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Variables affecting the rate of mixing in two tumbling mixers

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Abstract—Tumbling mixers are mild not aggressive equipment. They are preferable when different particle sizes and densities are to be mixed due to repeated reversal of direction of flow. Two of these tumbling mixers are the drum and cube mixers, they have their own characteristics and operate best at certain conditions, in most blending processes the two types of mixers are currently being widely used. Manufacturing a cubic mixer is much easier and less expensive than making a drum mixer, but it is difficult in cleaning due to presence of multiple corners. Drum mixer is more suitable for friable particles as it gives light movement but it has lower shear force. Based on that a comparison between these two mixers has been done to study the effect of three variables; speed of rotation, particle size, mixing ratio on the rate of mixing of solids. The results obtained revealed that utilizing a mixer of cubic shape improved the rate of mixing it reached to 1.5times more than that of drum mixer.

Index Terms— mixing rate, efficiency of mixing, rotation speed, particle size, mixing ratio and mixer geometry..

1 Introduction

Mixing is the most commonly encountered of all process operations. Many scientists have studied the effect of the type of mixer on mixing. [1-9]. Unfortunately, it is still one of the least understood. One of the key questions that comes up whenever amixture of solids is used, either to make a product directly or to be further processed (is this batch well enough mixed?).There are, however, some aspects of mixing which can be measured and which can be of help in the planning and designing of mixing operations.

Ideally, a mixing process begins with the components, grouped together in some container, but still separate as pure components. Thus, if small samples are taken throughout the container, almost all samples will consist of one pure component. The frequency of occurrence of the components is proportional to the fractions of these components in the whole container.As mixing then proceeds, samples will increasingly contain more of the components, in proportions approximating to the overall proportions of the components in the whole container.

Complete mixing could then be defined as that state in which all samples are found to contain the components in the same proportions as in the whole mixture. [10]

The mixer is a vessel which rates either on its own axis together with the mixing devices.The efficiency of mixing can be improved significantly by adjusting many factors such as speed of rotation, particle size, and mixing ratio.

Oyama [11] observed the state of motion in rotating horizontal cylinder under various conditions of speed and volume percent loaded, using black and white sand of particle diameter equal to about 1.3mm (between 12 and 16 U.S. mesh size).

He described the various state of motion by terms cascade "critical" and "equilibrium".

The cascade state, which he reported for low speeds, consisted of particles rolling down the inclined surface after leaving their circular paths. At certain speed the motion changed to critical state, which consisted of particles close to cylinder walls adhering to it until they reached a certain height. In the state called equilibrium, the particles in motion were considered to always keep their own fixed paths in flight and circular motion. The best operating condition existed between equilibrium and critical states, the particular optimum speed for Oyama's system being 80 rpm.

Oyama and Ayaki [11] suggested the determination of mixing rate according to the following rate equation:

$$\text{Log}\,(1/(1-M)) = Kt \qquad (1)$$

Where M is the mixing degree of mixed solid materials, t is the time of mixing and K is the coefficient of mixing velocity or rate constant.

It was found that the rate equation of mixing by Oyama and Ayaki [11]semi- empirical formula:

$$K = C\,W^n \qquad (2)$$

Which represents a relation between the rate constant, Kand the tested variable, W, where C and n are constants for empirical relation.

The above equation can be written in a linear form

$$\text{Ln}\,K = \text{Ln}\,C + n\,\text{Ln}\,W \qquad (3)$$

Values of n and C can be easily determined. With the aid of the last derived equation, the performance of the suggested cubic mixer model can be accurately assessed by comparing it with that of the drum mixer. The magnitude of K can be used as

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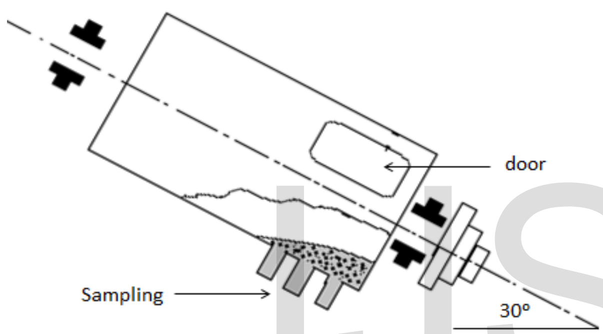
a measure for the mixing efficiency for most problems involving solids blending.

2 Experimental Work

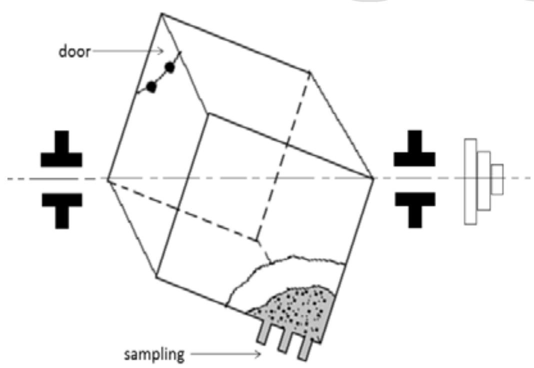
2.1. *Equipment*

Two laboratory models for mixing of solids were used. One is in the form of cylindrical vessel and the other is cubic. They were made up of a steel sheet of 3 mm thick, and had the following dimensions, for the drum mixer 48.67 cm length x 33.5 cm diameter and for the cube mixer 35 x 35 x 35 cm.

The dimensions of both mixers were chosen to give the same volume. The drum mixer was designed to rotate on the horizontal axis; however the cube mixer rotates on one of its four diagonals (see Figure1, A and B).



(A)



(B)

Fig.1. The schematic diagram of the mixers (A) drum (B) cube

The gear drive used, gave three different speeds: 16, 25 and 35 rpm. The samples were withdrawn with the aid of sampler from different positions; all samples were taken from the door of each mixer at constant periods.

The samples were withdrawn with the aid of a vacuum pump which was adjusted to give a sample of about two grams weight. The particles of each sample were manually counted.

2.2. *Material and procedure*

To examine the performance of the mixer, identical solid materials except in color were selected, one of them is white colored and the other is black.

We used two types of materials basalt and calcite. Basalt is a dark dense looking rock, often with small prophetic crystals, and has a black to brown colored surfaces. However, Calcite is a white colored hard rock.These materials were screened into three different particle sizes 2.5:2, 2:1.5 and 1.5:1 mm.

The charge of solids remained constant for all experiments. The charges were introduced into the mixers through the doors (Figure1). One kilogram of each colored powder was fed to make a total load of 2 kg in the mixer for each run.

As was stated before, the rate of mixing is affected by the mixing degree, the time of mixing, the speed of rotation, the particle size and the mixing ratio. Hence these factors were studied in order to estimate the value of the rate constant parameter to compare the performance of the suggested types of mixers.

3 RESULTS AND DISCUSSION

Figure (2) shows the effect of the mixing time in the cube and the drum mixers on the mixing degree, M.

It can be seen that the degree of mixing increases with the increase in the mixing time until it reaches its maximum value at 90 second for mixing ratio (1:1) and particle size (2.5-2mm), these in case ofcube mixer also for the drum mixer, the maximum degree of mixing reaches to (0.98) at time 90 second.

Nearly the same results were obtained for different particle size, mixing ratio and speed of rotation.

Three speeds of rotations, 16, 25 and 35 rpm were chosen. From Figures 3, 4 it is noted that the rate of mixing is increasing with enhancing of rotation.

At 16 rpm the rate of mixing was found to be 0.0169(s^{-1}) for cube and 0.0115(s^{-1}) for drum.

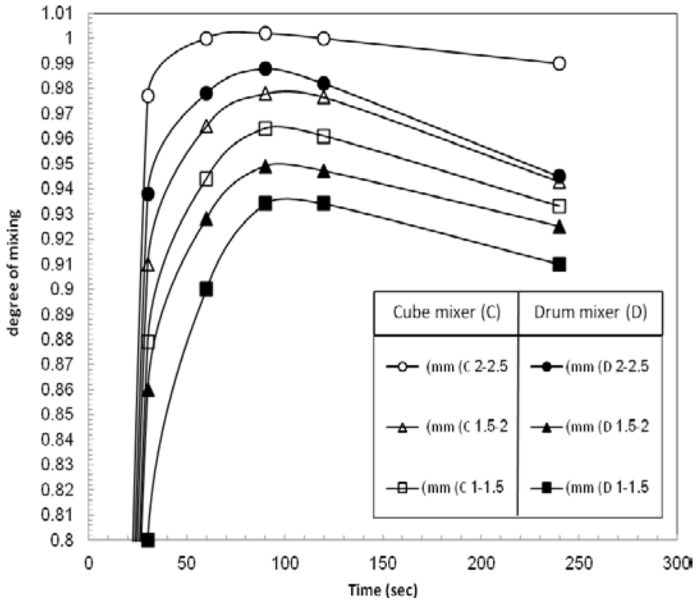


Fig.2. Effect of time on mixing degree for cube and drum mixers at different particle size.

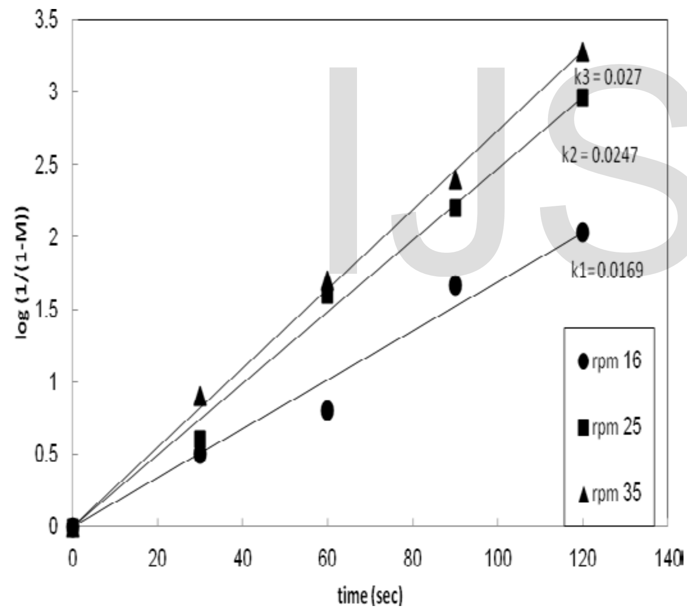


Fig.3. Effect of speed of rotation on mixing rate at mixing ratio (1:1) and particle size (2.5-2) mm for cubic mixer.

The rates of mixing increase until reaching to 0.0273 (s^{-1}) for cube and 0.0191 (s^{-1}) for drum at 35 rpm. This may be explained due to increasing the mixing-driving force and decreasing the segregation force that delay the rate of mixing.

Figure (5) showed the relationship between logarithm of mixing rate and logarithm of speed of rotation. From the figure it can be seen that this relation follows a straight line behavior by applying equation (1), it can be obtained the following equations:

For cube mixer, $K_c = 0.003\ W^{0.6258}$

For drum mixer, $K_d = 0.0019\ W^{0.6545}$

It proved that the rate constant of cube mixer is about 1.5 times that of drum mixer.

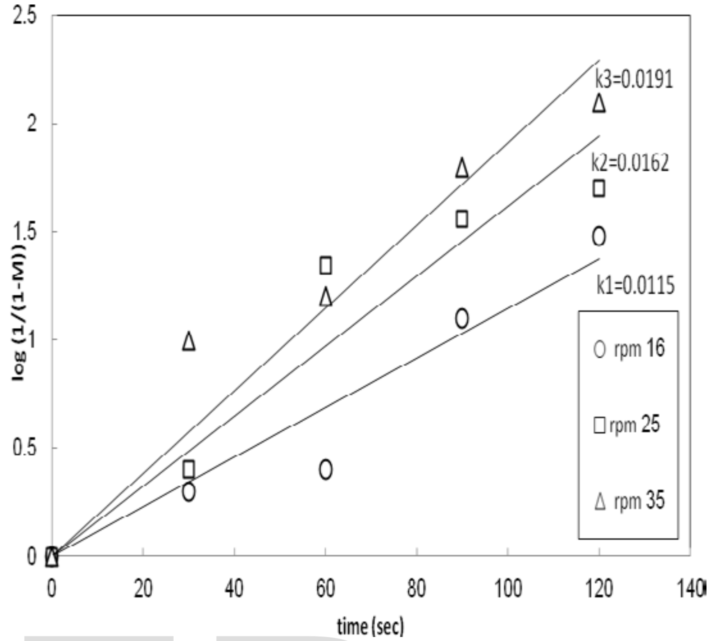


Fig.4. Effect of speed of rotationon mixing rate for drum mixer atmixing ratio (1:1) and (2.5-2) mm.

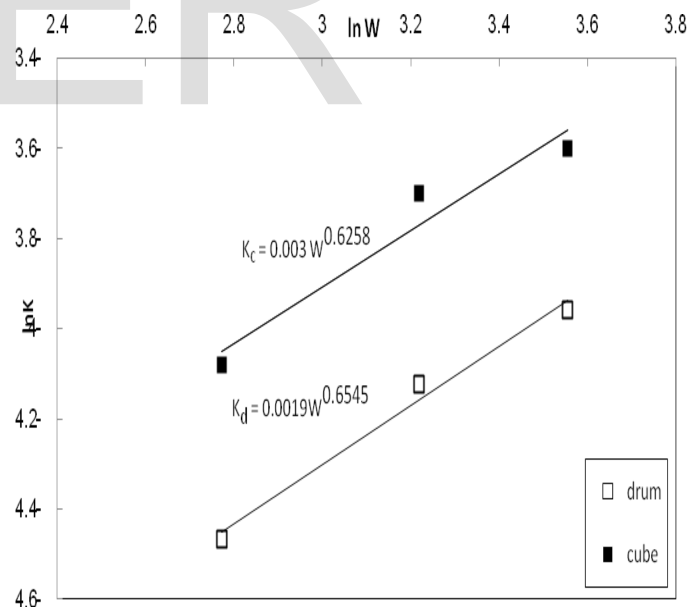


Fig.5. Effect of speed of rotation on mixing rate constant for both cube and drum mixers.

Effect of particle size on the rate of mixing was studied in Figures 6 and 7 for cube and drum mixers, respectively. The particle sizes used in this part were (2.5-2mm), (2-1.5mm) and (1.5-1mm) at mixing ratio (1:1) and speed of rotation 35 rpm.

In Figure (6) our results revealed that the rate of mixing in-

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creases with the increase in particle size.

For example at particle size (1.5-1mm) the rate of mixing was 0.0184 (s^{-1})and it increased at particle size (2-1.5mm) to the value of 0.0233(s^{-1}), however the particle size (2.5-2mm) gave the higher value of 0.0273(s^{-1}).

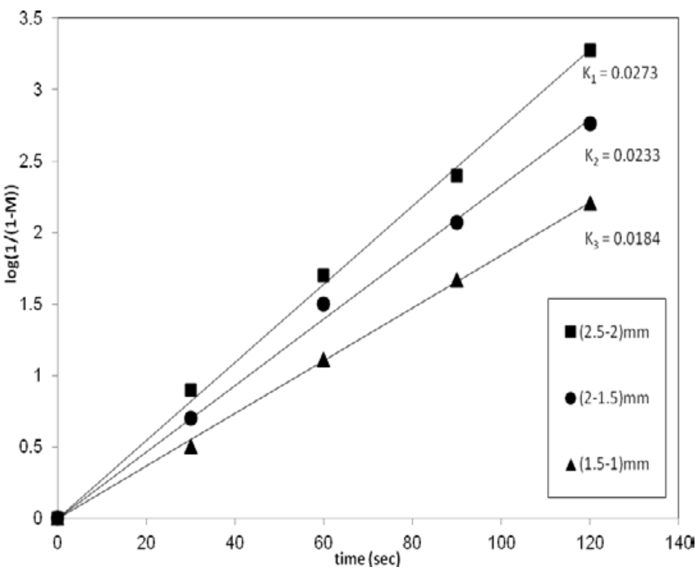

Fig.6. Effect of particle size on the rate of mixing at mixing ratio (1:1) and speed of rotation 35 rpm for cube mixer.

For the drum mixer, a similar observation were obtained as shown in Figure (7), the lowest value of rate constant was 0.0125 (s-1) for the lowest particle size (1.5-1 (mm)), however the highest particle size 2.5-2 (mm) gave a rate constant of 0.0191 (s-1).

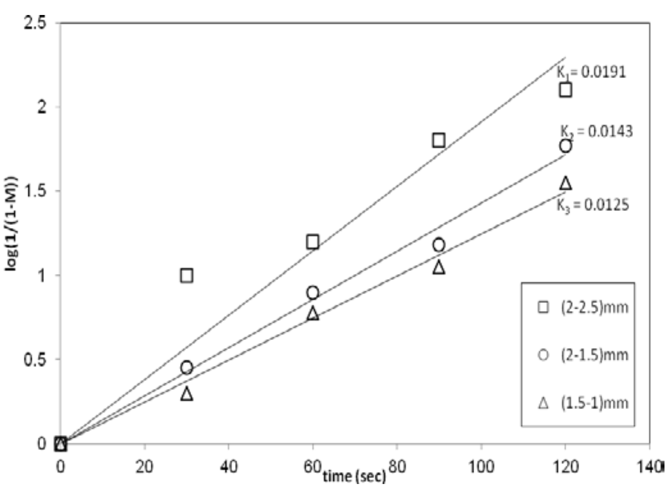

Fig.7. Effect of particle size on the rate of mixing at mixing ratio (1:1) and speed of rotation 35 rpm for drum mixer.

The predicted empirical equations were calculated according to Oyama's [11] and Figure (8) assured that the rate constant of cube mixer is about one and half times that of drum mixer.

As shown in Figure (8) the relationship between logarithm of mixing rate constant and logarithm of particle size follows a straight line behavior by applying equation (3), we obtained the following equation:

For cube mixer, $K_c = 0.016\ W^{0.65}$

Fordrum mixer, $K_d = 0.0103\ W^{0.69}$

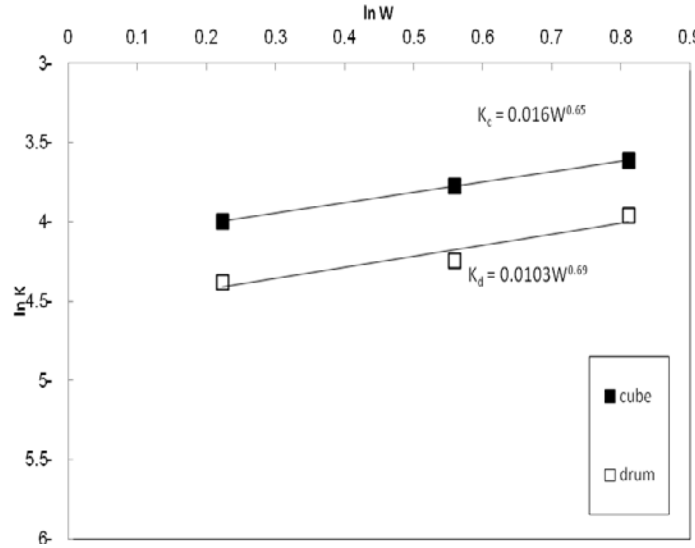

Fig.8. Effect of particle size on mixing rate constant for both cube and drum mixers.

Increasing the mixing ratios has significant effect on increasing the rate of mixing (Figures 9 and10); this may be attributed to the increase in the uniformity of the batch and consequently, the decrease in the segregation tendency by increasing the ratio of substance to another.

From Figure (9), it can be seen that for the cube mixer as mixing ratio increased from (1:1) to (1:2) and then (1:3), the rate of mixing reaches to 0.0273, 0.041, and 0.0537 (s^{-1}) respectively.

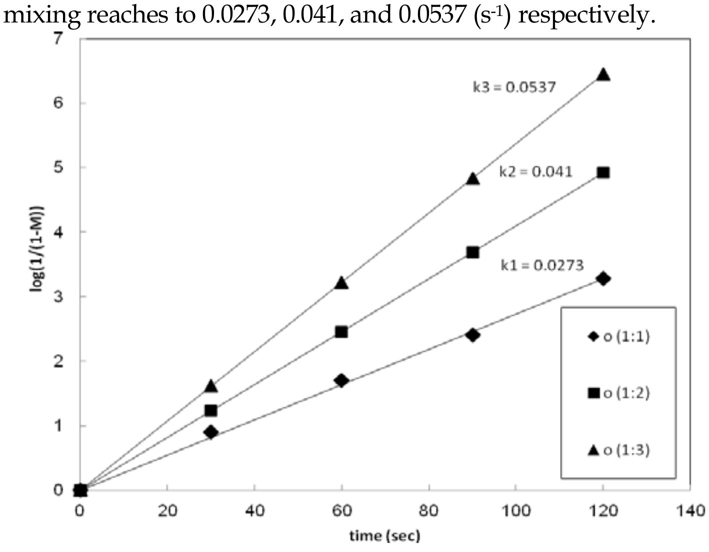

Fig.9. Effect of mixing ratio on the mixing rate at particle size (2.5-2 (mm)) and speed of rotation 35 (rpm) for cube mixer

It can be explained from Figure (10) the rate of mixing increased from 0.0191 to 0.0345 (s-1) for the increase in the mixing ratio from (1:1) to (1:3).

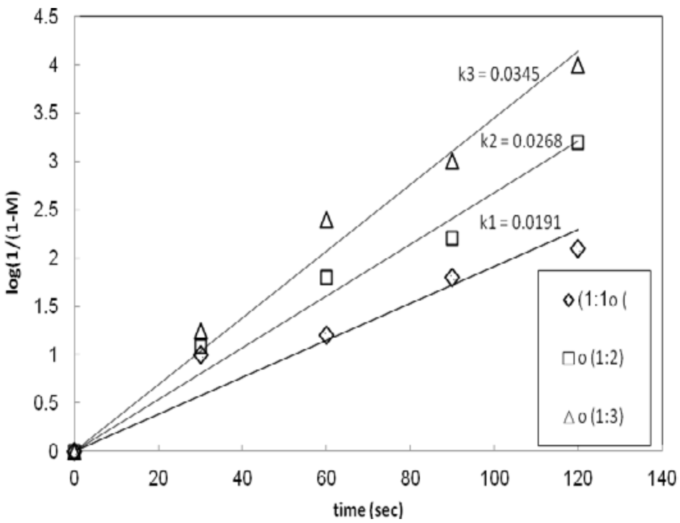

Fig.10. Effect of mixing ratio on the mixing rate at particle size (2.5-2 mm) and speed of rotation 35 (rpm) for drum mixer

We calculated the equations relating the mixing ratio and mixing constant. As shown in Figure (11) it was found that:

For cube mixer, $K_c = 0.0286\ W^{0.98}$

Fordrum mixer, $K_d = 0.019\ W^{0.85}$

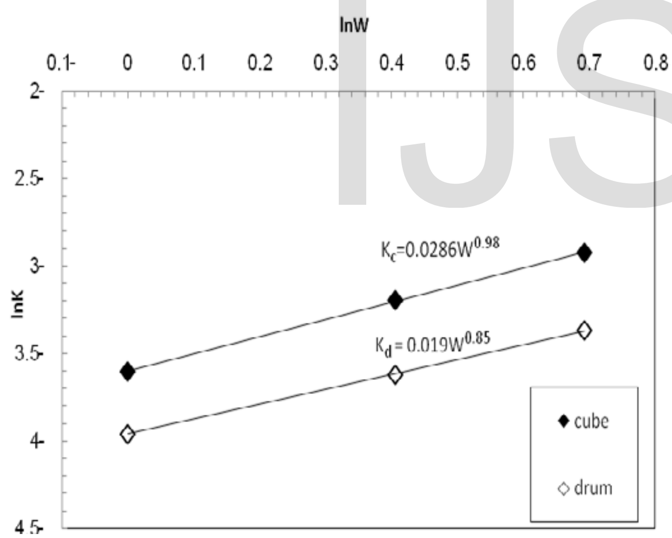

Fig.11. Effect of mixing ratio on mixing rate constant for both cube and drum mixers

Figures 5, 8 and 11 insured that the cubic mixer gives better results and higher rate of mixing than that of drum mixer. It reached its highest value 0.0537 (s^{-1}) for the cube mixer compared to 0.0345 (s^{-1}) for the drum mixer at the same conditions.

From the predicted equations it can be said that the mixing rate in case of cube mixer is one and half times greater than that of drum mixer when all variables, such as speed of rotation, particle size and mixing ratio, are constant.

The higher rate of mixing in cubic mixer can be attributed to the geometry of cube mixer. As when it rotates around its diagonal, the remaining six corners will work as lifters for the feed charge along the rising side of the mixer causing the particles to slip until the position of a dynamic equilibrium is reached. This is repeated six times in each revolution and occurs whether the speed of rotation is high or low. However, with the drum, lifting the charge will be only due to the rotation and friction of the mixer shell where the slip between the particles is at a maximum for the higher speed of rotation at which excessive slipping of the particles is prevented.

4 Conclusion

From the experimental results we can conclude that:

1- The performance of mixers for mixing solids and the rate of mixing are affected by several factors. The rate of mixing increases with the increase in the speed of rotation, the higher value was found at 35 rpm while the lower value was found at 16 rpm.

2- Increasing the particle size gives a higher mixing rate, as the particle size range (2.5-2mm) gave the best result.

3- Mixing ratio (1:3) could be chosen as it gave the best mixing rate comparing to that obtained from mixing ratios (1:2) or (1:1).

4- The use of cubic mixer is more effective, it gives better mixing rate about 1.5 times more than that of drum mixer.

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NOTATION
C = constant

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K = rate of mixing
M = degree of mixing
n = constant
t = time of mixing (s)
W = variable being tested