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Effect of Reynolds Number on the Spread of Surface Buoyant Jets

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SUMMARY On the basis of experiments conducted with surface buoyant jets two ranges of Reynolds numbers have been identified within which the effect of Reynolds number on the spread of the buoyant jet is negligible, if any, as long as both prototype and model Reynolds numbers fall within any one of the ranges.

1 INTRODUCTION

Hot water from Thermal power plants, which is lighter than the receiving cold water body, is discharged in many cases in the form of surface jets. These buoyant jets spread vertically by entrainment and laterally by entrainment and buoyancy, in the receiving cold water body. As the hot water jets spread, they loose their heat to the surrounding water and atmosphere. The temperature distribution resulting from the spread of hot water jets sometimes causes ecological and hydraulic problems. So in order to obtain a hydraulically efficient and ecologically satisfactory solution for the waste heat disposal, hydraulic modelling is resorted to.

The near field region of buoyant surface jet discharging into an ambient quiescent water body can be modelled hydraulically if geometric similarity and the identity of densimetric Froude number and Reynolds number of the jets in the model and prototype are achieved. To achieve the identity of densimetric Froude numbers and Reynolds numbers is extremely difficult if not impossible. In certain cases of flows it is known that the rigid identity of Reynolds numbers can be relaxed to the extent that it is enough if the model Reynolds number value is kept within a certain range (Yalin 1971).

The paper presents the results of an experimental investigation conducted at the Indian Institute of Science to explore the existance of any such ranges of Reynolds numbers for the case of a buoyant surface jet discharging into an ambient quiescent water body.

2 EXPERIMENTS

Experiments were conducted in a 1.2m wide, 13.5m long, glass-walled flume which was filled with water at room temperature. Hot water was discharged through a nozzle of circular cross section in the form of a jet into the receiving still water which was kept at the room temperature. The hot water was heated in a small tank kept above the level of the surface of the ambient water and connected to the nozzle by a pipe fitted with flow regulating valves. The nozzle was so arranged in all the experiments that its axis was horizontal and coincident with the centre line of the ambient water surface. Two sizes of nozzles were used; 5mm and 10mm diameter. The width of the flume was constricted to 90cms and 60 cms in certain experiments. The temperature field was measured with an array of thermister probes.

3 EARLIER RESULTS

For the region in which the width of the expanding jet is less than the width of the ambient water, certain results which have been obtained earlier (Muralikrishna 1976) are first presented. These results are valid for all Reynolds numbers studied. They form the basis for evaluating the effect of Reynolds number in the later part of this paper. The following notation is used.

- D = Diameter of the nozzle
- X = Longitudinal distance from the outlet point
- B = Width of the ambient water
- U = Velocity of the jet
- W = Half width of the jet defined as the lateral distance at any section from the axis of the nozzle to a point where the temperature is 13.5% of the centre line temperature (If the temperature distribution is gaussian this would correspond to 2 sigma band)
- H = Thickness of the jet defined as the vertical distance at any section from the axis of the nozzle to a point where the temperature is 13.5% of the centre line temperature
- ν = Kinematic viscosity
- g = Acceleration due to gravity
- P_a = Mass density of the ambient water
- P_j = Mass density of the hot water at the outlet point
- F = $U/\sqrt{(P_a - P_j/P_a)\, gD}$
- Re = UD/ν

Throughout this paper the results are presented in terms of nondimensional parameters. Following are the results mentioned earlier.

(i) The lateral temperature profiles are similar

(ii) The vertical temperature profiles are similar

(iii) For a given Re and X/D, W/D α $F^{-1/2}$ and H/D α $F^{1/2}$

(iv) The constants of proportionality in both the cases are linearly related to (B/D)-1.

The date of Jen et al (1966), Tamai et al (1969) and Wood and Wilkinson (1967) have been used along with the data of Muralikrishna (1976) to arrive at the above results.

4 RANGE OF DATA USED

The values of B/D, Re and F for which experiments have been conducted to study the effect of Re are tabulated in Table I

TABLE I

D in mm	B/D	Re	F
5	240	7980	25.0
		5260	18.8
		1025	5.1
10	120	20600	36.5
		17060	30.5
		16410	48.8
		15500	18.9
		14300	78.8
		13100	14.5
		11320	15.8
		10400	29.2
		8700	48.2
		8220	24.9
		7000	8.5
		6896	9.2
		2520	4.5
		2420	6.0
		1980	3.5
	90	18060	20.0
		13260	39.0
		12530	33.7
		11240	15.5
		9730	24.0
		8690	9.6
		8490	26.5
		7820	8.6
		6440	11.4
	60	18000	33.7
		13770	36.2
		13650	40.0
		9700	17.1
		9610	13.7
		8630	10.9
		7850	24.5
		6820	20.0
		6470	9.0

5 ANALYSIS

5.1 Lateral Spread

A preliminary analysis of the data of W/D showed that for a given Re and F it varied directly as $(X/D)^{4/3}$ when $5260 \leqslant Re \leqslant 21600$ and as $(X/D)^{3/4}$ when $1025 \leqslant Re \leqslant 2420$. Hence the following relationships are formulated for the two ranges.

When $5260 \leqslant Re \leqslant 21600$ (Range I)

$$W/D = [a+b/(B/D)]\ (X/D)^{4/3}\ F^{-1/2} \qquad (1)$$

and

When $1025 \leqslant Re \leqslant 2420$ (Range II)

$$W/D = [a_1+b_1/(B/D)]\,(X/D)^{3/4}F^{1/2} \qquad (2)$$

a, b, a_1 and b_1 are functions of Re. From Figs. 1 and 2 it can be seen that a and b in the range of Re from 5260 to 20600 and a_1 and b_1 in the range of Re from 1025 to 2420 have the following constant values.

$a = 0.55$, $b = 30$, $a_1 = 0.5$ and $b_1 = 240$

Fig. 1 also shows that the observations pertaining to Range II deviate clearly from the trend of the observations pertaining to Range I. The constancy of the values of a and b in Range I implies that the lateral spread of the buoyant surface jet is independent of the value Re takes in Range I. This result can be used with advantage in modelling. For instance if the prototype Re is 18000, the model Re can be 6000 which is one third of the prototype value. It is felt that Range I extends beyond the highest Re value of the present experiments. This aspect requires further study.

Fig. 1 also suggests that at some value Re_t of Re between 2520 and 5260 transition from one type of jet flow to another is occurring. Below Re_t there appears to be a narrow range Range II where again the lateral spread is independent of the value Re takes in that range. Fig. 2. It is possible that a_1 and b_1 of Eq.(2) are only apparently constant because of the narrowness of the range while actually they are functions of Re as originally assumed. Experiments are now being conducted to study this aspect.

5.2 Vertical Spread

A similar analysis carried out for the thickness of the buoyant jet has yielded a single relationship for both the ranges I and II. Fig. 3. The relationship is as follows.

$$H/D = [0.031 + 0.6/(B/D)]\,(X/D)^{2/3}F \qquad (3)$$

From Eq.(3) we can conclude that gravity is the predominant force in determining the vertical spread of the surface buoyant jet and that the effect of viscous forces can be neglected. It is known that the vertical spread is inhibited by the density difference in the case of a surface buoyant jet. Eq. (3) gives smaller H/D values for smaller F values which is in agreement with the above statement.

6 CONCLUSIONS

There is a range of Reynolds numbers above a certain value Re_t ($2420 < Re_t < 5260$) upto 20600 in which the lateral spread of a surface buoyant jet is independent of the value of Re. Further experiments are necessary to determine the Re_t value and to show that this range extends beyond 20600.

The vertical spread is governed only by the densimetric Froude number. The effect of Re if any is negligible.

7 ACKNOWLEDGEMENT

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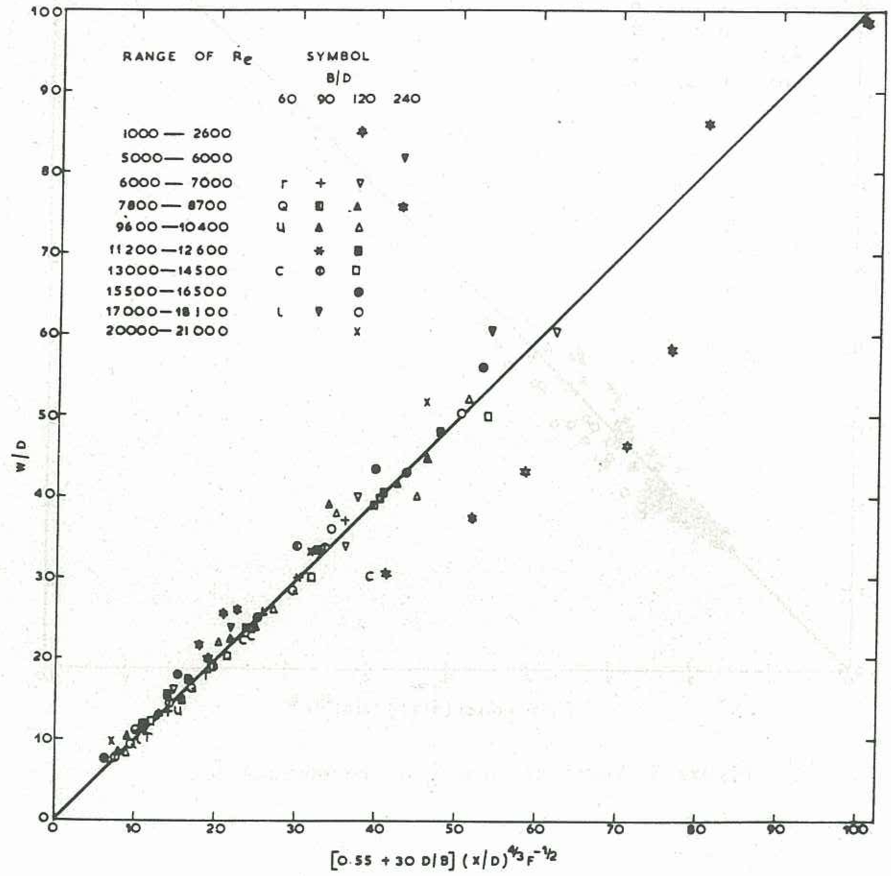

Figure 1 Lateral spread of the buoyant jet

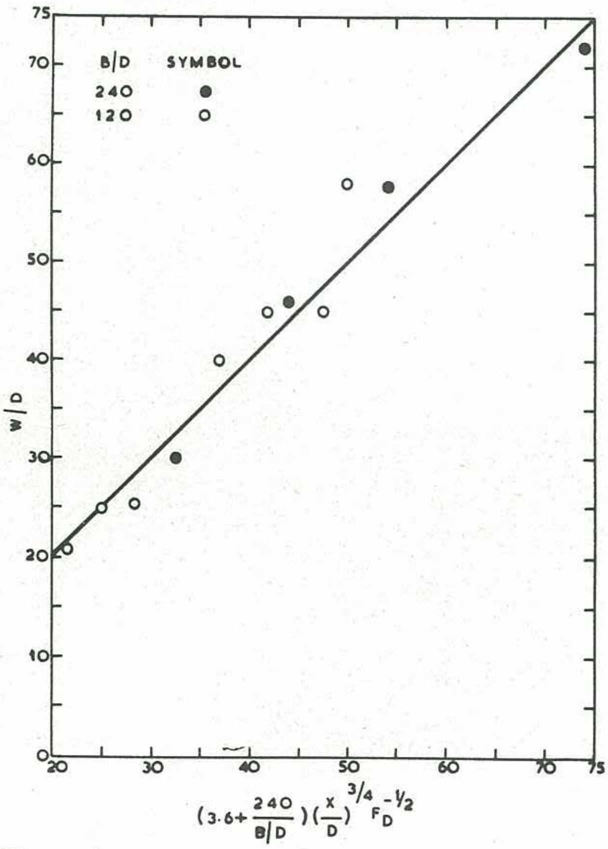

Figure 2 Lateral spread of the buoyant jet for Range II

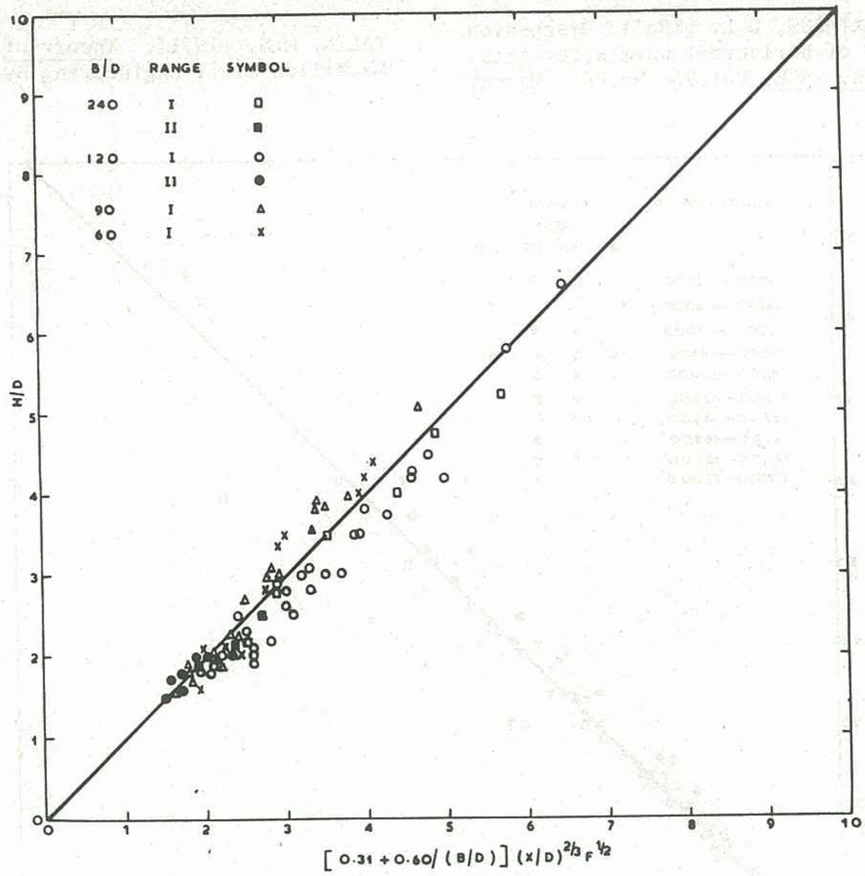

Figure 3 Vertical spread of the buoyant jet