DETERMINATION OF TURBULENCE PARAMETERS BY USING METHYLENE BLUE TRACER IN VERTICAL PIPE WATER FLOW

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INTRODUCTION

Tracers can be used to label substances or objects in order to distinguish them, to follow their movement, changes of concentration, distribution between phases, etc. Such properties as colour, refractive index, conductivity, radioactivity and density of additive substances have been successfully used in tracing experiments.

Turbulence parameters characterise the turbulent flow essentially. Dye is one of the most universal and practical tracer for the turbulent investigations. Methyl violet is used as dye tracer frequently and conventionally. Vertical pipe flow problems are important for the industrial applications but the investigation of the vertical flow has some troubles in point of experimental procedure. In this work a set of experiments has been carried out to investigate the fluid particles behaviour in the vertical pipe water flow and methylene blue was used as dye tracer differently.

THEORY

In discussing the mixing and diffusion of fluid in a turbulent flow, Taylor's turbulent diffusion theory, known as 'one-particle analysis', is often quoted[1]. According to , Taylor's turbulent diffusion theory, mean-squared displacement $\overline{y^2}$ is related with mean-squared radial velocity fluctuations $\overline{u}^2$ and Lagrangian velocity correlation coefficient $R_L(\tau)$[1-2]:

$$\overline{y}^2 = 2\overline{u}^2 \int_0^t \int_0^{t'} R_L(\tau)\, d\tau\, dt' \qquad (1)$$

Lagrangian velocity correlation coefficient:

$$R_L(\tau) = \frac{\overline{u(t)\, u(t-\tau)}}{\overline{u(t)^2}} \qquad (2)$$

is defined. For the small values of τ, $R_L(\tau)$ goes to 1 and,

$$\lim_{\tau \to 0} \overline{y}^2 = \overline{u}^2\, t^2 \qquad (3)$$

can be found. If the time is large enough, "Lagrangian integral time scale";

$$T_L = \int_0^{\infty} R_L(\tau)\, d\tau \qquad (4)$$

is defined. As using of Eq: 2;

$$\lim_{\tau \to \infty} \overline{y^2} = 2\, \overline{u^2}\, T_L\, t \qquad (5)$$

is found. An important parameter is Lagrangian velocity correlation coefficient for calculation of mean squared displacement. Frenkiel has proposed several simple forms for $R_L(\tau)$ all of which are semi-empirical[3]:

$$R_L(\tau) = \exp\left[-\frac{\tau}{2T_L}\right] \mathrm{Cos}\left[\frac{\tau}{2T_L}\right] \qquad (6)$$

$$R_L(\tau) = \exp\left[-\frac{\pi\tau^2}{4T_L^2}\right] \qquad (7)$$

$$R_L(\tau) = \exp\left[-\frac{\tau}{T_L}\right] \qquad (8)$$

The expressions fitted were found by substituting Eq. (6) to Eq. (8) into Eq. (1) to give, respectively:

$$\overline{y^2} = 2\, \overline{u^2}\, T_L \left[\, t - 2\, T_L \exp(-t/2T_L)\, \mathrm{Sin}(t/2T_L) \,\right] \qquad (9)$$

$$\overline{y^2} = 2\, \overline{u^2}\, T_L \left[-t\, \mathrm{erf}\left(\frac{\sqrt{\pi}}{2T_L}\, t\right) + \frac{2T_L}{\pi} \exp\left(-\frac{\pi}{4T_L^2}\, t^2\right) - \frac{2T_L}{\pi} \right] \qquad (10)$$

$$\overline{y^2} = 2\, \overline{u^2}\, T_L \left[\, t - T_L \left[\, 1 - \exp(-t/T_L) \,\right] \right] \qquad (11)$$

EXPERIMENTAL PROCEDURE AND RESULTS

An experimental system was set up in the laboratory similar to that of Taylor and Middleman, which used Methyl violet as a dye tracer[4-5]. Experimental system is shown schematically in Fig. 1[6-7]. A main element is a vertical tube, which is made of transparent acrylic pipe with 2.54 cm radius and 289 cm length. Adding the main vertical pipe, experimental test device consists of one water storage tank, one constant level storage tank, a flowmeter, pump and related pipes.

Experiments have been done with four Reynolds numbers, which are 17800, 24500, 35000, and 45000. Water-methylene blue mixture was prepared in 60 ml, which contains 200 mg methylene blue in it. This mixture was injected through a small capillary aligned along the pipe axis. Samples of fluid have been withdrawn downstream from the injection point in different (generally nine) radial cross sections on the flow direction between three main planes. At least 2 ml samples were collected from each sampling point[6-7].

Methylene blue ($C_{16}H_{18}ClN_3S.2H_2O$) shows very strong absorption at 663 $m\mu$[8]. Measurements of absorbance as a function of dye concentration were made with a Shimadzu UV-160 A model spectrophotometer at 663 $m\mu$. Optical absorbance is directly proportional to concentration of dye. The raw data from measurement of optical absorbance of the dyed solutions was fitted to a Gaussian distribution given by:

$$A = A_o \exp\left[\frac{-(Y-\overline{Y})^2}{2\overline{Y^2}}\right] \tag{12}$$

Where A is absorbance, A_o is maximum absorbance, Y is distance from pipe centerline, $\overline{Y}$ is mean and $\overline{Y^2}$ is variance of the concentration distribution. In this work, the parameters A_o, $\overline{Y}$ and $\overline{Y^2}$ were found from a non-linear least squares calculated by mathematica computer package program[9].

Turbulence parameters that characterise the turbulent flow are namely Lagrangian integral time scale (T_L), turbulent intensity (u') and dispersion coefficient (E_D) differ depending on which model for $R_L(\tau)$ is used in Eq. (1). The non-linear least squares fit of models relating mean-squared-displacement to dispersion time was accomplished by obtaining best estimates of mean-squared radial velocity fluctuations and Lagrangian integral scale ($\overline{u}^2$ and T_L respectively). From these estimates it was a simple matter to calculate turbulent intensity (u') and the dispersion coefficient (E_D) from:

$$u' = \sqrt{\overline{u}^2} \Big/ u_c \tag{13}$$

and

$$E_D = T_L\, \overline{u}^2 \tag{14}$$

For the graphical evaluation, Fig. 2-4 were drawn which show turbulence parameters (Lagrangian integral time scale, turbulent intensity and dispersion coefficient) as a function of Reynolds numbers, calculating by using Equations (6) to (8) for $R_L(\tau)$. Methylene blue results were compared with Taylor and Middleman data which were used methyl violet. Comparison graphs can be seen in Fig. 5-7. The appropriation of the results with Taylor and Middleman data is sufficiently good.

CONCLUSIONS

Methylene blue dye tracer technique has been applied to the vertical pipe water flow for the determination of turbulence parameters and the results were acceptable and reliable when the compared with the methyl violet results. It can be concluded that:

- Turbulence parameters can be determined easily by using methylene blue in water
- Changing of the turbulence parameters for methylene blue in water via Reynolds numbers appropriate to methyl violet in water results

- Methylene blue application showed that it can be used as dye tracer for turbulent investigations due to its strong color and easily solubility in the water.
- The validity of the Methylene blue dye tracer technique has been confirmed.

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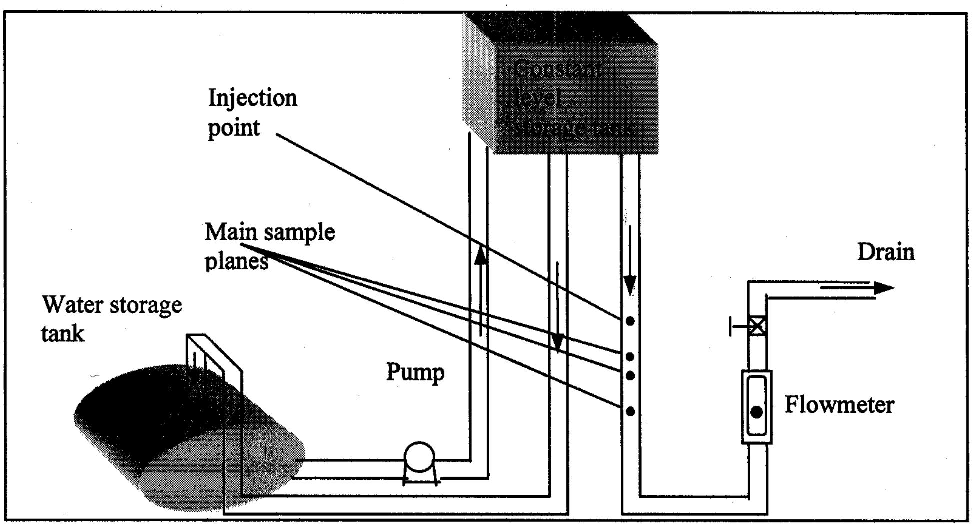

Figure 1. Schematic view of the experimental system.

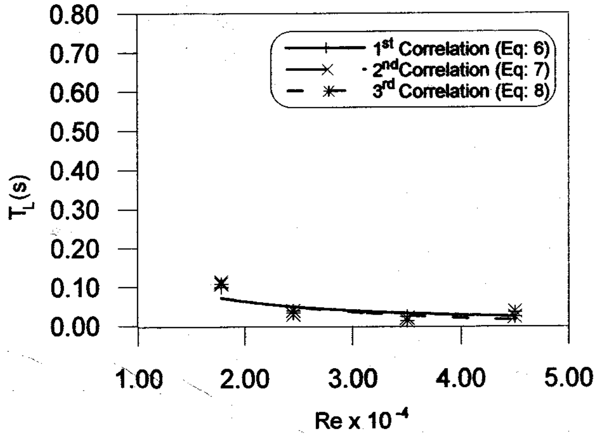

Figure 2. Variation of Lagrangian integral time scale with Reynolds number, using Equations: 6-8

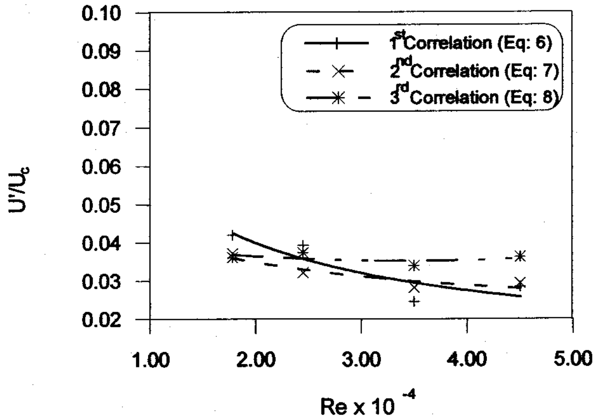

Figure 3. Variation of turbulent intensity with Reynolds number, using Equations: 6-8

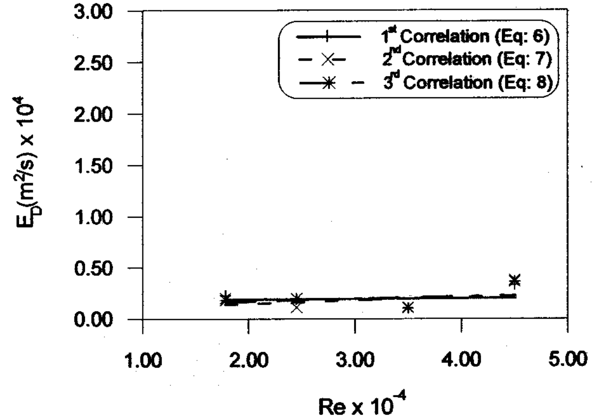

Figure 4. Variation of dispersion coefficient with Reynolds number, using Equations: 6-8

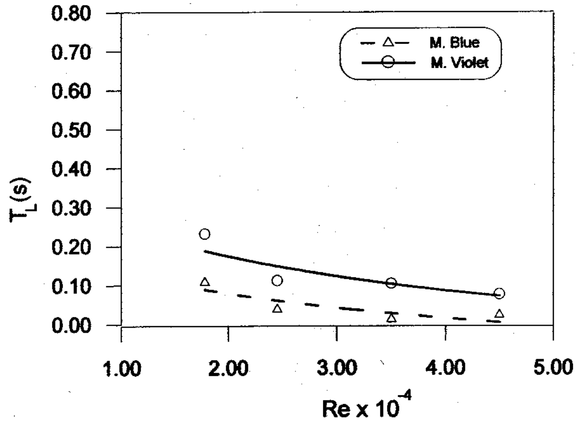

Figure 5. Comparison of Lagrangian integral time scale for M. blue and M. violet

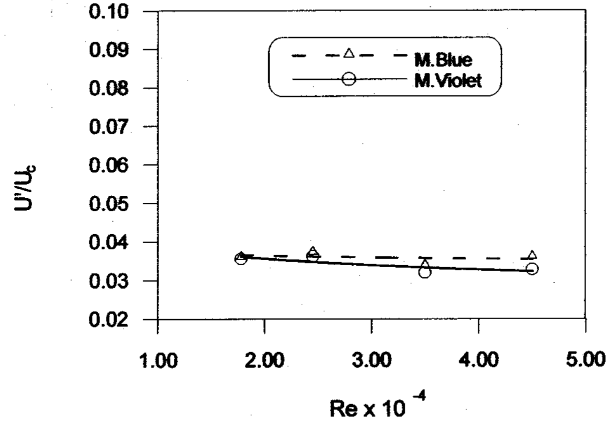

Figure 6. Comparison of Turbulent intensity for M. blue and M. violet

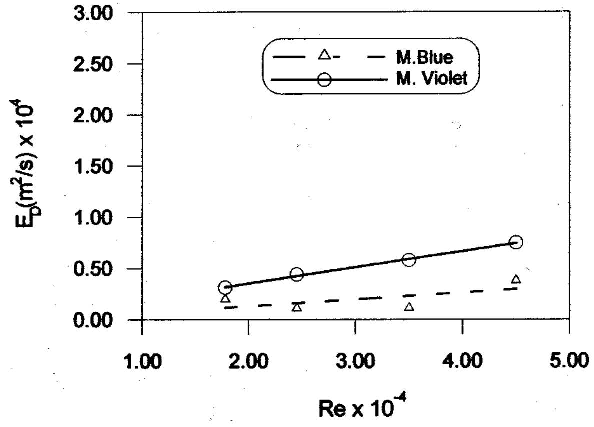

Figure 7. Comparison of dispersion coefficient for M. blue and M. violet