Study The Homogeneity of Mixing a Binary Polyethylene Granular Mixture in Fluidised Bed Mixer

Almahdi Atteya. Alhwaige, Siti Masrinda Tasirin, Ahmad Mokhtar Sowedan, Wan Ramli Wan Daud

***Abstract*—Since the 1940s the techniques of mixing indices have been used to determine the level of homogeneity in solid mixtures. At present, many mixing indices have been proposed to measure the evolution of the homogeneity of mixture. This paper presents observation the analysis of variance six of these mixing indices. The study is based on the comparison of experimental data obtained on mixing a binary polymer mixtures using bubbling fluidised bed. Experimental results are discussed and compared with values obtained for various gas velocity and bed depth. However, variance mixing indices proposed in the literature give different results for the determination of mixing indices. The results obtained show that gas velocity and bed depth are important parameters influencing solid mixing in a bubbling fluidised bed. Whilst it was obtained the Lacey mixing index is the best efficient compared with others.**

***Index Terms*—Particle mixing; Fluidisation; Mixing indices; Mixture homogeneity.**

I. INTRODUCTION

Many industrial processes involve the mixing of solid particles including pharmaceutical, chemical, petrochemical, and plastics. Ideally, final particle powder mixture should be completely homogeneous, that is, unsegregated [1]. This is critical in an area such as the plastics industry where the manufacturer must produce a specific amount of different types of polymer in the final mixtures and the consequences of being wrong can change the properties of products.

The basic mechanism of solids mixing in bubbling fluidised beds is well understood [2]. Achieving good mixing particulate solids of different size and density is important in many of the process industries, and yet it is not a trivial exercise. The mixing process depends on numerous parameters such as time, temperature, sequence of material addition, powder size and shape, shear rate and powder loading [3].

The objective of the present work is comparative study of mixing indices and determines the optimum operating conditions in order to obtain a final mixture of specified compositions of white polymer and black polymer, namely, 3:1, respectively.

II. THE QUALITY OF MIXING

The end use of particle mixture will determine the quality of mixture required. The quality of mixing can be assessed by examining the degree of mixing of particles in the final mixture. Over the past fifty years many indices have appeared in the literature. Most of these indices have been developed based on statistical analysis an especially on the definitions of the specified property.

The most common approach to evaluate mixture homogeneity was first introduced by Lacey [4] namely the use of mixing indices. Considering Number of samples, each containing ***n*** particles, estimate of the mixture composition value is given by Eq (1), and the sample variance is given by Eq (2).

$$\bar{y} = \frac{1}{N}\sum_{i=1}^{N} y_i \tag{1}$$

$$S^2 = \frac{1}{(N-1)}\sum_{i=1}^{N} \left(y_i - \bar{y} \right) \tag{2}$$

Where $\bar{y}$ is the mixture composition, y_i is ith value of the proportion of one component in the samples, N is the number of particles in the sample and S is the standard deviation.

Lacey [4] showed that the variance of completely segregated mixture, σ_0^2, can be expressed as:

$$\sigma_0^2 = P(1-P) \tag{3}$$

where P and *(1-P)* are the proportions of the two components estimated from the samples. When any sample is withdrawn from a fully randomized mixture, the variance, σ_R^2, may be calculated from:

Manuscript received August 12, 2007. This work was supported in part by the Libya. Department of Chemical and Process Engineering, El-Mergib University.

Almahdi Atteya Alhwaige is with the Department of Chemical and Process Engineering, El-Mergib University, Libya. (Phone: +218-92-628 5341; e-mail: almhdi_e2000@yahoo.co.uk; almhdi_e2000@hotmail.com).

Siti Masrinda Tasirin is with the Department of Chemical and Process Engineering, Universiti Kebangsaan Malaysia, 43600 Bangi, Selangor, Malaysia. (e-mail: masrinda@vlsi.eng.ukm.my).

Ahmad Mokhtar Sowedan is with the Department of Chemical and Process Engineering, El-Mergib University, Libya. (e-mail: sowedan254@hotmail.com).

Wan Ramli Wan Daud is with the Department of Chemical and Process Engineering, Universiti Kebangsaan Malaysia, 43600 Bangi, Selangor, Malaysia. (e-mail: wramli@vlsi.eng.ukm.my).

$$\sigma_R^2 = \frac{P(1-P)}{N} \tag{4}$$

This value is normally the minimum attainable variance within a mixture. The well-known Lacey index [5] is defined as:

$$M = \frac{\sigma_0^2 - S^2}{\sigma_0^2 - \sigma_R^2} \tag{5}$$

where S^2 is the variance of the mixture between fully random and completely segregated mixtures [2].

The degree of mixing can be represented by a variety of more complicated mixing indices, which attempt to measure the extent to which mixing has approached complete randomness. Schofied and Sutton [6] have critically reviewed the more commonly used indices. These are shown in Table 1. [7]

TABLE 1. The mixing indices used.

Index no.	Author	Mixing index	Range
1	Lacey	$M= (\sigma_0^2 - S^2)/(\sigma_0^2 - \sigma_R^2)$	0 to 1
2	Kramer	$M= (\sigma_0 - S)/(\sigma_0 - \sigma_R)$	0 to 1
3	Lacey, Weidendam and Bonilla	$M= \sigma_R/S$	<1 to 1
4	Ashton and Valentin	$M^2=(\log \sigma_0^2 - \log S^2) / (\log \sigma_0^2 - \log \sigma_R^2)$	0 to 1
5	Poole, Taylor and Wall	$M= S/\sigma_R$	>>1 to 1
6	Carely-Macauley and Donald	$M= (S^2 - \sigma_R^2)/(1-(1/n))$	>>0 to 0

III. EXPERIMENTAL

A. Physical Properties of Feed Particles.

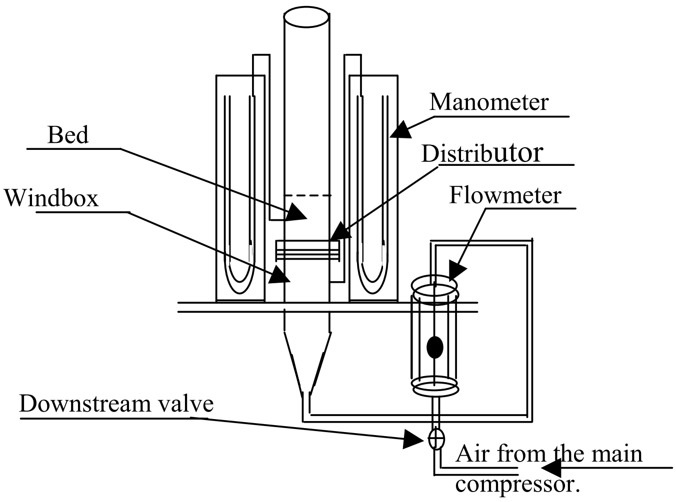
Two types of polymer particles referred as white polymer and black polymer materials were used as the feed material in this study. Table 2 lists the physical properties of polymers used.

TABLE 2. Some physical properties of polymers used.

Parameter	White polymer	Black Polymer
Mean particle size, $\bar{d}_p$ μm)	3465	3502
Size range, d_p (μm)	4750-2360	4750-2360
Particle density, ρ_p (kg/m^3)	923	1105
Bulk density, ρ_b (kg/m^3)	617	745
Geldart classification [8]	D	D

B. Experimental Set-up and Methodology.

Experiments were conducted in a fluidised bed. The fluidisation column was constructed from Perspex cylinder, 143 mm in diameter and 1000 mm length. A pressure probe connected to a water manometer measured the pressure drop across the bed. A transparent scale was attached on the bed wall to provide direct bed expansion measurement. The gas inlet system comprises of variable speed motor, a flow and gas distributor was designed according to recommended of Wen et al. [9], and the total number of orifice was calculated to be 217 orifices. The schematic of the fluidised bed column is shown in Figure 1.



Figurer 1. Conceptualised fluidised bed used in this work.

The experiment was started by charging a known weight of particles into the bed to give a predetermined bed depth as listed in Table 3. The bed depth used was chosen such that slugging won't occur in the bed; H_{msc}.

TABLE 3. Experimental series of mixing in a fluidised bed.

Parameter	Range of values
U_{mf} *(m/s)*	1.35
Operating gas velocity, U	U_{mf}, 1.15 U_{mf}, 1.38 U_{mf}
Bed depth, H *(cm)*	10, 15, and 17
Bed weigh, m *(kg)*	1.042, 1.563, and 1.772
H_{msc} *(cm)*	18.98
Duration, t *(sec)*	5,10,12,15,20 and 30

In every case it was ensured that the white polymer was a fraction of 75% by volume (i.e. 71.3% by weight), black polymer 25% by volume (i.e. 28.7% weight) of the total weight fed into the column. Compressed air at rang from 0.4 to 0.6 MPa was the supplied into the bed to fluidise the particles mixture. The air was supplied to give a gas velocity above the minimum fluidisation velocity, U_{mf}, namely 1.35 m/s. Several gas velocities were used in this case as listed in

ISBN: 978-988-98671-0-2

Table 3. Each experiment was carried out for durations of up to 30 seconds. In this work, side-sampling thief method is used. It removes sample portions from different locations in the mixture of fluidised bed.

The quality of mixing is assessed by examining the degree of particles in each sample. In this work, Lacey mixing index defined in (Eq.5), has been used to express the different in compositions throughout the mixture product.

IV. RESULT AND DISCUSSION

A. Comparison of Different Mixing Indices

Table 4 shows the comparison between different mixing indices obtained from this work, using fluidised bed mixer. The values listed Table 4 is that obtained at optimum operating time. In this case the optimum operating time is the time taken to result into the maximum and constant value of mixing index, M.

TABLE 4. Comparison between different mixing indices.

Mixing index, M	Mixing index, M, (-)								
	Depth height = 10 cm			Depth height = 15 cm			Depth height = 17 cm		
	U_{mf}	$1.15U_{mf}$	$1.38U_{mf}$	U_{mf}	$1.15U_{mf}$	$1.38U_{mf}$	U_{mf}	$1.15U_{mf}$	$1.38U_{mf}$
1*	***0.746***	***0.976***	***0.992***	***0.830***	***0.977***	***0.996***	***0.670***	***0.986***	***0.997***
2	***0.043***	***0.130***	***0.218***	***0.043***	***0.116***	***0.244***	***0.029***	***0.183***	***0.304***
3	***0.507***	***0.863***	***0.926***	***0.599***	***0.861***	***0.952***	***0.433***	***0.899***	***0.962***
4	***0.423***	***0.691***	***0.781***	***0.469***	***0.682***	***0.815***	***0.368***	***0.745***	***0.843***
5	***23.299***	***7.688***	***4.591***	***23.055***	***8.591***	***4.091***	***34.182***	***5.478***	***3.286***
6	***0.218***	***0.066***	***0.039***	***0.178***	***0.066***	***0.026***	***0.249***	***0.051***	***0.022***

*1 (Lacey), 2 (Lacey, Weidendaum, & Bonilla), 3 (Kramer), 4 (Aston & Valentin), 5 (Poole, Taylor & Wall), and 6 (Carely,-Macauuley & Donald).

B. Effect of Mixing Time.

There is a certain duration at which maximum mixing index is achieved. The time depends on the fluidisation velocity used, as well as the bed depth. Figures 2 (a), (b), and (c) show the results of mixing index at different mixing time for different operating velocities and bed depths.

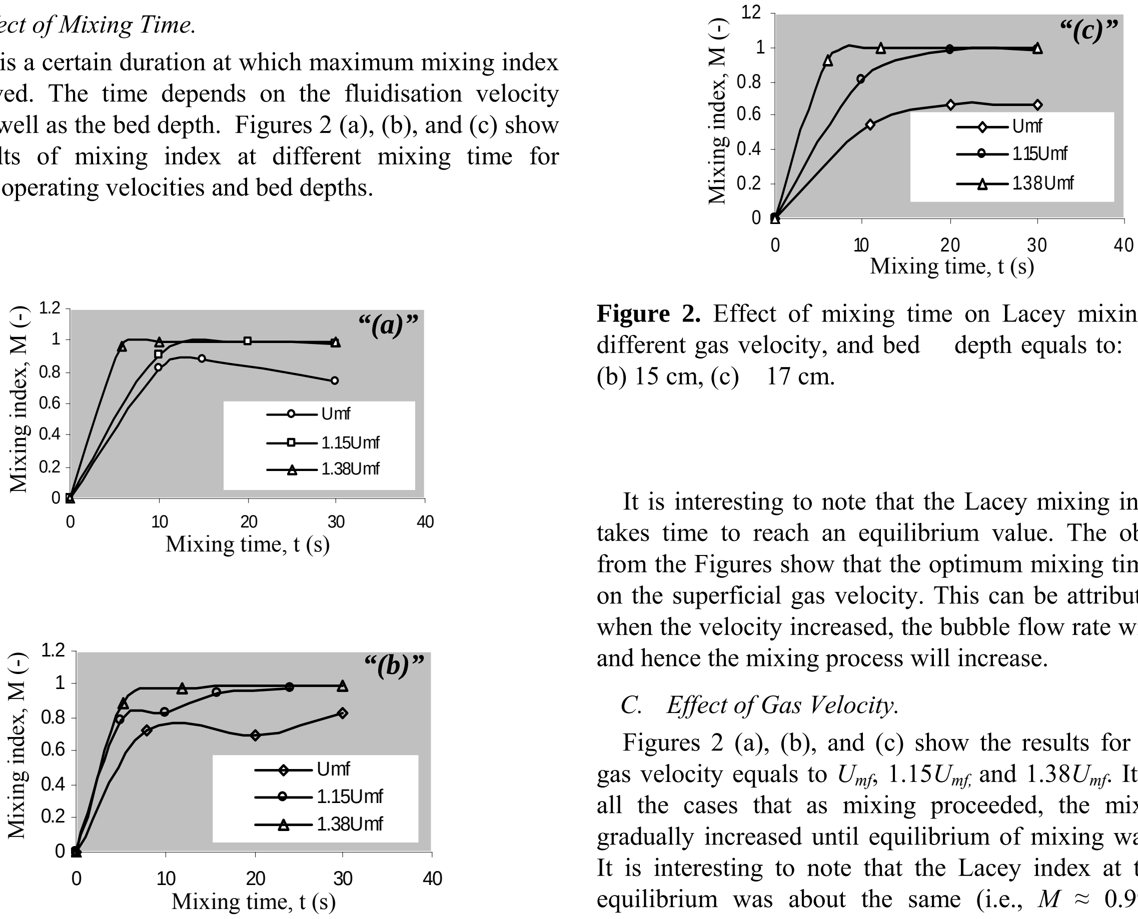


Figure 2. Effect of mixing time on Lacey mixing index at different gas velocity, and bed depth equals to: (a) 10 cm, (b) 15 cm, (c) 17 cm.

It is interesting to note that the Lacey mixing index for all takes time to reach an equilibrium value. The observations from the Figures show that the optimum mixing time depends on the superficial gas velocity. This can be attributed to that; when the velocity increased, the bubble flow rate will increase and hence the mixing process will increase.

C. Effect of Gas Velocity.

Figures 2 (a), (b), and (c) show the results for superficial gas velocity equals to U_{mf}, $1.15U_{mf,}$ and $1.38U_{mf}$. It shows for all the cases that as mixing proceeded, the mixing index gradually increased until equilibrium of mixing was reached. It is interesting to note that the Lacey index at the mixing equilibrium was about the same (i.e., $M \approx 0.99$) for the superficial gas velocity equals to 1.15 $U_{mf,}$ and 1.38 $U_{mf.}$ Nevertheless, the mixing index equilibrium less was ($M \approx$

0.65-0.85) for the superficial gas velocity equals to U_{mf}. This suggests that the degree of mixing achievable at this condition vary with gas velocity. This was due to the lack of bubbles under this condition, which was evident from analysis of snapshots. Results observed in Figures 2 (a), (b), and (c) also suggest that the average rate of mixing increase with increasing gas velocity for the conditions examined. It agrees with the general trend reported in the literatures.

D. Effect of Bed Depth.

The purpose of these experiments is to obtain the best bed depth of fluidised bed to give homogenous mixture at critical time. Figures 3 (a), (b), and (c) depict the variation of mixing index as a function of time and depth height. It is shown that the mixing index increases when the bed depth decreases. However, it is noticeable that the mixing index increases, as the gas velocity increases. These two remarks illustrate that there is relationship between the bed depth and gas velocity in order to attain good mixing. From Figure 3(c), it is exhibited that at a sufficiently high gas velocity (namely $1.38U_{mf}$ in this case) the effect of bed depth diminished.

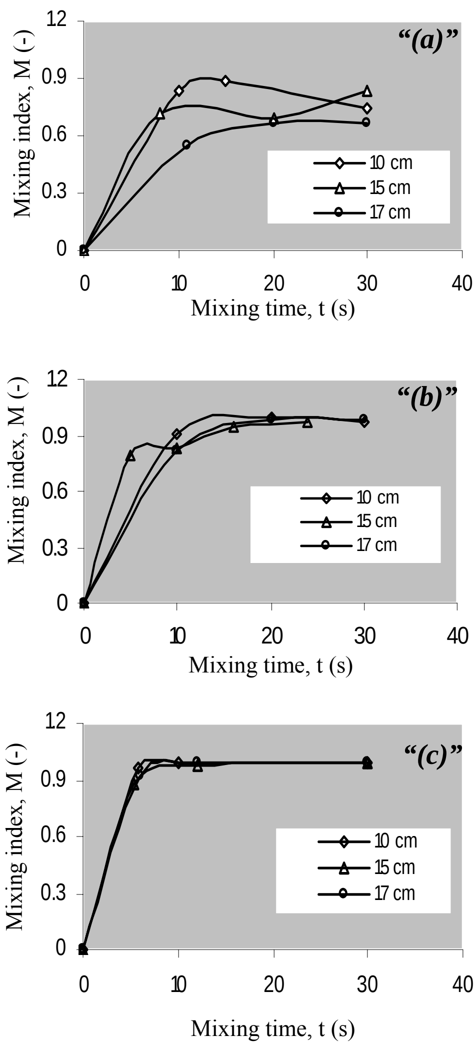


Figure 3. Effect of bed depth on Lacey index in fluidised bed, with gas velocity equals to: (a) U_{mf}, (b) $1.15U_{mf}$, (c) $1.38U_{mf}$.

E. Process Optomisation.

Process optimisation is important to produce required product at optimal conditions. For mixing by fluidised bed, the optimal mixing index depends on the gas flow rate, where the power consumption increases as gas flow rate increases.

In order to calculate realistic values of the optimal operation it is necessary to make assumptions about the pressure drops across the distributor plate, as well as across the fluidised bed. Of course if the pressure drops are assumed to be the same for all the cases an alternative value can be calculated simply relation based on the gas flow rate and mixing time per mixing index and mass of solids quantity, K namely, $(Q.\rho_g.t)/(M.m)$ against the Lacey mixing index. In this case the optimum operation would be given by the condition at which the K value is minimising for a specified M value. From Figure 4 the observation shows that the case of 17 cm bed depth with $1.38U_{mf}$ is the optimum operation, since it offers the minimum value of K, means minimum specific energy consumption, based on mixing index of 0.99.

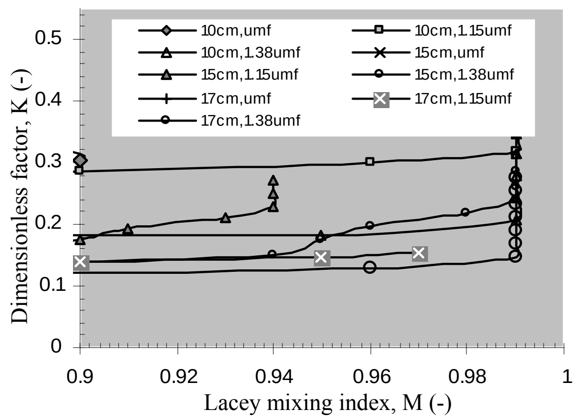


Figure 4. Dimensionless mixing factor, K .vs. Lacey mixing index, M *(-)* for mixing by a Fluidised bed

V. CONCLUSION

The experimental investigation of this paper leads to conclusion can be summarised as follows:

A fluidised bed mixer has been used in this work. Results are shown the comparison between different six mixing indices used in this work. The results show that the Lacey mixing index is the best efficient compared with others.

In the fluidised bed, three gas velocities had been used namely 1.35 m/s (U_{mf}), 1.55 m/s ($1.15U_{mf}$) and 1.87 m/s ($1.38U_{mf}$), whilst bed depths used were 10, 15 and 17 cm. The results indicate that the rate of solids mixing increases with increasing gas velocity, whilst the degree of achievable mixing is unaffected by gas velocity. The degree of mixing was found increase with increasing time until an equilibrium mixing index was achieved. The effect of bed depth was found decrease with increasing mixing index. Optimising the process by minimising the K value and choosing an optimum equilibrium mixing index of 0.99, it has been shown that conditions at $1.38U_{mf}$ and bed depth of 17 cm gave the most desirable result.

Finally, it is shown that mixing in a fluidised bed is the most efficient and economical way. An advantage of this model is that it is easy to use, not as complicated as complete mixing is attained in few seconds, and exhibit the lowest power losses.

ACKNOWLEDGMENT

The authors gratefully acknowledge the financial support from El-Mergib University and Universiti Kebangsaan Malaysia. Special thanks extend to the Dr. Ayub Som for his help. We are gratefully acknowledged for valuable assistance, especially Mr. Rahim.

REFERENCES

[1] Derrick, K. Rollins, Donna L. Faust, and Duana L. Jabas. (1995). *A superior approach to indices in determining mixture segregation* Powder Technology, 84. pp. 277-282.

[2] Rhodes, M. J., Wang, X. S., Nguyen, M, Stewart, P. and Liffman, K. (2001). *Study of mixing in gas-fluidised beds using a DEM model,* Chemical Engineering Science, 56. pp. 2859-2866.

[3] Supati, R., Loh, N. H., Khor, K. A. and Tor S. B. (2000). *Mixing and characterization of feedstock for powder injection molding*. Materials Letters, 46. pp. 109-114.

[4] Lacey, P. M. C. (1943). *The mixing of solid particles*, Transactions of the Institution of Chemical Engineers, 21. pp. 53-59.

[5] Lacey, P. M. C. (1954). *Developments in the theory of particulate mixing*. Journal of Applied Chemistry, 4. pp. 257-268.

[6] Schofied, C. and Sutton, H. M. (1978). Mixing fundamentals in Powder Europa, Seminar A, Powder mixing systems, Rhein-Main-Halle, Wiesbaden, Warren Spring Laboratory, Stevnage, UK, and International Powder Institute, Chicago IIIINOIS 60690, USA.

[7] Poux, M. Fayolle, P., Bertrand, J., Bridoux, D. and Bousqet, J. (1991). *Powder mixing: some particle rule applied to agitated system*, Powder Technology, 68. pp. 213-234.

[8] Geldart, D. (1973). *Type of gas fluidisation*, Powder Tecnology, 7. pp. 285-292.

[9] Wen, C. Y., Krishuna, R., K alyananraman, R., (1980). in J. Grace and J. Masten (eds.), Fluidisation, Plenum, New York.