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## Short Communication

# Studies on motionless mixer for radial mixing of solid particles

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**Abstract**

Studies on motionless mixer for radial mixing of particles have been carried out. The effect of various parameters on degree of mixedness was investigated for the continuously operated motionless mixer. The proposed design equation is found to explain the mixing characteristics satisfactorily.

Key words: Motionless mixer, radial mixing, mixing and blending, chemical and pharmaceutical industries.

## 1. Introduction

Mixing or blending of solids, a common operation in many chemical and pharmaceutical industries, is mainly carried out in batch mixers. In these mixers, segregation of particles during handling and storage takes place resulting in a non-homogeneous mixture. A continuous mixer, on the other hand, is more advantageous in avoiding segregation due to handling and storage.

Motionless mixer, a new type of continuous mixer for mixing of solids, is reported in the literature[1-4]. Immobile in-line mixing devices that work by multiple splitting are employed to achieve intermixing of a process stream. The multiple splitting is achieved by the right and left handed helices. The validity of motionless mixer as a continuous mixer has been established by Chen *et al*[4]. When the motionless mixer is used for continuous operation, the radial mixing of particles decides the quality of mixing. The variables affecting the mixing characteristics in these mixers are length and number of helices, and diameter of particles and of mixer tube. Of these variables, only the

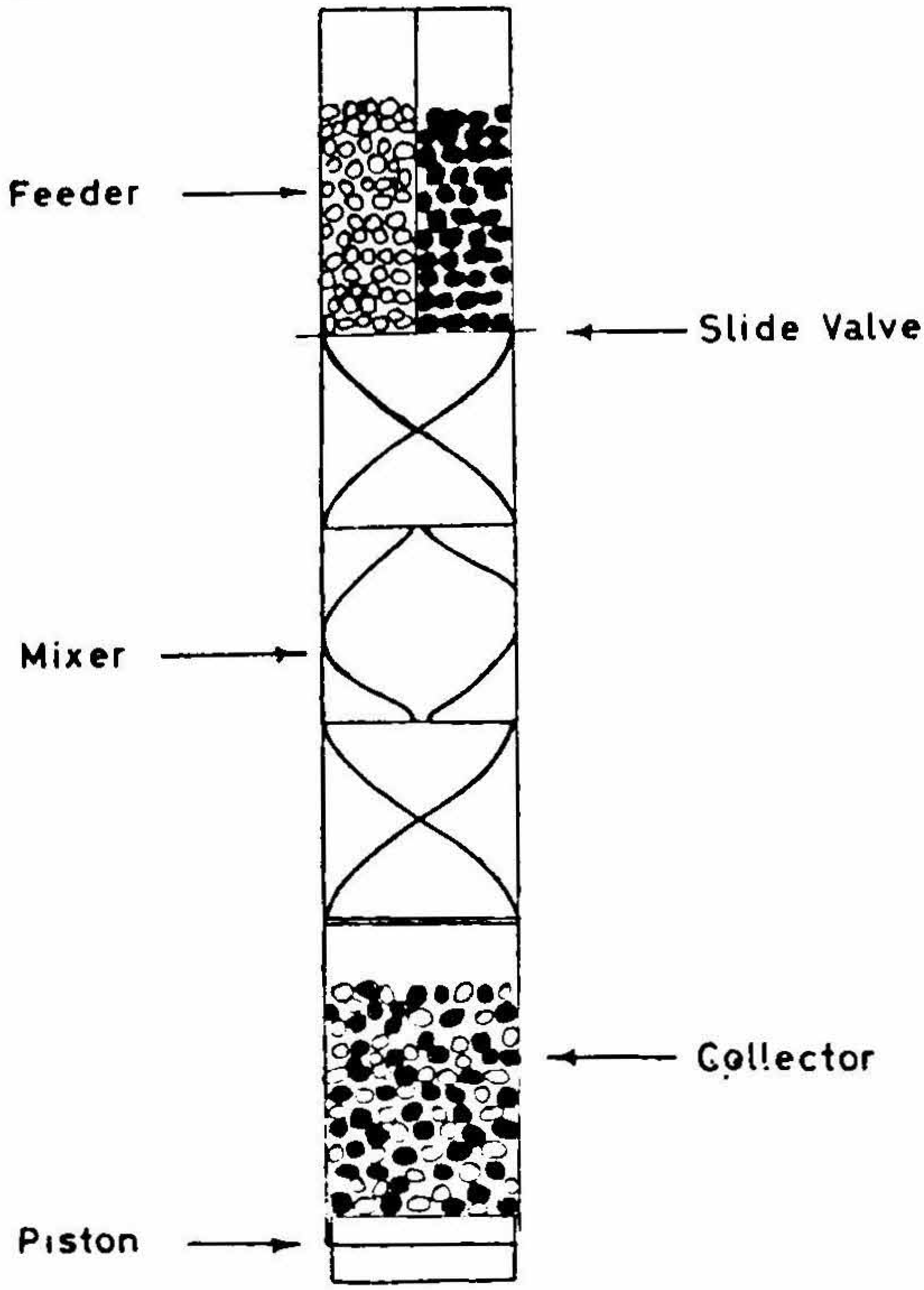


FIG. 1. Experimental set-up.

effect of number of helices on radial mixing is reported in detail[2]. The present investigation has been undertaken in order to study the effect of these different parameters on radial mixing in a motionless mixer and to develop an equation for design purposes.

## 2. Experimental

The motionless mixer employed for this study is similar to the one reported by Pattison[1]. The helices in the present investigations are made of thin perspex sheet. The lengths and widths of these helices are so chosen to cover the range of $L/D_T$ (Table I).

Plastic beads (density 1·020 gm/cc) with different colours are employed as solid particles. Three different diameters (3, 4 and 5 mm) of beads were used to cover the range of $D_P/D_T$ values given in Table I.

**Table I**

**Range of variables**

| Sl. No. | Variables | Range |
|---|---|---|
| 1. | Tube diameter ($D_T$) | 2·5 and 3·75 cm |
| 2. | Particle size ($D_P$) | 3, 4 and 5 mm |
| 3. | Length of helix (L) | 5·0 to 18·75 cm |
| 4. | Number of helix ($N$) | 2, 4, 6, 8 |
| 5. | Twist ratio ($L/D_T$) | 2, 3, 4, 5 |
| 6. | Particle ratio ($D_P/D_T$) | 0·08, 0·11, 0·13, 0·16 |

The experimental set-up, shown in fig. 1, consists of feeder, mixer and collector. The feeder was divided into two halves by a thin band of sheet as shown in the figure. It was filled with coloured beads on one side and approximately the same amount of beads of another colour on the other side. In all experimental runs, the overall composition of any one colour by number was 0·50. After passing through the mixer, the beads were collected in the collector. The samples corresponding to one centimetre height were removed by pushing the rubber piston slowly from the bottom along the collector without disturbing the mixture. Each time a sample was removed, the cross-section of the collector was divided into four quadrants as shown in fig. 2 by keeping a perspex sheet having circle of tube diameter with four quadrants drawn on it. Each quadrant was considered to be a sample for radial mixing studies. Composition of the coloured particle in any quadrant was calculated as reported by Chen *et al*[2].

Degree of mixedness is calculated as follows[8]:

$$M = 1 - (\sigma^2/\sigma_0^2).$$

Variances of the beads of any one colour in the sample were calculated for each mixer used by the following equation:

$$\sigma^2 = \frac{\sum_{i=1}^{n} (X_i - \bar{X})^2}{n}$$

Variance before mixing is given by[2]

$$\sigma^2 = \bar{X}(1 - \bar{X}),$$

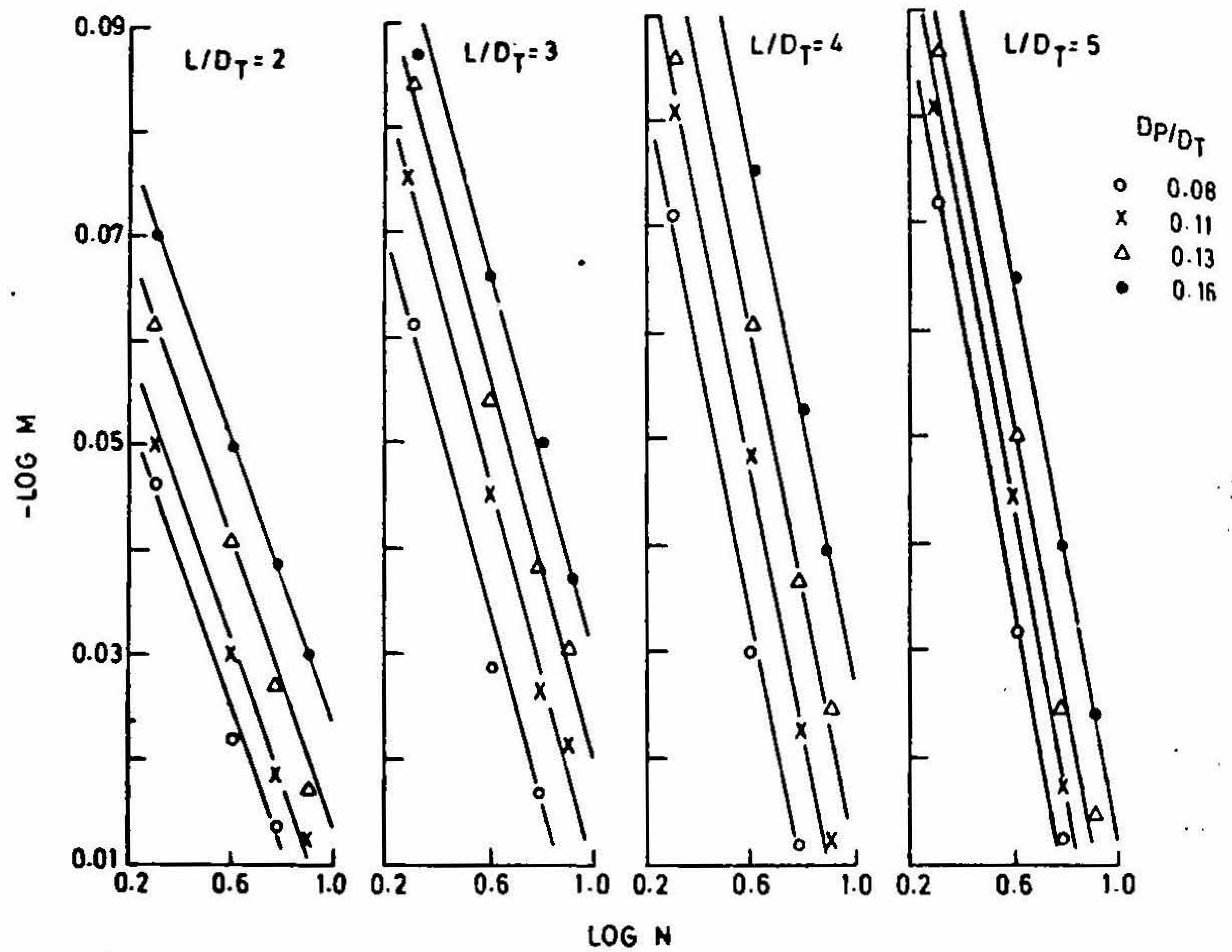


FIG. 2. Effect of $N$ on $M$.

Values of degree of mixedness used in the calculations were the averages of two replications.

## 3. Results and discussion

From the experimental results, it was observed that the degree of mixedness increases with an increase in the number of helices, and decrease in twist and particle ratios. A first order equation relating the degree of mixedness and the rate of change of degree of mixedness with the number of helices was proposed by Wang and Fan[6] for the axial mixing of particles.

Even for one helix, a degree of mixedness of about 0·9 was observed for the radial mixing of particles. Increasing the number of helices and other variables only result in increasing the degree of mixedness from 0·9 to about 0·99. In practice, a maximum amount of power is spent only to increase the degree of mixedness from 0·9 onwards.

Table II

Values of constants of equation (1)

| $L/D_T$ | $D_P/D_T$ | $k \times 10^3$ | $p$ |
|---|---|---|---|
| 2 | 0·08 | 7·273 | 13·710 |
| | 0·11 | 5·546 | |
| | 0·13 | 4·088 | |
| | 0·16 | 2·968 | |
| 3 | 0·08 | 9·475 | 10·110 |
| | 0·11 | 6·971 | |
| | 0·13 | 6·592 | |
| | 0·16 | 4·839 | |
| 4 | 0·08 | 16·220 | 7·166 |
| | 0·11 | 12·470 | |
| | 0·13 | 9·661 | |
| | 0·16 | 7·290 | |
| 5 | 0·08 | 18·750 | 6·548 |
| | 0·11 | 15·890 | |
| | 0·13 | 14·190 | |
| | 0·16 | 10·840 | |

The change in degree of mixedness with the number of helices is very small, when the degree of mixedness is greater than 0·9. This necessitates a power function other than a first order equation for the degree of mixedness. Hence, the following power function is assumed in the present investigation.

$$dM/dN = k\, M^{-p}. \tag{1}$$

After integration, simplification with initial boundary conditions (*i.e.*, when $N = 0$, $M = 0$) and taking logarithms, equation (1) reduces to

$$\log M = \frac{\log[k(p+1)]}{p+1} + \frac{1}{p+1} \log N. \tag{2}$$

Figure 2 represents the plot of log $M$ *vs* log $N$ for various operating conditions. Table II gives the values of constants $k$ and $p$ calculated from the slopes and intercepts of fig. 2.

The rate constant $k$ depends on both twist and particle ratios. The decrease in these ratios leads to an increase in the degree of mixedness. If the two factors are assumed

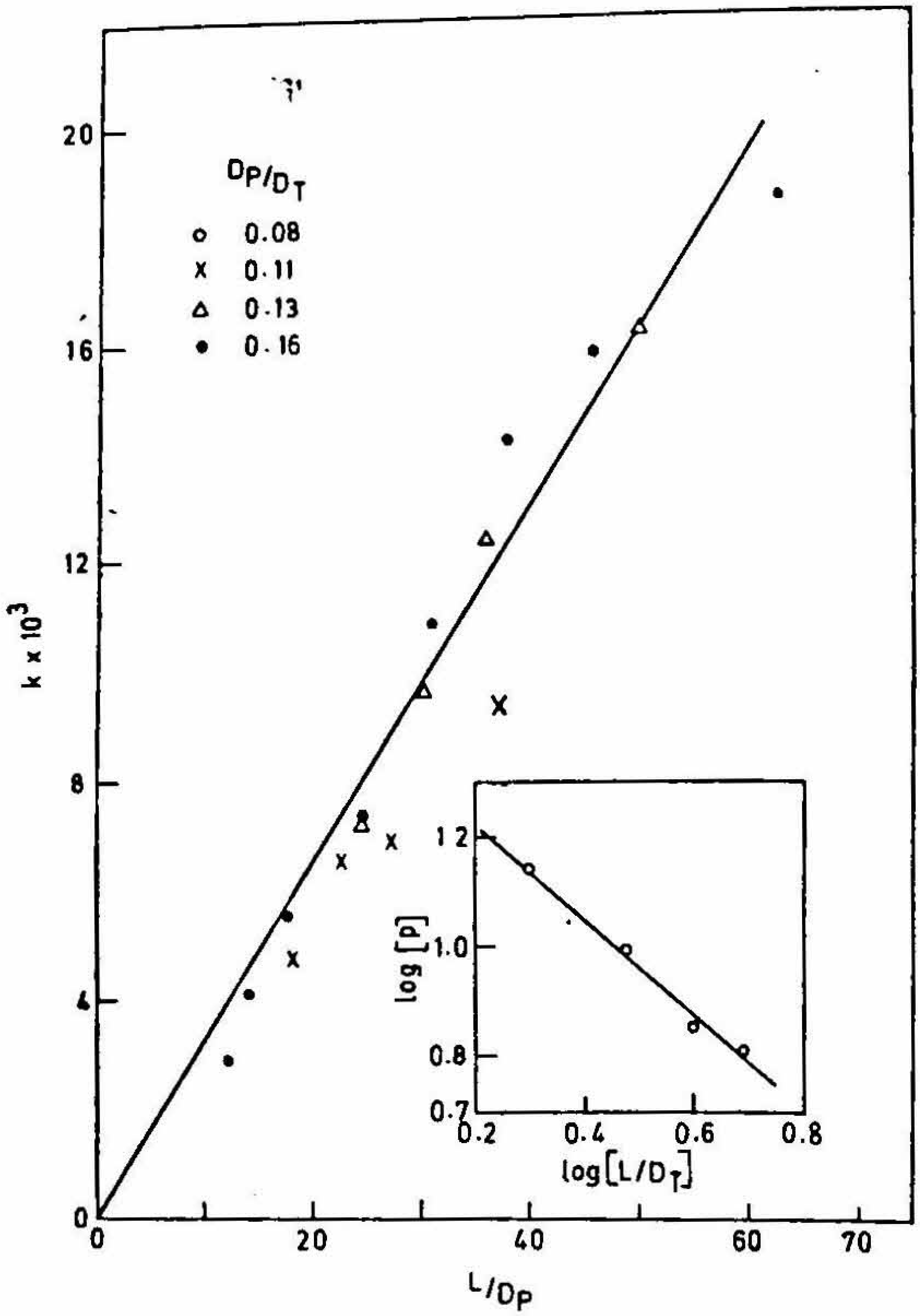


FIG. 3. Parameter correlations.

to have the same effect, they can be combined into one, *i.e.*, $L/D_P$. The plot of $(L/D_P)$ *vs* $k$ is shown in fig. 3. Thus the constant $k$ can be related linearly to $(L/D_P)$ as follows :

$$k = 3 \cdot 26 \times 10^{-4} [L/D_P].$$

The exponent $p$ varies only with the twist ratio $(L/D_T)$ as is evident from fig. 2. It is seen from fig. 3 that they are related as follows :

$$p = 25 \cdot 12 [L/D_T]^{-0.8423},$$

After substituting for the constant and exponent, the degree of mixedness and other operating variables are related as given below :

$$M = 3{\cdot}26 \times 10^{-4}[1 + 25{\cdot}12\,(L/D_T)^{-0{\cdot}8428}]\,[(L/D_P)\,N]^{\frac{1}{1+25\cdot12\,(L/D_T)^{-0\cdot8428}}}.$$

The above equation fits the data with a standard deviation of $\pm$ 7·5%. This equation relates the degree of mixedness.

## 4. Conclusions

Studies have been carried out for radial mixing of solids in a motionless mixer. An equation relating the degree of mixedness with other operating variables was derived and the constants were evaluated using the experimental data. The agreement between the experimental and the calculated values of degree of mixedness is found to be satisfactory.

## Nomenclature

$D_P$ diameter of particles, cm.

$D_T$ diameter of mixer tube, cm.

$k$ constant of equation 1.

$L$ length of the helix, cm.

$M$ degree of mixedness.

$N$ number of helices.

$n$ number of samples.

$p$ constant of equation 1.

$X_i$ composition of the particular coloured particles in the '$i$' sample.

$\bar{X}$ overall composition of the same coloured particles.

$\sigma^2$ variance after mixing.

$\sigma_0^2$ variance before mixing.

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