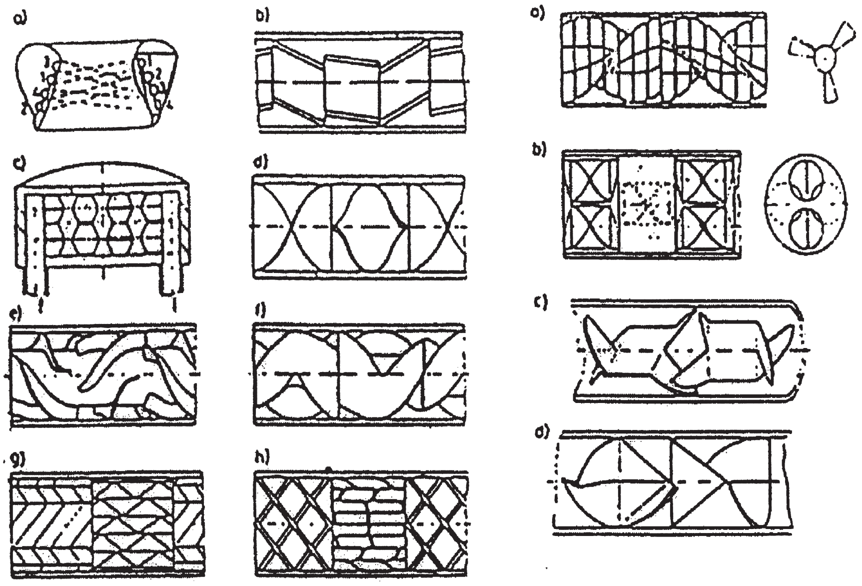


Fig. 2 – *Different types of mixing elements*

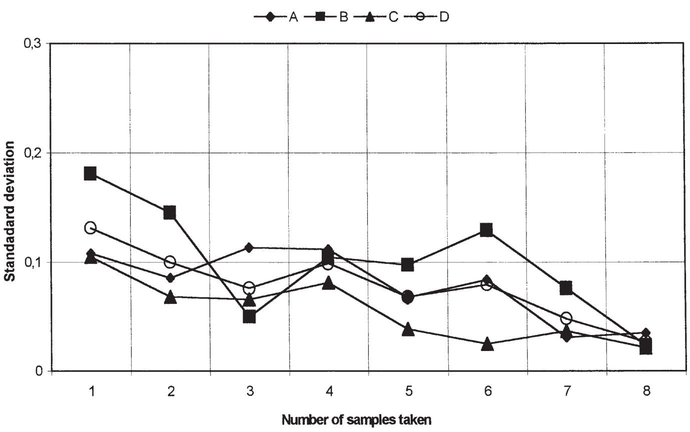


Fig. 3 – *Quartz sand mixture of components A and D mixed in 1:1 ratio*

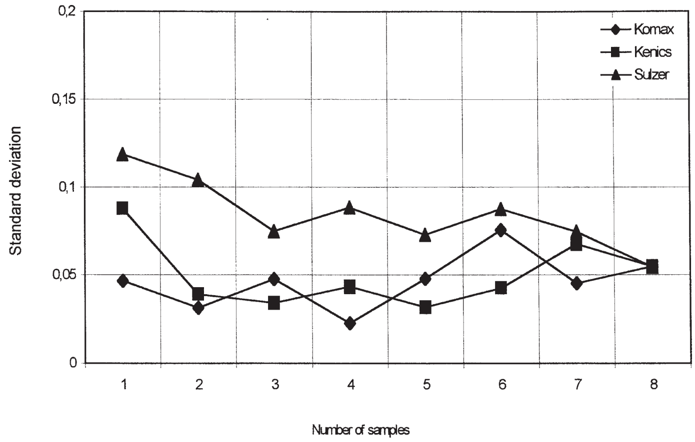


Fig. 4 – *Results reproducibility of componets C and B mixed in 1:1 ratio*

must be evaluated. The smaller the number of measurements, the more indeterminate the value for homogeneity. If the system variance is chosen as a measure for comparing the mixing quality[4], the sample granulation is irrelevant, since the system variance is independent of its influence. According to *Boss*[13] two to forty samples, taken from a mixture, give the correct information on the homogeneity. We have divided the whole mixture into eight individual samples and the results have shown high reproducibility for mixtures of model material (Figure 4. each value is a mean of eight samples). *Hersey*[12] has defined an ordered mixture as having zero standard deviation of the sample concentration at all sample sizes, provided that the sample size is greater than the size of a single order unit, as opposed to a random mixture, where the standard deviation decreases with increasing of the sample size.

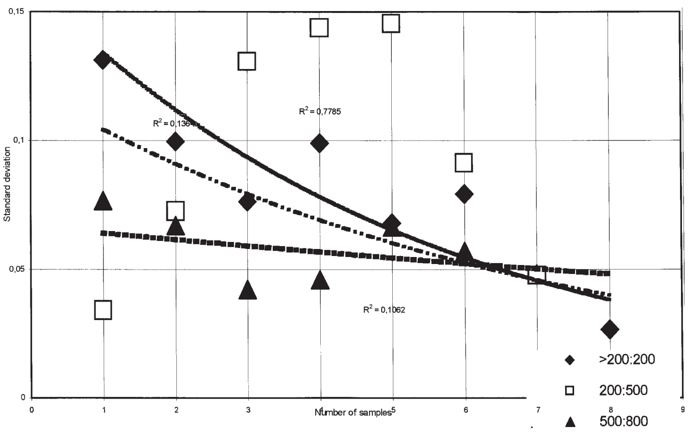
The mixing process is profoundly influenced by the flow characteristics of the particular matter to be mixed[15].

Mixing of small particles in a free flow in static mixers has given us a very homogeneous mixture, because the powder flows consistently and particles themselves have a great individual mobility[16]. It is substantial that both components flow continuously and at a similar speed[17]. For some materials the mixing elements should be changed to attain better results.

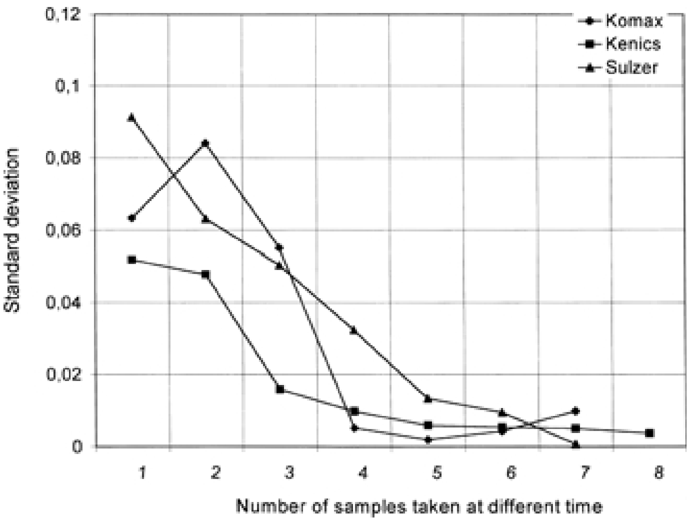
Results and discussion

When the mixture was made of equal quantities of both materials the only difference was in the mixer type. The quality of the mixture was good according to the standard deviation values. It was slightly different only with Komacs type of mixer, but absorbing the values of standard deviations which were lower than 0.05, all the mixtures could be considered very well homogenized (Figure 5). Three different mixtures with components that differed in the particle size, were analyzed (Figure 6). The particle size of surplus elements was not of any significance for the mixture quality, which had not been referred to in the literature[17,18].

Static mixers in general do not show traces of segregation, which is their main advantage. Some investigations have shown that segregated islands may exist in the flow[18]. They may give a better quality mixtures in the beginning before the flow is stabilized, but there is more material to be mixed, and the longer the process lasts the better the quality is and the better the mixture is stabilized, which is the reason why these types of mixing devices should be a part of a continuous mixing process in industry.



F i g . 5 – *Mixture of components A and D in 1:1 ratio mixed in three different mixer types*

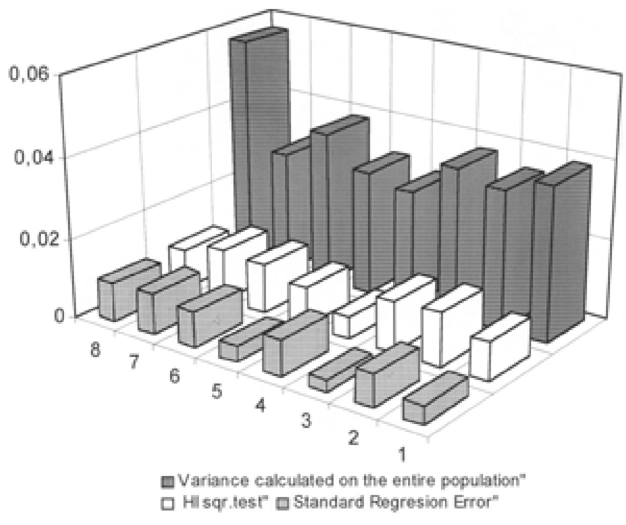


F i g . 6 – *Different component mixtures mixed in ratio 1:1 in Kenics static mixer*

Each type of mixing elements exhibit some advantage to a specific mixture. That is why the mixing elements should be chosen according to the mixture characteristics that can be obtained only experimentally.

Many authors[12,19] declare that mixtures with a component smaller in size will give a better mixture, when in excess, than the one with reversed additional amount of the grain size. In our case all the mixtures that have had one of the components in surplus, according to their standard deviation values, have shown that all types Kenics, Komax and Sulzer mixing elements give a good quality mixture. Figure 6 indicates that Komax type mixer (regression values) should be chosen for this type of mixture. If we look at figure 7 where the dissipation of variance values is shown, it can be seen that those values are very close and that the mixture quality is high. Experiments, where equal amounts of components have been mixed with only one difference, in particle size, show no significant difference in their quality (Figures 8 and 9). The main factor for good quality of the mixture is the mixer type chosen and the amount of components. The difference in the granulometric composition is not significant.

When mixing the powders with static mixers the main concern should be which type of the mixing element should be chosen. The choice should be based on the bulk density of the mixed materials, the ratio of components that are to be mixed and the characteristics of the component in excess.



F i g . 7 – *Mixtures of A and D components mixed in 1:9 ratio mixed in different mixer types*

Fig. 8 – *Statistical parameters for Kenics type mixer, with components A and D mixed in 1:3 ratio*

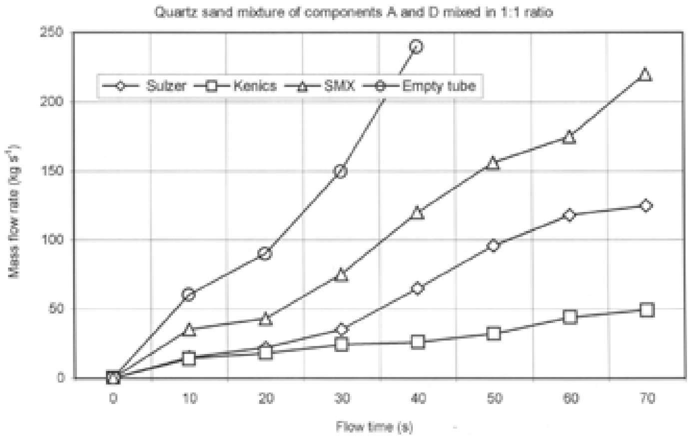


Fig. 9 – *Statistical parameters for Sulzer type mixer, with components A and D mixed in 1:9 ratio*

Conclusion

The aim of this work was to define the usage of static mixers for mixing powder materials, especially in those processes, where different batches are mixed and then put together in one tank before packaging. In this way the material segregated and the end result was not of the same quality as the mixture itself. Structure of a static mixer, which would provide segregation during the storage and improve the mixture quality before packaging, could prevent segregation. Three types of mixing elements were chosen. Two component mixtures were analyzed that differed in particle diameter. Statistical methods were used that characterize the mixture. They were tested many times and several of them proved to be better than the others. Some mixing indices did not prove appropriate for these types of mixtures, because they did not give a real picture. Lacey's index, for example, gave the qualitative mixture analyses in the case where different methods, like standard deviation or variance, indicated a poor quality mixture. Therefore, several comparisons had to be made. Variance calculation was reliable, which was proven by reproducibility of more samples. The standard variation was calculated on the basis of asymptotic value of variance in a certain period of time. The non-linear test square technique was used. Computer programs for these calculations were made.

Different mixture combinations were analyzed on three different mixing elements. First combination was with equal amounts of each component, so the only difference was in the particle diameter.

The study shows that those mixtures compared to other combinations gave the poorest results for each of the mixer type.

When one of the components was in surplus the bigger the surplus was, the homogeneity of the mixture was higher, which was the parameter that lead to the conclusion that the difference in amount of component in the mixture was not important for its quality.

Other parameters, like the shape of the mixing elements or the length of the pipe, that is, the number of elements put into the device, played a significant role. Each type of element showed some good results for a certain type of mixture.

In our investigations the Kenics type mixer was proved to be the best when the components were more or less equal in the mixture. In the case when one of them was in great surplus other two mixing devices gave much better results.

Further investigations should be made with real materials, especially food powders or components used in pharmaceutics, to show how these mixers can be integrated in real systems for use in industry.

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