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Effect of Jet Fluid Temperature on Flow Characteristics of Submerged Round Jet

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Abstract

This paper presents the effect of jet fluid temperature on scaler diffusion characteristics of a free round vertical jet. Water is considered as the jet and ambient fluid. The experimental investigation was carried out at three different temperatures, and at a Reynolds number of 4000. The dye based flow visualization technique was adopted to visualize and study scaler diffusion characteristics of the jet which was coloured using methylene blue dye of specific gravity 1.12. The jet parameters such as spreading rate, virtual origin, and cone angle and concentration profiles along and across the jet were estimated. Spreading rate and cone angle was found increasing in order with increase in jet fluid temperature.

Introduction

Research in the field of jet flow has found its roots in 1930s but still sustained research is being undertaken by many researchers due to the rich physics involved in jet fluid flow. When a stream of fluid is projected into the same or similar surrounding fluid from an aperture, nozzle or an orifice, as shear layer is developed between these fluids. Fluid on either side of the shear layer is termed as jet [1]. Submerged round jet has a wide range of applications, in waste water disposal in sea or river, water discharged from thermal power plant, diffusion of drug in ventilator, and release of exhaust gas in ambient.

Jet can be mainly classified into three different categories jet, plume and buoyant jet. A pure jet occurs when it is purely driven by momentum source only. Contrarily if jet is driven by both momentum and density differences, then jet is known as buoyant jet. In initial region

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jet is driven by momentum and later is driven by buoyancy force. And if the jet is driven by the density differences of fluid, then it is known as plume.

A. Jet behaviour

Jet behaviour mainly depends on three parameters (i) jet parameters such as initial momentum, initial diameter, the initial concentration, so on (ii) geometrical parameters such as nozzle diameter, orientation of discharge, water depth, nozzle topology and (iii) environmental parameters such as ambient fluid.

Jets are mainly classified in three different regions, namely potential core region, transition region and self-similar region [2]. In the immediate vicinity of nozzle the mixing between the jet fluid and ambient fluid is negligible. This region is termed as potential core region in jet, which generally extends from 3d to 6d, where d is the diameter of nozzle. In transition region concentration starts to decay as ambient fluid starts penetrating radially. This region generally corresponds from 6d to 20d. The third region is known as self-similar region, because in this region concentration profiles will be Gaussian. This region is also termed as zone of flow establishment. The jet half width (b) is the lateral distance from the centreline concentration becomeshalf its value. When nondimensionalised concentration half width (b/d) is plotted on graph, is linearly proportional to the axial distance (x/d) and the constant of proportionality is known as spreading rate (k_1) [3].

$$\frac{b}{d} = k_1\left(\frac{x}{d} + k_2\right) \qquad (1)$$

EXPERIMENTAL SETUP AND METHODOLOGY

Figure 1 represents the schematic of experimental setup. The setup mainly consists of three glass tanks, a test fluid tank having dimension 40cm × 40cm × 40cm, a constant head tank having dimension 30cm × 30cm × 45cm and a ambient tank having dimension 50cm × 50cm × 100cm. Nozzle base chamber was made from 20cm diameter nylon rod, and a cavity of 10cm diameter and length was made. Connection were made as shown in Fig. 1. Two 180 W xenon lamp is used to enlighten the region of interest in fluid flow. A SONY α 6000 camera was used for recording video.

Initially dye is mixed with water in a bucket, then it is poured into the test fluid tank. A submerged pump is used to maintain constant head. For both normal and heated jet Reynolds

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number was fixed (*Re* = 4000). Initially experiment was performed at ambient temperature i.e. 30˚C. Then jet fluid was heated using water heater. Temperature was measured using thermometer and submerged pump was used for continuous mixing in order to maintain constant temperature throughout. The experiments were conducted at two different temperatures 45˚C and 65˚C.

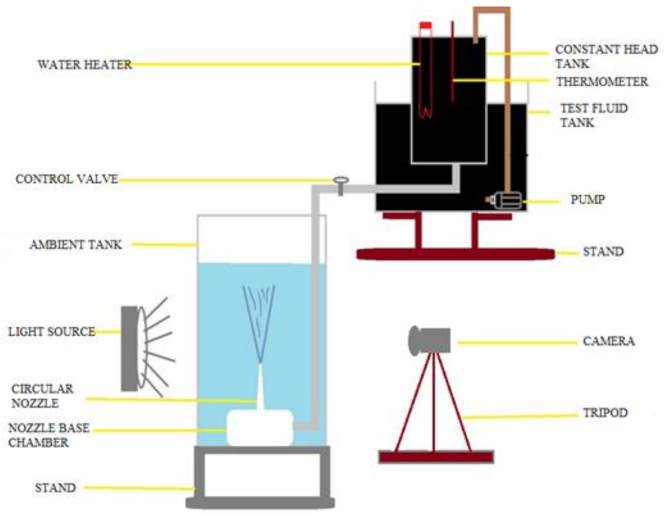

Fig.1 Schematic of experimental setup

RESULTS AND DISCUSSION

Since the methodology considered here is based on flow visualization, image processing is carried out by averaging of 500 images and thus error in estimation of jet parameters gets averaged out. Figures 2(a-c) represents the mean concentration distribution (C/C_o) i.e. ratio of localized concentration to concentration at nozzle outlet, for normal jet at Re = 4000 and temperature 25˚C, at three different axial locations 1.5cm, 3cm and 4.5cm. The axial location are chosen to observe changes in jet concentration profile along and across the jet. From Fig. 2, it was observed that as jet progresses entrainment of ambient fluid increases. Andconcentration profiles changes from top hat profile to the Gaussian profile. Jet spread on either side of jet was found 2*d*, 8*d* and 12*d* at axial distance of 1.5, 3 and 4.5 cm respectively.

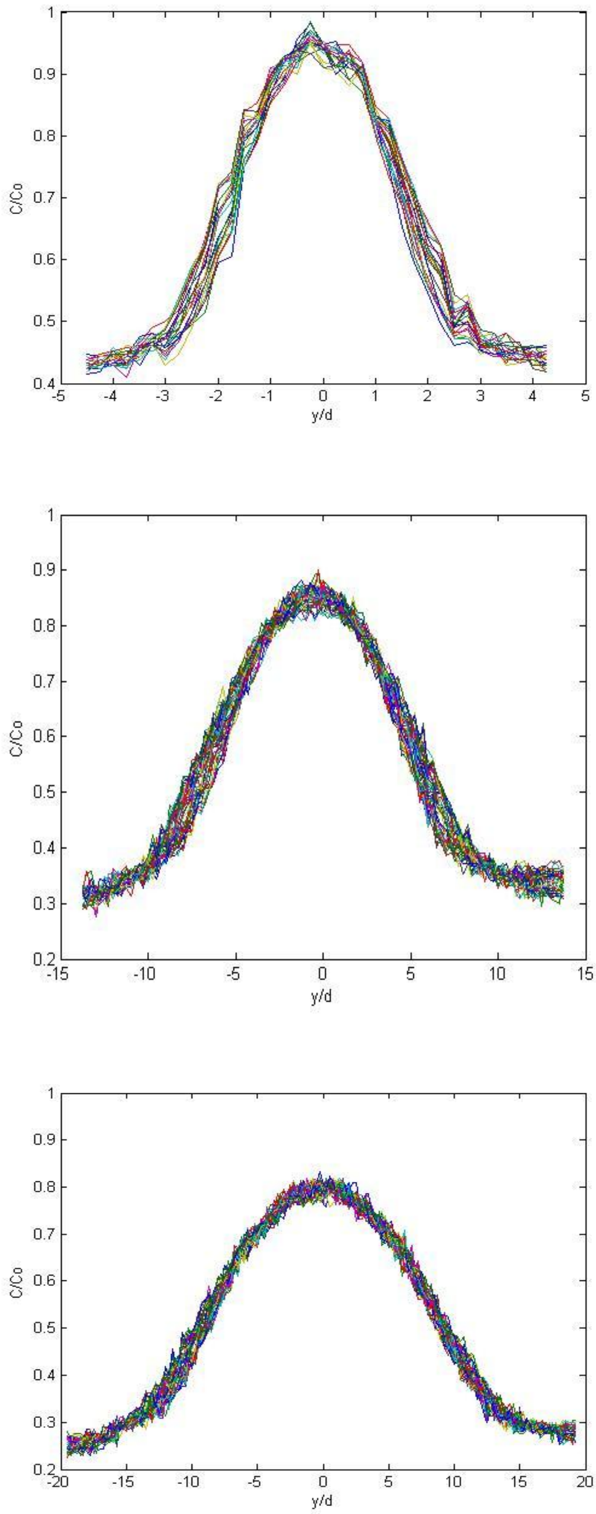

Fig. 2 Radial mean concentration distribution at an axial distance of (a) 1.5 cm, (b) 3 cm and (c) 4.5 cm

A shear layer is developed between jet and ambient fluid because of velocity difference. In vicinity of nozzle entrainment of ambient fluid is less and as jet grows, jet engulfs more

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ambient fluid in order to conserve its momentum. Ambient fluid penetrates up to centreline, because of mixing of jet fluid and ambient fluid centreline concentration starts decreasing and variation of centreline concentration is shown in Fig. 3.

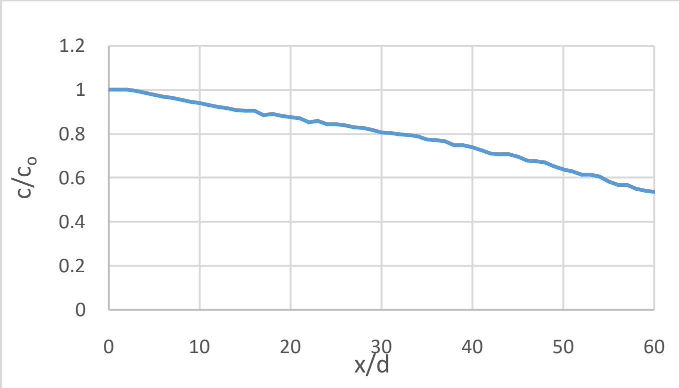

Fig. 3Centreline concentration variation

The jet concentration width represents the scaler spread of the jet. Figure 4 represents the jet half width (*b/d*) plot with axial distance (*x/d*), slope of line gives the concentration spread rate (Eq. 1), where R^2 tells about fitness of straight line to the chosen points. In similar way analysis was done for heated jet, temperature 45˚ C and 65˚C at same Reynolds number of 4000. The variation of jet parameters with increase in temperature is listed in Table 1. Cone angle was measured using ImageJ software. Concentration scale of half width was calculated by averaging the non-dimensional concentration half width. Velocity scale of half width was calculated using($k_c = 1.19k_v$), that is, concentration spread rate is 1.19 times the velocity spread rate [2]. With increase in temperature jet spread rate and cone angle increases due to higher entrainment of ambient fluid.

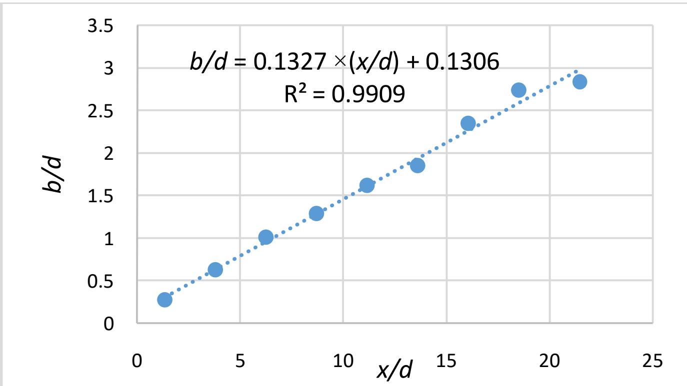

Fig. 4 Spread rate calculation

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Reynolds number 4000	**Isothermal Jet**	**Heated jet T = 45˚C**	**Heated jet T = 65˚C**
Spread rate	0.1325	0.1387	0.1421
Cone angle	14.80˚	15.505˚	15.576˚
Concentration scale of half width	0.12205	0.1236	0.1288
Velocity scale of half width	0.10331	0.10548	0.1064
Virtual origin	-0.96 mm	-1.15 mm	-1.25 mm

Table 1 Variation of parameters with increase in temperature.

CONCLUSIONS

The flow properties of a round vertical jet at Reynolds number 4000 (for both normal and heated jet) are described in detail. For turbulent jet potential core region was not observed. With increase in jet fluid temperature from 25˚C to 65˚C, due to more entrainment and better mixing spread rate increases from 0.1325 to 0.1421. Correspondingly cone angle also increases from 14.80˚ to 15.576˚. Virtual origin for turbulent jets lies downstream the nozzle. With increase in temperature it shifts downstream of nozzle from 0.96*d* to 1.25*d*.

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