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Residence Time Distribution in Semi-Fluidized Beds

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Residence time distribution (RTD) studies have been made in solid-liquid semi-fluidized beds with particle size, particle density, height of the static bed and position of restraint as variables. A comparison of experimental data with those obtained from various models, shows that the dispersed plug flow model represents the most Satisfactorily flow phenomenon in semi-fluidized beds. A number of correlations have been proposed for prediction of the mean residence time and the dispersion number based on dimensional analysis for the three stages—packed bed, fluidized bed and semi-fluidized bed of semi-fluidization. The correlations have been tested with independent runs and these are found to agree with the experimental data within 20% deviations.

NOTATION

D_c = diameter of column, cm
D_p = diameter of particle, cm
h_s = height of static bed, cm
R = expansion ratio in semi-fluidization, dimensionless
$\bar{t}$ = mean residence time, s
D/UL = dispersion number, dimensionless
Re = Reynolds number, dimensionless
ρ_p = particle density, g/cm³
ρ_f = fluid density, g/cm³

INTRODUCTION

semi-fluidization is a unique and novel technique, conceived in late fifties, for fluid-solid contact. This is obtained by restricting free expansion of fluidized bed by introduction of a restraint having a sieve at a proper place. This type of bed eliminates some disadvantages of both fluidized bed and packed bed systems. So far considerable attention has been paid to fluid dynamic aspect and some studies on mass and heat transfer aspects have also been reported[1]. But no significant work has been done on residence time distribution (RTD) which is essential for design and proper functioning of a semi-fluidized reactor.

The only work reported on RTD has so far been by Saxena and Pandey[2]. Nearly 175 runs were taken by them under fixed, fluidized and semi-fluidized conditions using glass beads of 0.373 cm, 0.427 cm and 0.540 cm and crushed calcite particles of 0.260 cm, 0.130 cm, 0.055 cm and 0.026 cm sizes and proposed correlations for mean residence time for the three stages. An equation relating the mean residence time of fixed and fluidized sections to that of semi-fluidized bed was proposed as

$$\bar{t}_{\text{semi-fluidized bed}} = \bar{t}_{\text{fixed bed}}(x) + \bar{t}_{\text{fluidized bed}}(1-x) \quad (1)$$

where x is the mass fraction of solid particles in the fixed section of the semi-fluidized bed. There has been no attempt to propose a suitable model for RTD and the effect of variables like particle density, restraint position, etc has not been considered.

In this paper, an attempt has been made to obtain experimental data on RTD in semi-fluidized beds, to find a suitable model to represent the system and to determine the effect of different variables on model parameters by means of correlations.

EXPERIMENTAL PROCEDURE

The set-up consists of a perspex column of 4.5 cm inner diameter and 1 m in length. A 60-mesh stainless steel screen is used as the distributor. A movable restraint also made of 60 mesh stainless steel screen and fixed to a mild steel rod extending from the top of the semi-fluidizer is used to vary the expansion ratio. To facilitate the injection of tracer and collection of samples, two holes are drilled on one side of the column wall, one at the bottom of the column and the other about 35 cm above. A constant level head tank is used as a reservoir for supply of water. Sodium chloride solution (2.6 N) is used as a tracer.

The column is filled with desired particles to the required height. The restraint is adjusted to a desired expansion ratio. The flow rate is adjusted for a particular value and after steady flow is attained the tracer of about 2 cm^3 is injected instantaneously at the bottom using a hypodermic syringe. A stop watch is immediately started and samples are collected in test tubes, from the hole at the top at different time intervals. The runs are taken for all the three cases, namely, packed bed,

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fluidized bed and semi-fluidized bed. The samples are analyzed by measuring the electrical conductivity of sodium chloride. The experiment is repeated by changing the variables. The scope of the experimental data is given in Table **1**.

TABLE 1 SCOPE OF EXPERIMENTAL DATA

Material	Diameter of Particles, mm	ρ_p, g/cm³
Glass beads	2.006 5	2.50
	2.578 0	
	1.079 5	
	3.000 0	
Lime stone	0.791 0	2.63
Iron ore	1.080 0	5.00
Dolomite	1.524 0	2.63

Heights of static bed, cm: 6, 7, 8 and 10
Expansion ratio, (R) 2.00, 2.25, 2.50 and 3.00

RESULTS AND DISCUSSION

Mean Residence Time ($\bar{t}$)

The following correlations have been formulated through dimensional analysis for prediction of mean residence time, $\bar{t}$, for all the three cases, that is, packed bed, fluidized bed and semi-fluidized bed, of semi-fluidization.

$$\bar{t}_{packed\ bed} = 589\ (Re)^{-0.62}\ (D_p/D_c)^{0.46}\ (h_s/D_c)^{-1.09} \quad (2)$$

$$\bar{t}_{fluidized\ bed} = 1.9 \times 10^4\ (Re)^{-1.07}\ (D_p/D_c)^{0.44}\ (h_s/D_c)^{2.34} \quad (3)$$

$$\bar{t}_{semi\text{-}fluidized\ bed} = 794\ (Re)^{-1.12}\ (D_p/D_c)^{-0.16}\ (h_s/D_c)^{1.17}\ (R)^{3.78} \quad (4)$$

The correlations are found to be accurate within ± 20% deviations. A comparison of the experimental values (experiments conducted independent of those required for development of correlations) with those predicted by equations (2), (3) and (4) and the correlations predicted by Saxena and Pandey[2] is shown in Fig 1.

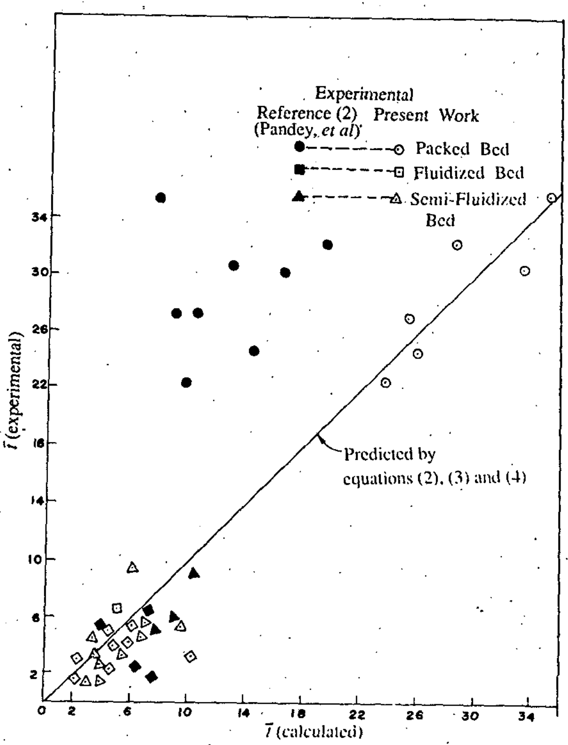

Fig 1 Comparison of data on $\bar{t}$ of Pandey, et al, present work and correlations

RESIDENCE TIME DISTRIBUTION MODEL

Experimental data have been compared with various standard models. It has been found that the dispersed plug flow model fits the data well and hence it is concluded that this describes the flow behaviour in a semi-fluidized bed. The following correlations have been proposed based on dimensional analysis for the prediction of the parameter of dispersed plug flow model, that is, dispersion number, D/UL, for all the three stages of semi-fluidization.

$$(D/UL)_{packed\ bed} = 3.98 \times 10^{-4}\ (Re)^{1.03}\ (D_p/D_c)^{0.15} \times (h_s/D_c)^{-1.33} \quad (5)$$

$$(D/UL)_{fluidized\ bed} = 6.3 \times 10^{-7}\ (Re)^{1.5}\ (D_p/D_c)^{-1.28} \times (\rho_p/\rho_f)^{-1.18}\ (h_s/D_c)^{-2} \quad (6)$$

$$(D/UL)_{semi\text{-}fluidized\ bed} = 5.01 \times 10^{-17} (Re)^{3.57} \times (D_p/D_c)^{-2.3}\ (\rho_p/\rho_f)^{2.86}\ (h_s/D_c)^{1.04}\ (R)^{2.82} \quad (7)$$

A comparison of the experimental results and those predicted by equations (5), (6) and (7) is given in Fig 2. These correlations predict the results within **a** standard deviation of ± 20%. It is proposed to develop suitable theoretical equation, apart from dimensional analysis, to predict the dispersion number and also cover a wider range of variables through experimentation.

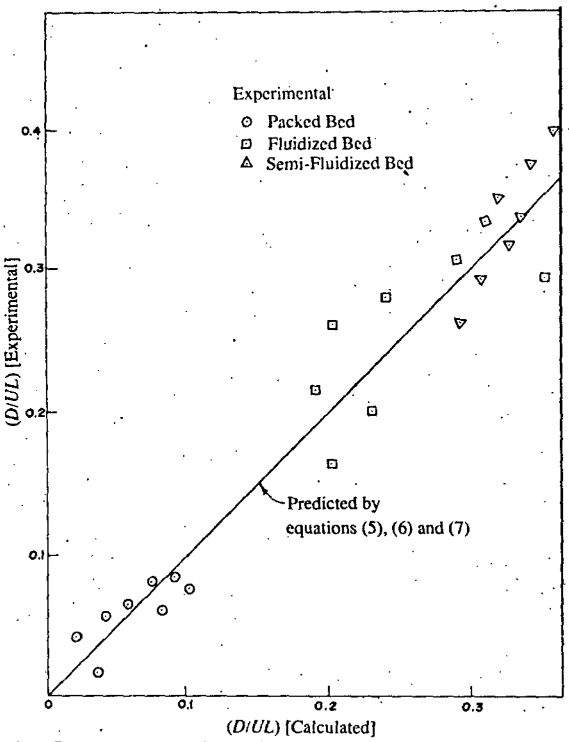

Fig 2 Experimental and calculated values of dispersion number

CONCLUSION

It is found that the dispersed plug flow model represents the flow behaviour in a semi-fluidized bed. The experimental work has covered all variables but the range is limited. Correlations developed for prediction of the dispersion number and mean residence time based on dimensional analysis agree fairly well with the experimental data.

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