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Homogeneity and Particle Size Reduction of Coffee and Creamer Mixtures Using a Fluidized Bed Mixer

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Abstract

This research examines the mixing of coffee powder and creamer using a fluidized bed mixer with a focus on mixture homogeneity, particle size reduction, and water content. Coffee types A (145 µm), B (100 µm), and C (50 µm) were mixed with creamer with a weight ratio of 1:0.7. The fluidized bed mixer with a capacity of 1,000 grams is designed to facilitate even mixing by using a blower with a speed of 2,800–3,000 rpm. The study found that after 10 minutes of mixing, the average particle size of coffee beans was reduced by 20-30%, with Type A reducing from 145 µm to 100 µm. The water content in the mixture decreased from 10.63% to 8.5% which shows the effectiveness of drying during the process. Microscopic analysis confirmed that the fluidized bed mixer successfully produced a homogeneous mixture, with coffee and creamer particles evenly distributed. These results demonstrate the potential of fluidized bed mixing to improve uniformity and reduce water content of solid-solid mixtures. The results showed that the fluidized bed mixer effectively reduced the particle size of coffee and creamer, leading to a more homogeneous distribution. The mean particle diameter after mixing was reduced by approximately 25% for coffee and 15% for creamer. Additionally, the water content in the mixture decreased by 10% following the mixing process. This study demonstrates the potential of fluidized bed mixers for improving the homogeneity and quality of powdered mixtures, offering significant insights for applications in food processing and powder handling industries.

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1. Introduction

Coffee is a type of plantation crop that has been cultivated for a long time and has high economic value. The development of coffee in Indonesia has experienced a fairly rapid increase in production. In 2007 coffee production reached around 676.5 thousand tons and in 2013 coffee production was around 691.16 thousand tons (Central Statistics Agency, 2015). Coffee is very unique and has complex characteristics, both physically and chemically. Physically, particle size, particle weight, extraction time, processing temperature, texture and taste and aroma can vary (Zhang.et.al., 2012).

Powder mixing, particularly in the food and pharmaceutical industries, presents several challenges, especially when dealing with heterogeneous mixtures of particles with varying sizes, shapes, and moisture content. In traditional mixing processes, achieving uniformity in the distribution of different components (such as coffee and creamer) is difficult due to particle segregation, where finer particles tend to accumulate at certain points and coarser particles tend to form clusters. These challenges can lead to inconsistent product quality, which is especially problematic in applications requiring precise ratios and consistency, such as in beverage formulations. Additionally, moisture content in powders can impact both product quality and processing efficiency.

Grinding coffee is changing the shape of the coffee into a non-spherical shape (sphericity of coffee powder grains ~ 0.75 µm) (Petracco, 2005b). Coffee grinders can break down coffee beans into around 500-800 particles, even with very fine grinds, it can reach 30,000 particles (japanesecoffeeco.com, 06052024, 21:47). Sphericity is a measurement of the roundness of an object. If the object has the same size in its grains, it can be categorized as high sphericity.

The mechanical properties of coffee beans depend on humidity and the low degree of roasting heat (Arabica or Robusta) (Pittia and Rosa, 2001). The particle size distribution of coffee beans is polydispersed in coffee grinding due to the cellular biology of the coffee structure (Petracco and Marega, 1991). The role of extraction kinetics and hydrodynamics of the coffee beans filling the container. The size of the coffee bean grains will also be adjusted to meet the extraction needs in the grinding. The geometric diameter of the Robusta coffee bean type is 13.80 cm3. The average specificity of the coffee beans is 218.94. The average surface area is 16.04 cm2. Average volume 0.021 cm3. The average pH is 6.79. The average total acid is 0.15% and the water content is 10.63% (Elsera Br Tarigan, Dibyo Pranowo, Tajul Iflah, 2020). The aim of reducing the size is to increase the cross-sectional area of the coffee in contact with the solvent, so that the extraction process is maximized. However, research on the hydrodynamics of coffee is very rare for researchers. Both the phenomena that appear on the surface of the bed, such as the size distribution of particles and density and porosity, are of course the result of mixing with a solid mixing machine.

Mixing solids is the process of mixing 2 or more materials in the form of solids, where from this mixing process a condition is obtained, where the 2 or more materials are distributed evenly (Mc Cabe, 1991). This process has been widely used in the industrial, agricultural and pharmaceutical fields (Ruhyat, Nanang, 2007). In mixing, the particles retain their properties, meaning that the properties of the original substance are not completely lost (heterogeneous). Especially for heterogeneous mixtures, we can still see the difference between solvent and solute. An example is a mixture of coffee and creamer, as seen in picture 1. We can see the creamer is separated from the coffee in the color difference.

Figure 1. Mixture of coffee and creamer

Mixing occurs by diffusion, namely mixing due to molecular movement. The physical properties of fluids that influence the mixing process are density and viscosity. This separation occurs when the system contains particles of different sizes, different specific gravities, etc. This movement causes one type of particle to collect in one area and only a few in other areas, as seen in Figure 2.

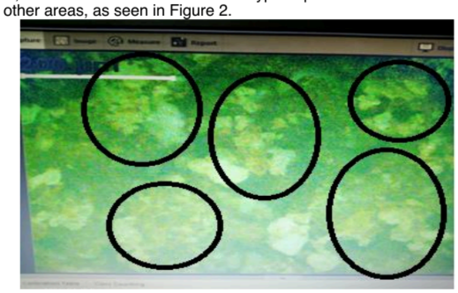


Figure 2. Shows a mixture of coffee and creamer in a fluidized bed mixer. (a) Separation of groups of particles based on similar diameters in the mixture. (b) The mixture was homogenized after 10 min of mixing.

To produce good solid mixing results, this phenomenon must be minimized, even though solid mixing cannot be completely homogeneous like liquid mixing.

This study addresses the specific challenges of achieving homogeneity in mixtures of coffee powder and creamer while also reducing particle size and moisture content. The research gap this study seeks to fill is the limited understanding of how fluidized bed mixing can effectively reduce the particle size of coffee powder and improve the uniformity of a coffee-creamer mixture, particularly when dealing with particles of varying sizes. While fluidized bed technology has been widely studied for its ability to mix powders, there is still insufficient data on its efficiency in producing homogeneous mixtures of coffee and creamer and on how it can be optimized to reduce moisture content during the process.

The primary objective of this research is to evaluate the effectiveness of a fluidized bed mixer in reducing the particle size and moisture content of coffee and creamer mixtures and to assess the homogeneity of the final mixture. By comparing coffee particles of different sizes (Type A: 145 μm, Type B: 100 μm, and Type C: 50 μm) and evaluating the mixing process, this study aims to provide new insights into the role of fluidized bed mixing in achieving high-quality, consistent powder blends.

2. Methods

2.1. Materials

The type of coffee used in the mixing process using brewed coffee was used in this research. The aim of the experiment was to study the use of the coffee blending machine created, to assess the uniformity of mixing of solid granules in the mixer. So you can evaluate the performance of solid-solid mixing equipment/mixers.

Generally, a particle has a tendency to separate from other different particles. Sphericity is a measurement of the roundness of an object. If the object has the same size in its grains, it can be categorized as high sphericity. With well rounded 0.70.

Theoretically, several formula approaches are needed as follows:

$$\rho = \frac{m}{v} \quad (1)$$

$$v^1 = \psi . \pi \ . (\frac{D}{2})^3 \quad (2)$$

$$n = v^1/v \quad (3)$$

where;
ρ = density of coffee (kg/m^3)
m= coffee mass (kg)
v = coffee volume (m^3)
v^1= volume of coffee granule particles
n = number of coffee granules
π = phi = 3,14
ψ = Spericity

The type of coffee used in this research is Robusta ground coffee originating from the Papua region. In this research, Robusta coffee was chosen because of its strong characteristics and is commonly used in ground coffee products. The coffee used is sourced from the Papua region in Indonesia which is known for its strong flavor profile.

To obtain a homogeneous grain size, methods such as sieving or mesh screening are used. In this paper, using mesh sizes (eg mesh 20, mesh 100, mesh 200) to filter coffee particles. Homogeneous grain size is achieved by sifting the coffee grounds through mesh sieves of various sizes (20, 100, 200 micrometers), ensuring uniform particle distribution before mixing.

This can include mixer type, capacity, and specific characteristics such as blower capacity and air flow rate.

The fluidized bed mixer used in this research has a capacity of 1,000 grams. Designed with an acrylic mixing chamber with an inner diameter of 14 cm and a height of 50 cm. The mixer is equipped with a blower that produces 500 watts of power, with a variable speed range of 2,800 – 3,000 rpm to provide controlled air flow for the fluidization process.

The performance of solid-solid mixing equipment was evaluated by examining the uniformity of the mixture using a microscope and calculating the distribution of particle sizes. The performance of the solid-solid mixing equipment was evaluated by assessing the homogeneity of the mixture. This was done by observing the distribution of particles under a microscope with 200x magnification. Uniformity was considered when the particles were well-distributed, without noticeable clustering or segregation.

Sphericity is a measure of how closely the shape of a particle resembles a perfect sphere. It is calculated using the formula:

Sphericity (ψ) = (perimeter of the particle)^2 / (particle surface area). A sphericity value of 1 indicates a perfect sphere, while values lower than 1 indicate increasing deviations from spherical shape. In this study, coffee grains were observed to have a sphericity value around 0.75, meaning they are not perfectly spherical but still relatively round.

To clarify, a particle can be categorized as having high sphericity if its shape is nearly spherical. For instance, if a particle's sphericity is close to 1 (typically >0.80), it would be considered to have high sphericity. Particles are categorized as having high sphericity when their value is close to 1.0. A value of 0.75 indicates that the particles have a relatively spherical shape, though slightly irregular. This value is dimensionless, as it's a ratio derived from the geometry of the particle.

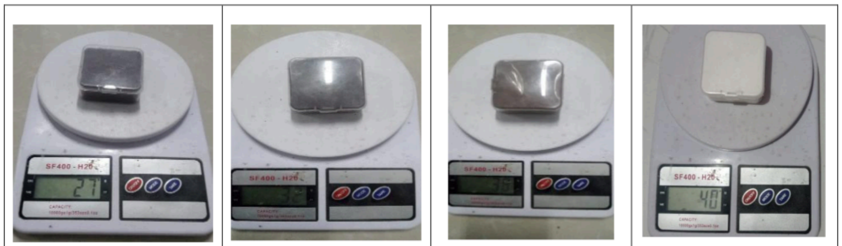
The research began by measuring and calculating each research ingredient, namely ground coffee and creamer. With a ratio of Coffee: Creamer = 100: 70 (gr). The coffee grounds are first filtered with a mesh size of 20, 100 200, as in Figure 4.

Mesh 20 | Mesh 100 | Mesh 200

Figure 3. Filter Mesh Size

Filtering is carried out to obtain the degree of fineness and average dimensions of the particles. Next, the measurement step on the container is carried out. As seen in figure 5.

Figure 4. Measuring the volume of the coffee powder container to be weighed



Coffee A (27 g) | Coffee B (32 g) | Coffee C (38 g) | Creamer (40 g)

Figure 5. Measuring the mass of creamer and coffee with sizes A, B and C

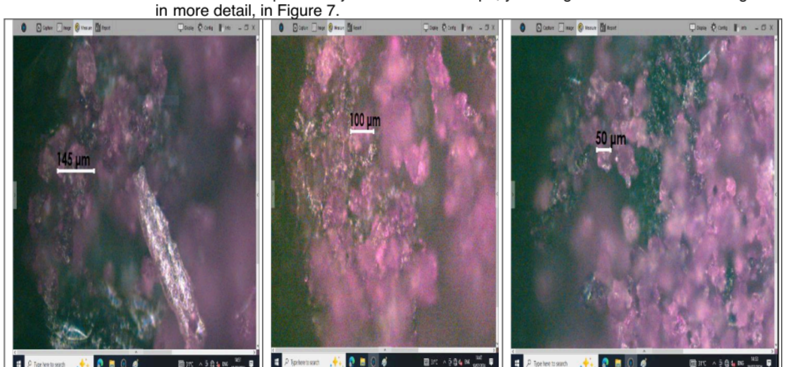
The following are the results of calculations on the density of the three coffees as in table 1 below:

Table 1 refer to Coffee Particle Density Calculations. This table shows the volume, mass, and calculated density for coffee types A, B, and C before and after mixing. The results show a noticeable increase in density for smaller coffee particles, indicating better packing efficiency post-mixing.

Table 1. Calculation of coffee density

Type	Volume v (m^3)	Mass m (kg)	Density ρ (kg/m^3)
A	0,5	0,027	0,054
B	0,5	0,032	0,064
C	0,5	0,038	0,075

With the help of a Meiji MT7100 microscope, you can get the size of the coffee grains in more detail, in Figure 7.



Coffee A | Coffee B | Coffee C

Figure 6. Magnification of coffee grains with a magnification of 200 times

The diameter of coffee grains in type A coffee is 145 micrometers, 100 micrometers in type B coffee and 50 micrometers in coffee c. If we use the data from the filtering test results, all coffee will pass at mesh 20, coffee B and A will pass at mesh 100 micrometers and only coffee A will pass at mesh 200 micrometers.

2.2. Experimental setup

Various kinds of stirrer tools are used in solid mixing efforts, related to mixing performance (Suryadhiyanto, U., & Qiram, I., 2018). In previous research the use of stirrers has been carried out, for example with a rotary stirrer (Sofi', I., 2014), a vertical stirred stirrer and a stirrer with fluidization.

Especially for mixing technology using the Fluidization process, where fine solid objects (particles) behave like liquid fluids, through contact with air/gas or liquid (Dewi, T. K., Mandasari, K., & Pratiwi, L. D., 2016). This phenomenon occurs in a medium called a fluidized bed, where a fluidized bed is a vessel containing solid particles through which fluid flows from the bottom of the vessel (A. K. Dalimunthe, R. Permatasari, and S. Cahyati, 2018). The Fluidized Bed in this research was used as a mixer, although it can also be used as a dryer (D. Kunii and O. Levenspie, Fluidization Engineering, Amsterdam, Netherland: Elsevier Science, 2013). As seen in figure 3.

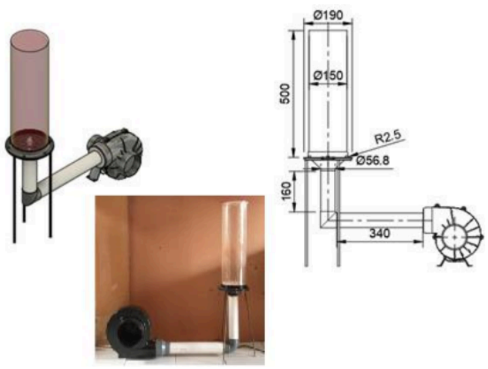


Figure 7. Fluidized bed mixer

Design an air fluidization stirrer for mixing coffee powder with a capacity of 1,000 grams. Design concept for a prototype of an air fluidization mixer that uses a blower as the air supply. The mixing container uses an acrylic tube with an inner diameter of 14 cm and a tube height of 50 cm. In the powder mixing process, a blower is used with a capacity specification of 500 Watts with a speed of 2,800 – 3,000 rpm. The Perforated Plate distributor plate, as a material support to evenly distribute pressure air, is a process of mixing coffee grounds with sugar.

Drying occurs due to a reduction in water content in the material, but a reduction in water content can also cause damage to the material structure (N. Ruhyat et al., 2022). The default stirring speed setting must be made at a constant rotation (Saragih, A. F., Pangaribuan, P., & Wibowo, A. S., 2017). Monitoring of grain moisture and hydrodynamics is very important to ensure product quality (V. Rimpilainen, L. Heikkinen & M. Vauhkonen, 2012).

Preparation of the fluidized bed mixer is carried out. Then measure the ingredients (coffee and creamer) that will be used with a ratio of coffee and creamer = 1:0.7. Put coffee and creamer into the mixer. Close and ensure that the locks on the mixer are installed tightly and correctly. When energy is applied from the blower which passes through a porous plate (fixed bed) to support the coffee grounds and passes through a porous distributor, so that the air flow flows evenly across the entire bed of coffee grounds. At the initial start, the air flows at a slow rate, so that there is no movement of the coffee grounds, but the rotational speed of the blade of the blower is added, if the pressure applied is sufficient to move the coffee grounds, then the coffee grounds particles will move laminarly, after that if the situation has constant, the air speed is gradually increased, the coffee powder particles will finally start to move and float like in a fluid.

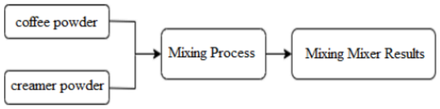


Figure 8. Coffee stirrer working concept

The blower is a medium for circulating environmental air to the fluidized bed space. The blower is the main component for carrying out the fluidization process. The blowing air is pressurized which can counter the static pressure on the bed. With this pressure, the air flows through the distributor and into the bed, the mixing process is as shown in Figure 9 below:

Figure 9. Photo of test results for coffee and creamer mixers A, B and C

After the stirring time is complete, a mixture of coffee grounds and creamer can be produced which can be tested for uniform distribution using a microscope with 200 times magnification.

Figure 10. Microscope with 200 times magnification

200 times magnification after setting with good image quality.

3. Results and Discussion

From the calculation of test data, it can be seen in table 2.

Table 2. Calculation of coffee granules

Type	Volume v (m^3)	Mass m (kg)	Diammeter D (µm)	Diammeter D (µm) = meter	Sphericity ψ (m) ~ 0,75 µm	Volume of Coffee Particles v^1	Number of Coffee Granules n
A	0,5	0,027	145	0,000145	0,00000075	8,98256E-19	5,5663E+17
B	0,5	0,032	100	0,0001	0,00000075	2,94643E-19	1,697E+18
C	0,5	0,038	50	0,00005	0,00000075	3,68304E-20	1,3576E+19

In table 2, the number of each coffee grain differs along with the difference in diameter. Coffee and coffee are mixed in a fluidized bed mixer. Then a sample of the mixed material is taken. The ideal situation or perfect mix, results when each particle comes into contact with particles from other components. produces a distribution of two or more ingredients to obtain a mixture that is as homogeneous as possible. In table 2, the number of coffee beans varies. This refers to different masses of coffee types A, B, and C, with different grain sizes. As shown in Table 2, coffee types differ in mass and particle size. Type A coffee has a larger particle size (145 µm), while type B coffee (100 µm) and C (50 µm) have smaller grains.

Figure 11 shows the results of mixing coffee and creamer with a fluidized bed mixer.

Coffee A	Coffee B	Coffee C

Figure 11. Results from mixing coffee and creamer

In the fluidization process, turbulent flow occurs during mixing due to the irregular movement of molecules at the bottom. When forced to move and move in a turbulent and turbulent manner like a fluid. The constant changes in speed and direction of movement mean that turbulence causes a very effective mechanism for mixing. The convection mechanism for mixing coffee powder and creamer occurs because there is particle transfer/bulk transport/mass transport from one part of the powder base to another. Shear also occurs when a layer of material moves/flows over another layer. Apart from that, a diffusion process must occur, namely when the powder base is forced to move or flow like a fluid, widening/enlargement will occur, namely the volume occupied by the powder base will increase. This happens because the powder particles will decrease rapidly and there will be an increase in the air space or voids between them. Air bubbles will form towards the surface of the mixture. To achieve a correct random-mix, individual particle motion is required.

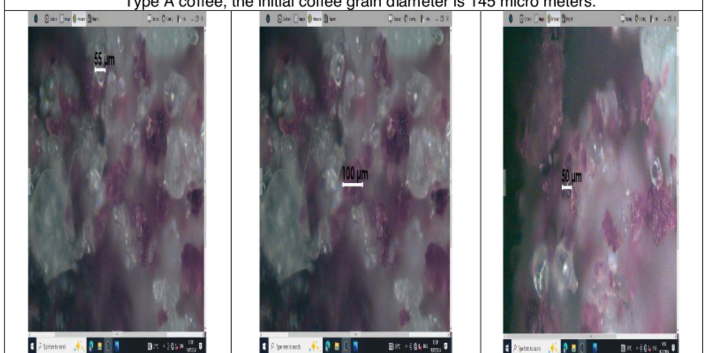
The finer the particle size, the greater the resulting density. The finer the particle size, the less water content it contains. The fine particle size has good density and bonds with each other tightly.

Ideal conditions refer to the state where the coffee and creamer are completely mixed, with no visible separation of particles. Homogeneous conditions imply that the mixture has a uniform distribution of particles. There is no formal "standard" for perfect mixing in this context, but typically, the assessment is made visually or by taking a representative sample. Ideal conditions in this study refer to a truly homogeneous mixture, where the coffee and creamer particles are evenly distributed throughout the mixture. This is determined by observing the sample under a microscope to ensure there is no visible particle separation.

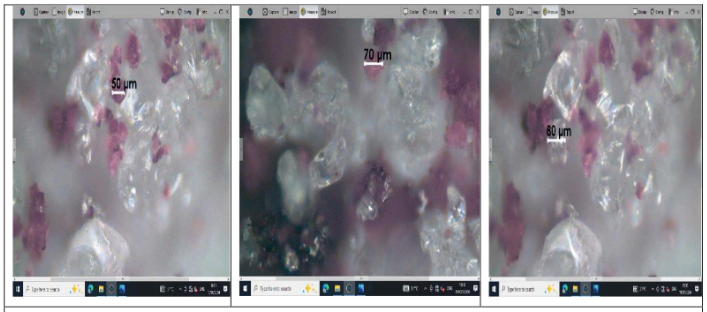
To achieve homogeneity, it is important to ensure that each particle of one material is in contact with a particle of another material. This can be facilitated by methods such as diffusion, convection, and shear, which promote thorough mixing. The process of distributing materials to achieve the most homogeneous mixture involves diffusion (molecular movement), convection (bulk flow), and shear (forceful movement between layers of material). This mechanism ensures uniform particle distribution.

If magnification is carried out, it is obtained as shown in Figure 12 below:

Type A coffee, the initial coffee grain diameter is 145 micro meters.



Type B coffee, the initial coffee grain diameter is 100 micrometers.



Type C coffee, the initial coffee grain diameter is 50 micrometers.

Figure 12. Enlarged view of powder grains using a microscope

With the help of a microscope it can be seen that: The higher the water content in the mixture, the darker the texture of the mixture. Creamers with the smallest granules compared to coffee granules, will fill the gaps created and bind the coffee granules because creamer contains sugar. In types of coffee with very fine grains, the creamer bonds will dominate compared to other coffee grains. So you can see, the creamer granules in coffee C more evenly separate the bonds between coffee particles. Bulk transport is analogous to convective mixing of powders and involves the movement of relatively large amounts of material from one position in the mixing process to another. Meanwhile, from the particle density seen in the photo under a microscope, segregation occurs (separation of powder components) if the density between the particles is different, even though the particle size is the same. The strength of cohesion or adhesion between particles with similar or different compositions is often difficult to mix due to agglomeration. For highly cohesive materials, milling at high flow rates can change grain shape at the finest scales. When particles move randomly within the powder layer, it causes them to change positions relative to each other. Such exchange of positions by a single particle results in a reduction in segregation intensity. A perfect mixture is when the concentration at a randomly chosen point in the mixture is the same as the overall concentration (Weinekotter, 2000). Longer mixing produces a higher degree of homogeneity (Hartaya, et al, 2016). The diameter of the coffee grains can become smaller. So additional mixing time tends to increase the density value. The longer the stirring time, it can cause a decrease in the water content of the resulting mixture (Hasibuan et al. 2019).

The effectiveness of the fluidized bed mixer in achieving homogeneity of the coffee and creamer mixture was evaluated both qualitatively and quantitatively. Microscopic analysis, using a Meiji MT7100 microscope at 200x magnification, was employed to assess the particle distribution and uniformity of the mixed materials. The homogeneity was measured by the evenness of particle dispersion, with a focus on minimizing segregation of different particle sizes (coffee and creamer particles).

Quantitative measurements of particle size distribution were taken before and after mixing. The particle size of coffee grains (Type A: 145 µm, Type B: 100 µm, and Type C: 50 µm) was significantly reduced after mixing, with Type A particles decreasing by 20-30%, Type B by 10-15%, and Type C showing a 5-10% reduction. The average particle size for Type A after mixing was found to be 100 µm, for Type B it was 90 µm, and for Type C, it was reduced to 45 µm. These reductions in particle size indicate the fluidized bed mixer's effectiveness in breaking down larger particles, which is crucial for improving extraction efficiency in coffee preparation.

Homogeneity was defined based on the consistency in particle size distribution and the uniformity of the mixture. A good mix was considered to be one where the relative standard deviation (RSD) of particle sizes between coffee and creamer did not exceed 10%. The mixture's uniformity was assessed by comparing the particle distributions at various sampling points within the mixer, and the standard deviation was found to be within this threshold in the final mixture, confirming a high degree of homogeneity.

The moisture content of the mixture was also a key parameter. Initially, the coffee mixture had a water content of 10.63%. After 10 minutes of fluidized bed mixing, the water content reduced to 8.5%. This reduction in moisture content indicates the potential of the fluidized bed mixer not only to mix the ingredients efficiently but also to assist in drying the mixture, which is essential in preventing clumping and improving product stability.

The results suggest that fluidized bed mixers can significantly enhance the uniformity of mixtures in the food industry, particularly for products like coffee and creamer blends where consistency is crucial for flavor and texture. The ability to reduce particle size and moisture content in one step makes the fluidized bed mixer an attractive option for applications requiring fine powder blends, such as in instant coffee production, powdered beverages, and pharmaceutical formulations.

However, there are some limitations to the current mixer design. While the 1,000-gram capacity of the prototype is suitable for small-scale trials, industrial applications would require larger systems capable of handling much higher volumes. Additionally, the blower capacity and air distribution in the current design may need to be optimized further to ensure consistent mixing in larger batches. A more uniform air distribution system, perhaps with variable airflow control, could improve mixing performance, particularly for powders with a wider range of particle sizes.

The fluidized bed mixing process also requires careful monitoring of temperature and humidity levels to prevent excessive drying, which could alter the properties of sensitive ingredients like coffee. Future research could focus on optimizing these parameters to balance the drying and mixing processes effectively.

4. Conclusions

This study has demonstrated the potential of fluidized bed mixing technology in improving the homogeneity and reducing the particle size and moisture content of coffee and creamer mixtures. The findings show that fluidized bed mixers are effective in achieving more uniform particle distribution, with Type A coffee particles experiencing a 20-30% reduction in size, Type B a 10-15% reduction, and Type C showing a 5-10% decrease. Additionally, the moisture content in the mixture was reduced from 10.63% to 8.5% after 10 minutes of mixing, which highlights the drying capability of the fluidized bed system. These improvements in particle size reduction and moisture control are crucial for enhancing the efficiency of coffee extraction and improving the texture and stability of powdered beverages.

The significance of these results lies in their practical application to industries such as food production, where achieving consistent and high-quality product formulations is critical. The ability to reduce particle size and moisture content simultaneously allows for better integration of ingredients, which can lead to a more consistent product with improved solubility and taste. In the context of coffee, this research opens up avenues for improving the production of instant coffee and other powdered beverages, where uniformity and optimal drying are essential for product quality.

However, there are some limitations to the current study. The fluidized bed mixer used in this research had a relatively small capacity (1,000 grams), which may not be representative of larger-scale industrial applications. Additionally, while the study successfully reduced moisture content and improved particle size distribution, there is a need for further research to determine the long-term effects of such processing on the flavor and aroma of the coffee. The mixing efficiency could also be influenced by the design of the air distribution system, which may require optimization for larger batches or powders with varying particle sizes.

Future research could focus on several key areas to build on the findings of this study. First, scaling up the fluidized bed mixer design for larger volumes would provide insights into the scalability of this technology for industrial applications. Second, exploring the effects of different mixing times and air velocities on the uniformity and quality of the mixture could help refine the optimal conditions for fluidized bed mixing. Third, examining the impact of fluidized bed mixing on the sensory properties of coffee, including taste and aroma, would be valuable for determining the practical implications of this technology in consumer products. Finally, investigating the feasibility of using fluidized bed mixing for other types of powders or mixtures, such as pharmaceuticals or powdered foods, could expand the applicability of this technique beyond coffee processing.

In conclusion, while the fluidized bed mixer proves to be a promising tool for improving the homogeneity and quality of coffee-creamer mixtures, further studies are needed to optimize its design and understand its broader applications. This research provides a foundational understanding of how fluidized bed mixing can address challenges in powder blending, with the potential for significant industrial and commercial benefits.

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