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Research Article

Residence Time Distribution Studies in Miniature Pipes

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ABSTRACT

The research work is focused on the residence time distribution (RTD) studies in small pipes using pulse input technique. The extent of dispersion is expressed in terms of dispersion coefficient (D_L). RTD studies are carried out by tracer analysis and D_L is estimated using axial dispersion model. Laminar flow in short pipes follow pure convection model but the experimental data in the present study is found to be in good agreement with axial dispersion model. The variance and dispersion coefficients are estimated and the effects of flow and geometric parameter on dispersion coefficients are studied. In scope of present study, the dispersion coefficient is found to increase with an increase in velocity and length of tube but the effect of pipe diameter on dispersion coefficient is found to be marginal.

Keywords: Residence Time Distribution**,** Dispersion Coefficient**,** axial dispersion model

INTRODUCTION

Non ideal flow patterns in process equipment are influenced by many factors like channeling of fluid, recycling of fluid, or by stagnation zones. The distribution of residence periods (times) of the flowing fluid in non ideal flow pattern can be determined by stimulus-response experiment. This experimental work is focused on the Residence time distribution (RTD) studies in small pipes using pulse input. RTD indicates the time spent by fluid elements in the reactor. It can also be considered as the characteristics of mixing prevailing in the reactor. Such studies are useful for the understanding of macro-mixing phenomena. Spread of residence time distribution is considered in term of variance which can be used to calculate the dispersion number for the fluid in the reactor.

Residence time distributions have been in use as diagnostic tools for mixing in chemical engineering device for a long time. RTD studies are useful in vessel design to improve the performance. Detailed knowledge of residence time distribution with the understanding of the overall flow pattern helps in development of a model of the system and the model can be used for handling complicated kinetics. The choice of RTD characterizing parameters is often a matter of balancing complexity against the required degree of precision. The effect of mixing of fluids flowing through conduit to enhance efficiency of the equipment has been studied earlier by various authors [1 – 5.] The present study is focussed on dispersion of fluid in miniature pipes. The dispersion is expressed in terms of dispersion coefficient (D_L) by conducting RTD studies. RTD studies are carried out by tracer analysis and D_L is estimated using axial dispersion model, suggested by Levenspiel [6.] Pulse input technique is used here for RTD studies. The variance and dispersion coefficient are estimated. It was found from literature review that the studies on dispersion in miniature pipes is found to be meagre and hence an attempt was made in this work to study the dispersion in miniature pipes.

LITERATURE REVIEW

Feroz et al[5,] studied axial mixing in open and packed columns with and without the application of pulsation. They found that the dispersion coefficient increases with an increase in flow rate, amplitude of pulsation in both open and packed columns, and with frequency it increases to some extent and then decreases. In packed columns, the dispersion coefficient is found to increase with increasing particle diameter. The dispersion coefficient is found to be much higher with pulsation than without pulsation in both open and packed columns. Their experimental data without pulsation follow pure convection model for open column and Bischoff correlation for packed column. They also proposed correlations based on modified Peclet and Reynolds number.

Igor Mezic et al.[6] studied RTD for chaotic flows in pipes in which they derive two rigorous properties of residence time distributions for flows in pipes and mixers motivated by computational results of khakhar et al.[7] In this paper the author's found the link between the residence time and average velocities along particles paths using ergodic theory. The residence-time plots contain more information about the cross-sectional motion, and essentially no information about the axial motion. They also establish two different mechanisms for the multimodality of finite-time residence-time distributions.

Castelain et al.[8] studied experimental and numerical characterization of mixing in a steady spatially chaotic flow by means of residence time distribution measurements. Their experimental system is made up of a succession of bends in which centrifugal force generates a pair of stream wise dean roll-cells. Fluid particle trajectories become chaotic through geometrical perturbation obtained by rotating the curvature plane of each bend [plus or minus]90[degree] with respect to the neighbouring ones. Different numbers of bends, ranging from 3 to 33, were tested. RTD is experimentally obtained by using a two-measurement-point conductimetric method, the concentration of the injected tracer being determined both at the inlet and at the outlet of the chaotic mixer. The experimental RTD is modeled by a plug flow with axial dispersion volume exchanging mass with a stagnant zone. RTD experiments were conducted for Reynolds numbers between 30 and 13000 and Peclet number based on the diameter of the pipe was found to increase with Reynolds number. In order to characterize more completely the efficiency of the device, a criterion is proposed that takes into account both the mixing characteristics and the pressure drop. The RTD is calculated by following the trajectories of 250,000 numerical particles along the device and found that the numerical results are in good agreement with experiments in the same Reynolds number range.

Sandeep et al.[9] studied modeling - Newtonian two–phase flow in conventional and helical-holding tubes. The research was undertaken to test the hypothesis that the fluid mechanics and heat-transfer aspects involved in aseptic could be modeled. In order to do this, a finite difference FORTRAN program (using the fourth-order, four-stage explicit Runge Kutta method) was written by the authors to compute the velocity of fluid elements and particles during fully 3-dimensional flow in conventional and helical-holding tubes. The effect of particles on the fluid-flow field and the interaction between particles was taken into account during the modeling. Simulation results showed that an increase in specific gravity, tube diameter or coil diameter resulted in an increase in the residence time of the particles, while an increase in the flow rate decreased the residence time of the particles. An increase in the particle diameter or the flow rate narrowed the RTD of the particles, while an increase in specific gravity or the tube diameter increased the RTD of the particles.

Reyes et al.[10] studied analysis of mechanically agitated fluid-particle contact dryers.The physical phenomenon occurring in these dryers with several liquid substrates was analyzed and the RTD were obtained by the use of dye tracers. The residence time was found to be a function of the rate of agitation (n) and the RTD was modelled by series of consecutive dryers.

Zitny et al.[11] studied heat transfer enhancement and RTD in Pipes with flow inversion and found that the inversion of streamlines between the centreline and wall region of a pipe improves RTD characteristic and heat transfer in laminar flows. They suggested one-parametrical inversion models to predict RTD and Nusselt number value for the flow of a Newtonian liquid in a pipe with one or more flow inverters.

Rodraguez et al.[12] studied a new hole cleaning criteria for drilling operations of oil wells and presented drilling fluid flow in the annular space and drill pipe through RTD analysis of a tracer injected in impulse form while drilling an oil well. Two field trials were carried out in order to evaluate the technical feasibility and potential practical application of the RTD theory and the dispersion model. From their results it is possible to explain physically the flow behaviour and its relation with parameters such as carrying capacity of the drilling fluid and hole cleaning conditions. The RTD analysis of tracer response indicates the presence of anomalous flow in both trials, characterized by two fluid volume fractions travelling with different velocities. The dispersion number (RTN) as well as other distribution functions are suggested as a measure of the overall behaviour of the fluid in a hole. This criterion is compared with empirical correlations employed in the industrial practice.

Castelain[13] studied residence time distribution of a purely viscous non-Newtonian fluid in helically coiled or spatially chaotic flows and the results have been compared with those previously obtained using Newtonian fluids, the values of the Peclet number are greater for the pseudo plastic fluid, the local change of apparent viscosity affecting the secondary flow. For pseudo plastic fluid, the apparent viscosity is lower near the wall and higher at the centre of the cross section. The maximum axial velocity is flattened as the flow behaviour index is reduced, inducing a decrease of the secondary flow in the central part of the pipe and an acceleration of it near the wall, which reduces the axial dispersion. These results are encouraging for the use of this system as continuous mixer for complex fluid in laminar regime, particularly for small Reynolds numbers.

EXPERIMENTAL SET- UP

The experimental set-up as shown the schematic diagram **(Fig. 1.)** is consists of feed tank (T) made of mild steel with a capacity of $0.00125m^3$(0.13m x 0.16m x 0.06m). The tank is placed over the stand and the miniature pipes (G) are fitted with slight inclination so as to maintain the gravity flow. The stand (S) is made up of two mild steel plates welded to a base plate in such way that one is kept perpendicular and the other inclined to the base plate. The feed tank is welded on the top of the stand at a height of 1m. The outlet of the tank is connected to the glass tubes through copper pipes (C) of ¼ inch and it is branched with "T" fitting and each branch is connected with valves (V). For each pipe, two inlet valves are provided, one for the control of distill water and the other to inject the tracer. The dimensions of the various miniature glass pipes used in the present study are shown the **Table -1.**

Table – 1: the various miniature glass pipes used in the present study.

Sl	Item	Length(L), m	Diameter(D), m	L/D
1	Glass Pipe - 1	0.150	0.003	50.0
2	Glass Pipe - 2	0.150	0.004	37.5
3	Glass Pipe - 3	0.150	0.005	30.0
4	Glass Pipe - 4	0.150	0.006	25.0
5	Glass Pipe - 5	0.125	0.003	41.7
6	Glass Pipe – 6	0.100	0.003	33.3
7	Glass Pipe - 7	0.075	0.003	25.0
8	Glass Pipe - 8	0.050	0.003	16.7

EXPERIMENTAL PROCEDURE

The feed tank is filled with water and is it allowed to pass through the copper tubes fitted with valves and then into the glass tubes. When the distill water is flowing to one glass tube the other glass tube inlets are kept closed and once the flow is stabilized, by adjusting the inlet valve, the flow is kept at the desired rate (ranges from $3.33\times10^{-6} m^3/s$ to 16.67×10^{-6} m^3/s).

A 1ml acetic acid is used as tracer and it is injected as pulse input with the help of one ml syringe. Prior to injection about 12 to 15, 100mLclean and dry beakers are kept ready with numbers on them in a sequential manner. Once the tracer is injected, the samples are colleted with a time interval of 5 seconds each. 0.1mLof sample collected from the first beaker is taken into another clean & dry beaker with the help of one ml syringe. One or two drops of fresh phenolphthalein indicator is added to it and then it is titrated with 0.01N sodium hydroxide solution using a one ml syringe and the volume of sodium hydroxide run down is noted. Similarly all the samples collected are analyzed and the readings tabulated as shown in the **Table – 1.** one mL syringes are used here for micro-level titration.

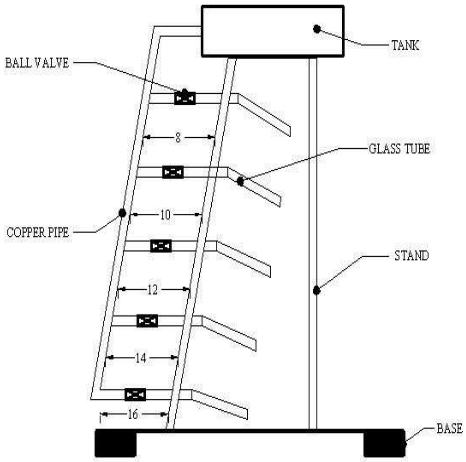

Figure 1: Schematic diagram of the experimental set-up

RESULT & DISCUSSION

The experiments are conducted for two sets of pipes. One set consist of fixed length 0.15m and diameter varying from 3mm to 6mm, the second set consists of fixed diameter 3mm and varying length of 0.05m to 0.15m as shown in **Table – 1.** For each pipe, samples are collected and analyzed for different flow rates varying from $3.33 x 10^{-6}$ m^3/s to $16.67 x 10^{-6}$ m^3/s. The readings are tabulated as shown in the **Table -1.** The outlet concentration (C_i) with respective time (t), the mean residence time ($\bar{t}$), the variance (σ^2), and the dispersion coefficients (D_L) are calculated.

Outlet Concentration versus Time: The outlet concentration (C_i) versus time (t) plots at different flow rates for different pipes is shown in the **Figures 2 – 9.**

The outlet concentration (C_i) versus time (t) plots at different flow rates for different pipes is shown in the Figures 2 – 9.

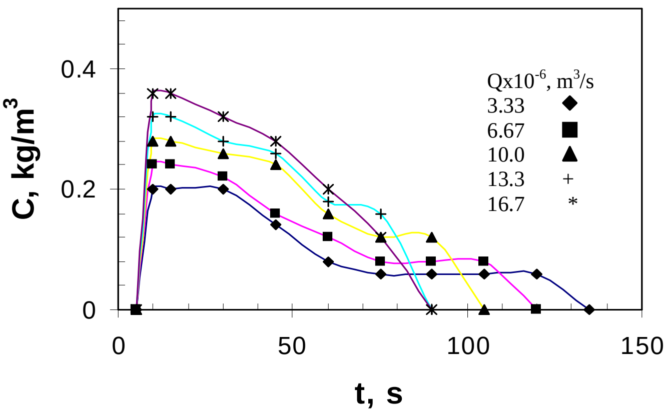

Figure 2: Concentration versus time at different flow rates for Pipe diameter 0.003m & length 0.15m.

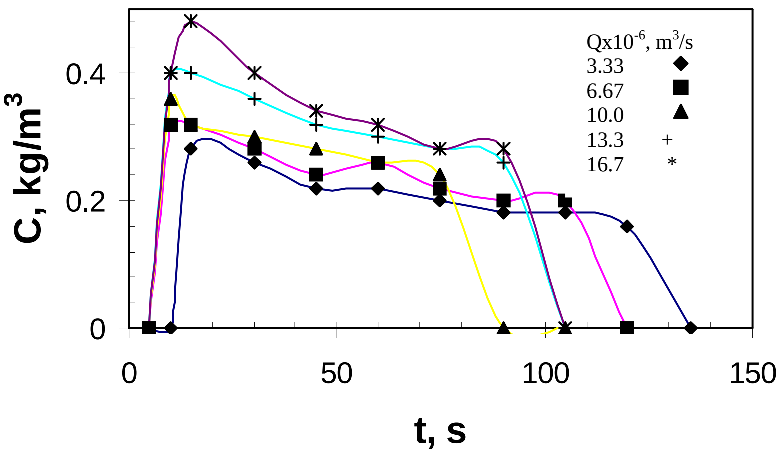

Figure3: Concentration versus time at different flow rates for Pipe diameter 0.004m & Length 0.15m.

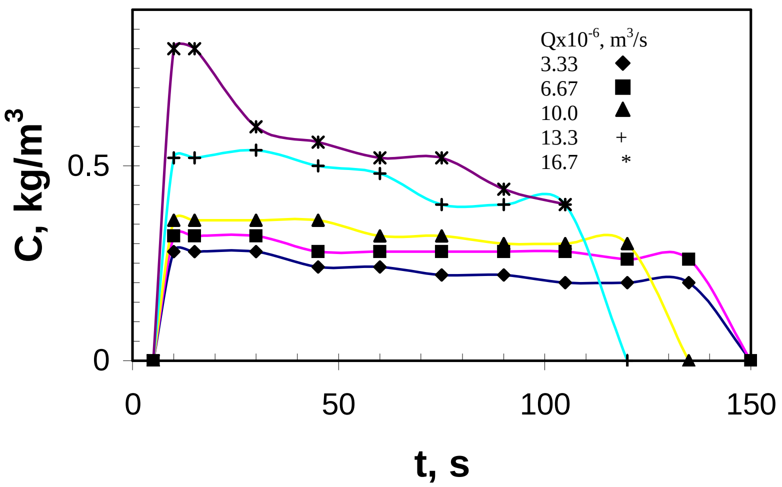

Figure 4: Concentration versus time at different flow rates for Pipe diameter 0.005m & length 0.15m.

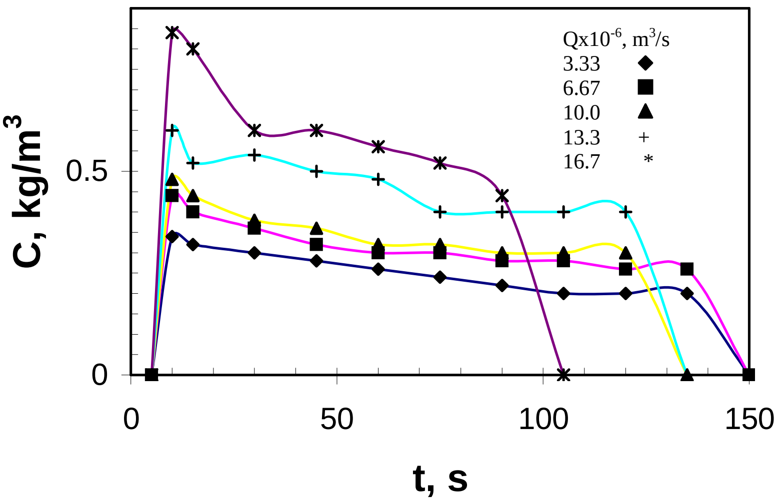

Figure 5: Concentration versus time at different flow rates for Pipe diameter 0.006m & Length 0.15m.

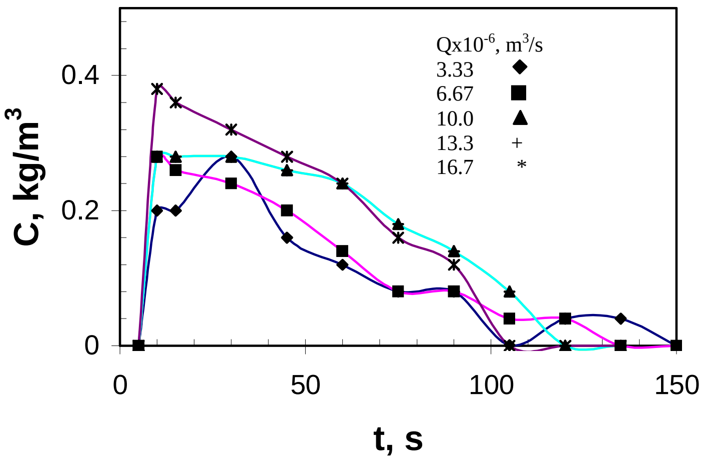

Figure 6: Concentration versus time at different flow rates for Pipe diameter 0.003m & length 0.125m.

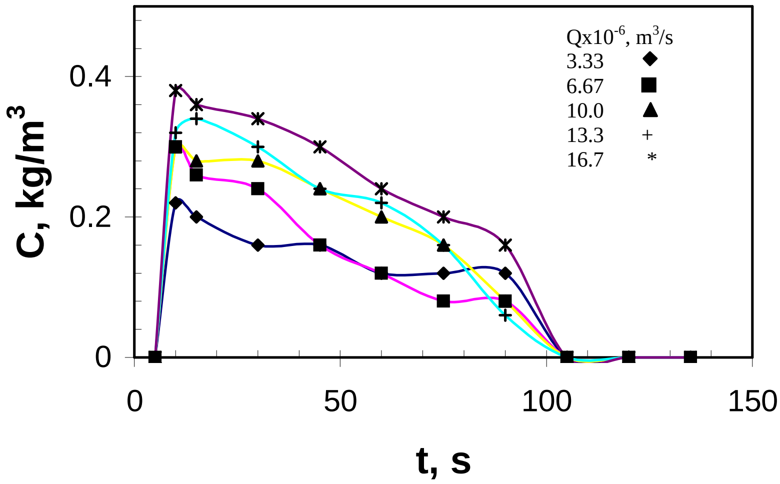

Figure 7: Concentration versus time at different flow rates for Pipe diameter 0.003m & Length 0.10m.

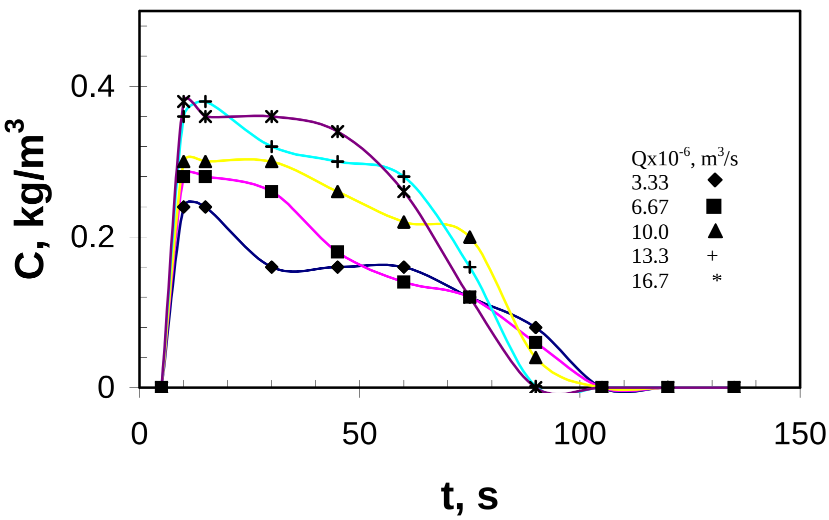

Figure 8: Concentration versus time at different flow rates for Pipe diameter 0.003m & length 0.075m.

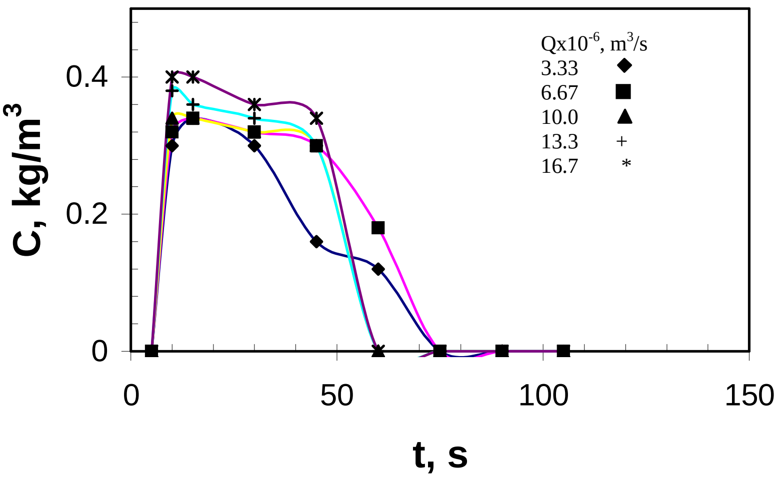

Figure 9: Concentration versus time at different flow rates for Pipe diameter 0.003m & length 0.05m.

The Effect of velocity (v) on Dispersion Coefficient (D_L): The dispersion coefficients (D_L) versus velocity (v) for different geometry of pipes are shown in the **Figures 10 – 17.**

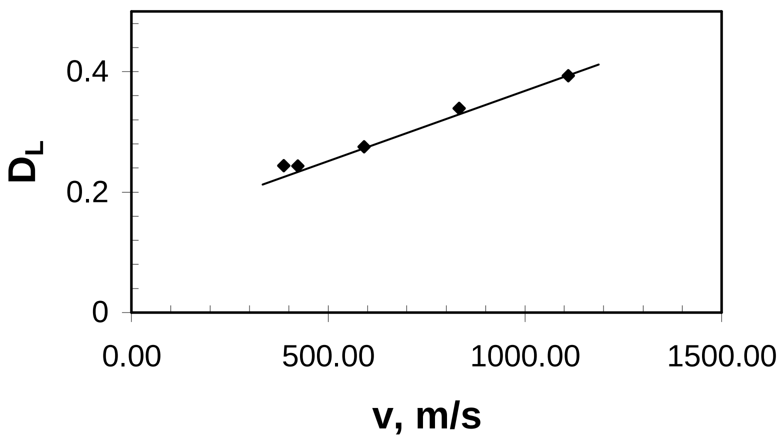

Figure 10: Dispersion coefficients versus velocity for Pipe diameter 0.003m & length 0.15m.

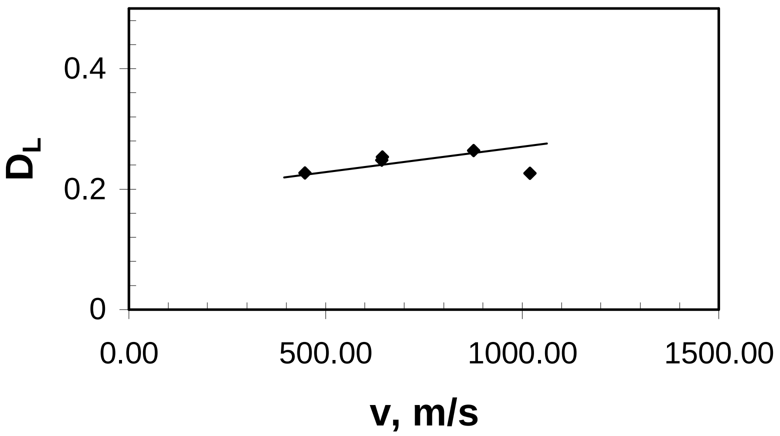

Figure 11: Dispersion coefficients versus velocity for Pipe diameter 0.004m & length 0.15m.

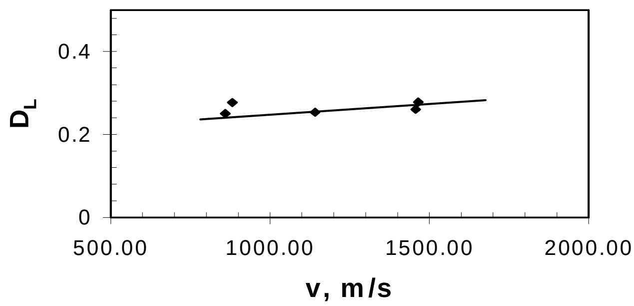

Figure 12: Dispersion coefficients versus velocity for Pipe diameter 0.005m & length 0.15m.

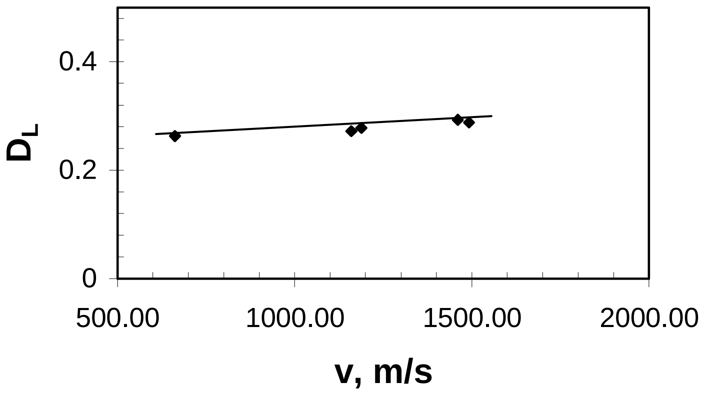

Figure 13: Dispersion coefficients versus velocity for Pipe diameter 0.006m & length 0.15m.

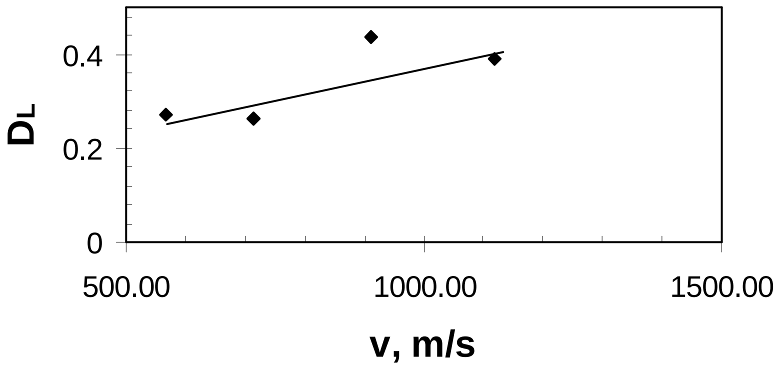

Figure 14: Dispersion coefficients versus velocity for Pipe diameter 0.003m & length 0.125m.

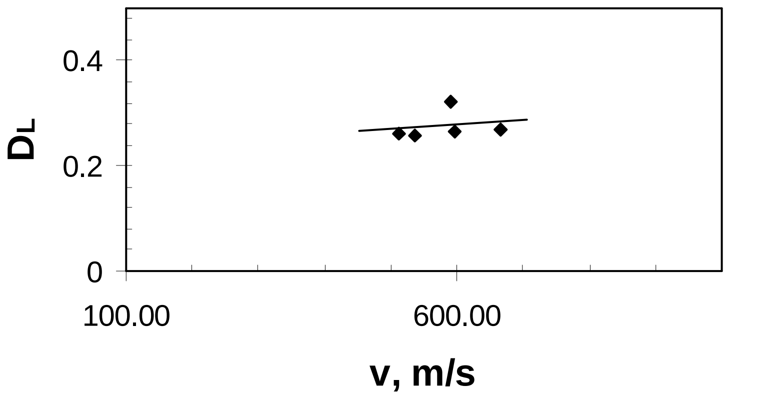

Figure 15: Dispersion coefficients versus velocity for Pipe diameter 0.003m & length 0.10m.

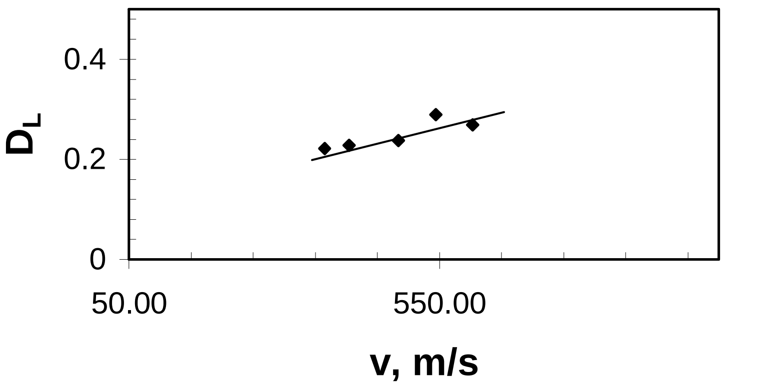

Figure 16: Dispersion coefficients versus velocity for Pipe diameter 0.003m & length 0.075m.

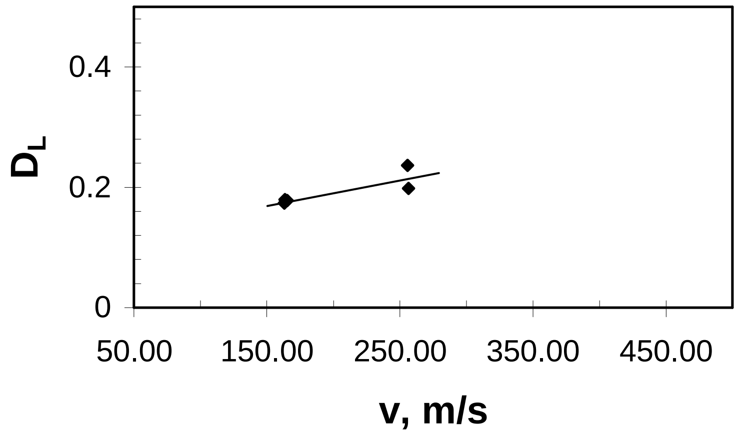

Figure 17: Dispersion coefficients versus velocity for Pipe diameter 0.003m & length 0.050m.

It is observed from the above figures that the dispersion coefficient is found to increase with an increase in velocity in all the pipes and this may be due to more axial missing of fluid particles at high velocity.

Effect of Pipe Diameter (d) on Dispersion Coefficient (D_L): The dispersion coefficient data for different pipe diameters at varying velocity are shown in Figure 18 and it was observed that the effect of pipe diameter on D_L is marginal which might be due to negligible effect pipe diameter within the scope of study on axial mixing of fluid particles

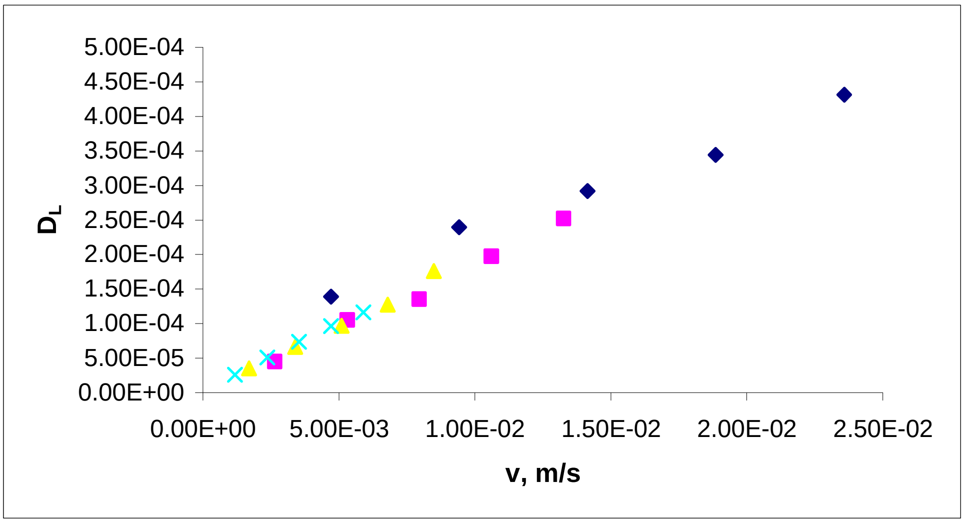

Figure 18: Comparison plot of Dispersion coefficients versus velocity for different Diameters of pipes

The dispersion coefficient data for different pipe diameters at varying velocity are shown in Figure 18 and it was observed that the effect of pipe diameter on D_L is marginal which might be due to negligible effect pipe diameter within the scope of study on axial mixing of fluid particles.

Effect of Pipe Length (L) on Dispersion Coefficient (D_L): The dispersion coefficient data for different lengths of pipe at varying velocity are shown in Figure 19 and it was observed that with an increase in length the D_L is increased which might be due to increase in axial mixing of fluid particles with increase in length.

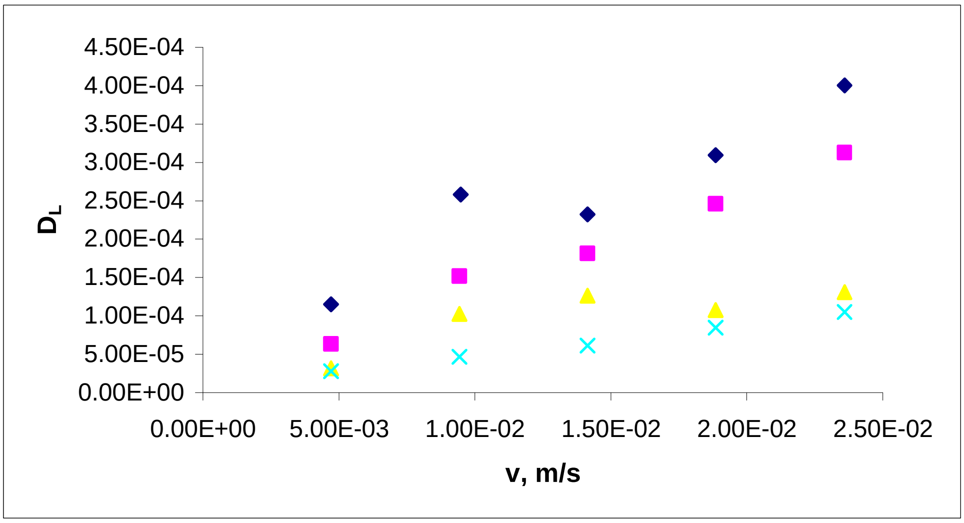

Figure 19: Comparison plot of Dispersion coefficients versus velocity for different Lengths of pipes

Fitting of experimental data into theoretical model: Ananthakrishnan et al., [6] has given a chart to show which model to be used as shown in Figure 20. The present experimental data is found to be in good agreement with axial dispersion model as almost all the data points fall in that region as shown in the Figure 20. Depending on this the dispersion coefficient was estimated based on axial dispersion model.

CONCLUSIONS

In this project work an attempt was made to study experimentally Residence Time Distribution (RTD) in a miniature pipes and from the data and graphical interpretation the following conclusions have been drawn:

1. The experimental data is found to be in good agreement with axial dispersion model though for laminar flow in small pipes pure convection model is appropriate.
2. The dispersion Coefficient (D_L) is found to increase with velocity and pipe length.
3. The effect of pipe diameter on D_L is seems to be marginal.
4. As a part of future study the experiments can be conducted for pipe diameters less than 0.003m.

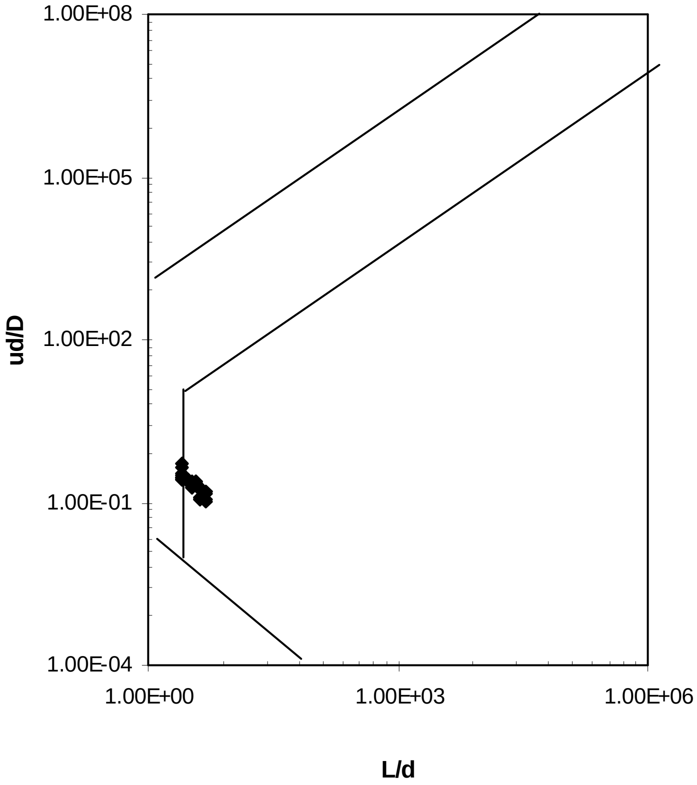

Figure 20: Maps showing which flow model to be used in any situation

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