STUDY ON OUT FALLS IN SHALLOW CROSS FLOWS

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Abstract: This paper presents the results of a laboratory study on the mixing of circular jets discharged into shallow water streams. The experiments were carried out with different concentration and with a velocity ratio (α) varying from 3.5 to 10 where α is the ratio of the velocity of the jet stream to the cross flow velocities. Three, two and one ports were used, the spacing S between the ports was 6d, 8d and 16d where d is the diameter of the nozzle. The concentration measurements were carried out for x / d up to 200 and αd/D was from 0.40 to 0.67 (Shallow cases) where x is the longitudinal distance measured from the nozzle along the cross flow and D is the depth of the cross flow. Also the concentration measurements were carried out for deep case at αd/D 0.20, 0.27 and 0.32. The results from this study on minimum Dilution were compared with circular jets in cross flow (Hodgson 1992 and Moawad 2001) for single and multiple deep cases and Moawad (2005) for single shallow cases. From experimental results the minimum dilution for shallow water jets were less than that for deep water jet. It was found that the minimum dilution decreases with the increase of the velocity ratio α and the increase in the number of ports n. An increase of the spacing between the ports would lead to an increase in the minimum dilution. On comparing the width of the single jet for deep case to that of the multiple jets for shallow case. It was noticed that the width was larger for the case of shallow multiple jets. On comparing the thickness of the single and multiple jets for deep case to that of the multiple jets for shallow case. The thickness of jets in shallow water was less than that of the deep water jets. These results are believed to be useful in the design of outfalls in rivers. Keywords: Waste Water Discharges, Mixing and Dilution, Cross flows, Environmental, Shallow and River.

1. Introduction

Waste water treatment plants commonly discharge treated effluents through outfalls into rivers. These plants are designed to minimize environmental impacts by reducing the pollutant concentrations of the effluent. Generally, the discharge of these effluents need to mixing zone. The efficiency of the initial mixing of this liquid waste involved in reducing the risk of this waste will pose to human health. The initial mixing and the flowing dilution of the pollutants are greatly influenced by the design of the outfall. Most of studies on sewage outfalls in the ocean have been investigated [see Moawad (1998); H.J wang (2001); Law (2002) Bl. Smith (2003) and F.Lalli (2004) for a list of references].Although many studies have been carried out on circular jets in crossflows (Rajaratnam (1976]; Langat (1994);Moawad (2005) and Tobis (2007), mixing in cross flows in the case of shallow rivers have not been studied in detail. One effective way of achieving maximum dilution is to discharge the effluent as circular turbulent jets perpendicular to the river flow (jets in cross flow). Another way of achieving rapid dilution in the vicinity of the outfall is to use multiple circular jets in cross flows. Hodgson (1992) considered circular jets discharging from the bottom of a receiving stream, normal to the direction of flow. Hodgson (1992) differentiated between jet discharges into deep water and shallow water using the dimensionless parameter $\alpha d/D$, where D is the depth of flow. The critical value of this parameter was found to be approximately 0.34. If this parameter is smaller than 0.34, the jets behave like deep water jet whereas if it is larger than 0.34, the jets behave like shallow water jets. The minimum dilution at any section is defined as the ratio of the concentration at that section C_m in terms of the concentration at the ports C_o was found (Hodgson and Rajaratnam 1992) to be given by the equation:

$$\frac{C_o}{C_m} = 1.09\left(\frac{\alpha x}{d}\right)^{0.56} \qquad (1)$$

Moawad and Rajaratnam (1998) presented the results of a laboratory study on the mixing of circular nonbuoyant multiple jets discharged into relatively deep river-like cross flows. Moawad ,Rajaratnam, and Stanley (2001) conducted laboratory experiments were carried out to investigate the effectiveness of multiple jets for chemical mixing in an open channel .The results of this study show that turbulent jets could be a successful alternative to mechanical methods for achieving chemical mixing. According to Moawad (2005) for single jet discharging in shallow crossflow, the minimum dilution at any section is defined as the inverse ratio of the maximum concentration at that section C_m in terms of the concentration at the ports C_o was found to be given by the equation:

$$\frac{C_o}{C_m} = 0.89\left(\frac{\alpha x}{d}\right)^{0.55} \qquad (2)$$

This paper presents the results of an investigation on the efficiency of multiple circular outfalls for diluting the pollutants in shallow streams as rivers.

2. Experimental arrangements

2.1. Experimental flume

The experimental investigation was carried out in the hydraulic laboratory of the faculty of engineering, Al- Azhar University using a channel of rectangular section with 4m long; 0.3m wide, the walls of the channel were made of glass of height 0.30 m .Water was supplied to the channel by means of centrifugal pump placed in the laboratory sump. The water level in the flume was controlled by adjustable tailgate located at the end of the channel. The velocity in the channel was measured locally at various points within each section at different depths above bed and up to water surface. A mini flow meter with outer diameter 7.00 mm was used to measure the velocity in (Hz) after that the velocity could be expressed in (cm/sec) by using a calibration curve that specifies this apparatus.

2.2. Arrangements of jets

The nozzles with diameters of 8mm and 10mm were placed in the bed midway across the channel at a distance of 1.50m from the entrance. Identical jets with diameter of 8mm were produced from the bed using a cylindrical reservoir, 180mm in diameter and 300mm long (see Fig 1 for a definition sketch). The jet flows were produced by a 1/3 horse power (250 watts) Jacuzzi pump. The pump raised water from a 600 L tank to a constant head tank (placed about 3.00 m above the flume) which in turn supplied water to the jet nozzle. The flow rate through the jet nozzle was measured by Fischer Rota meter. The velocity was calculated from the measured flow rate and the nozzle diameter. The number of ports n was three. The spacing between the ports S was equal to 6d, 8d and 16d.

2.3. Concentration measurements

To simulate the pollutants concentration, sodium chloride was used as a tracer in these experiments. The experiments were carried out with different concentration up 1000 ppm at the out falls. For flow visualization, Potassium Permanganate was used as dye. This dye was mixed thoroughly in the 600 L tank with water pumped from the same pump that provided the cross flow.

2.4. Sampling rake arrangement

Fluid samples were obtained by means of sampling tubes attached to a sampling rake. The sampling rake consisted of a minimum of 9 L- shaped. The inside diameter of the probes was 2.00 mm. The spacing between the probes was 20.00 mm. The tubes were used to discharge the samples from the flume into 50ml opaque plastic bottles.

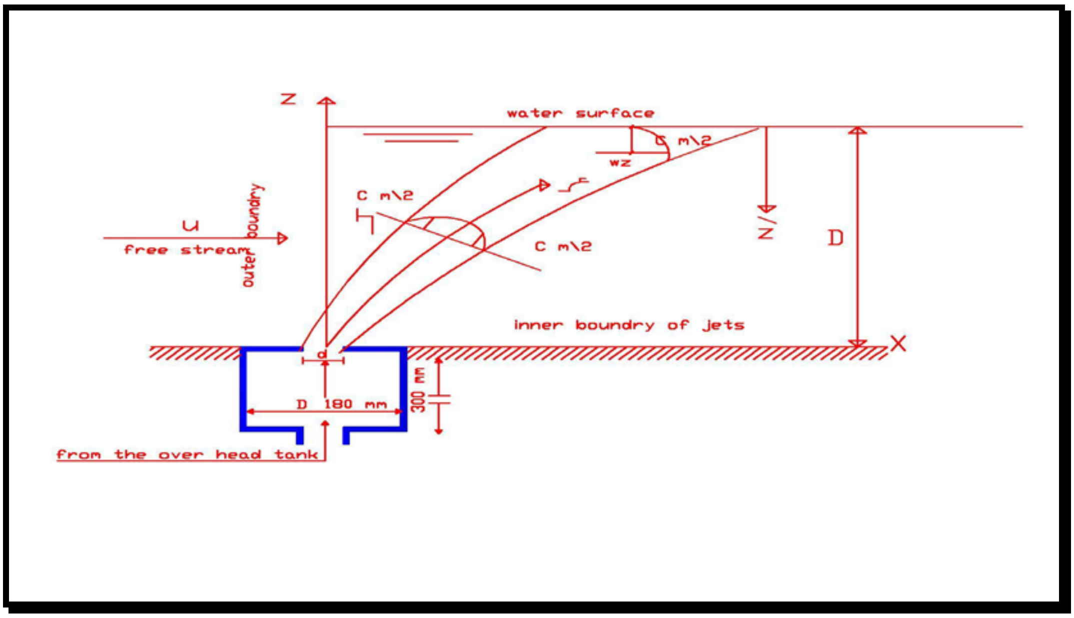

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Fig.1.a: Side view of jet in cross flow

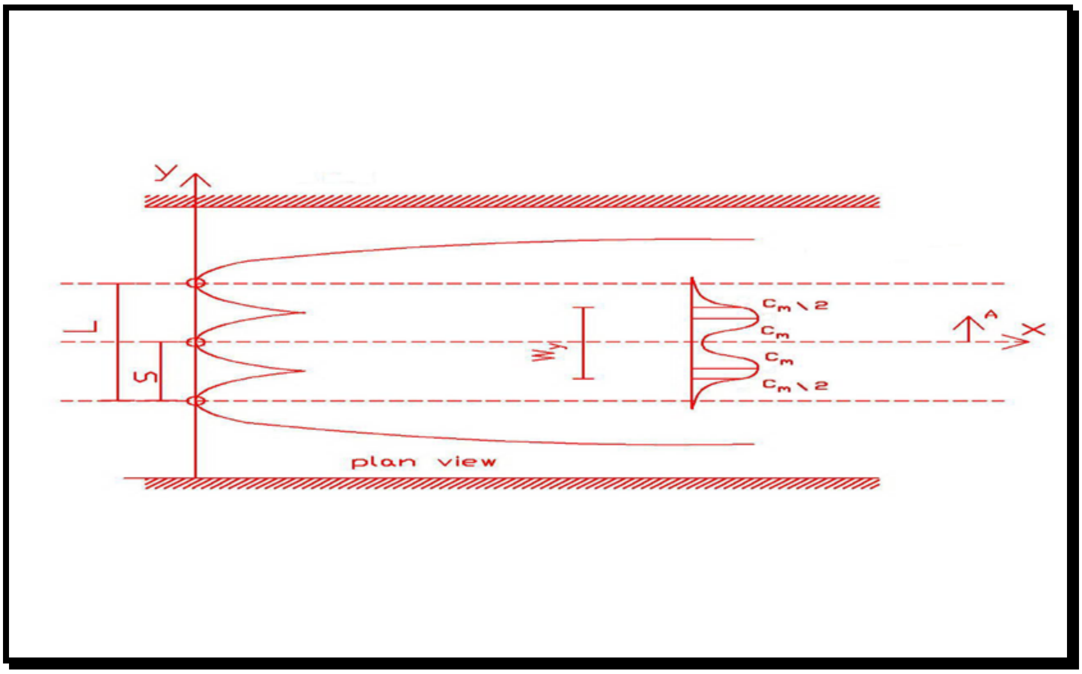

Fig.1.b: Plan view of jet in cross flow

3. Experiments and Experimental Results

A total of thirteen experiments with almost 1000 runs were conducted and the primary details of these experiments are shown in Table 1. The experiments were two cases (deep and shallow water jets).The jet nozzle had two diameter 8mm and 10mm to total of experiments. Spacing between the ports S was equal to 6d, 8d and 16d to total of experiments. For deep water jets three cases with α equal to 3.5 (D1), 5(D2) and 8(D3) were studied with the α d/D was equal to 0.2, 0.27 and 0.32 respectively.

For shallow water jets nine cases with α was equal to 8 (S1), 10(S2), 5(S3), 5 (S4), 8(S5), 10(S6), 8(S7),10(S8),5(S9) and 8(S10) were studied with the α d/D was equal to 0.41, 0.45, 0.40, 0.40, 0.42, 0.48, 0.43,0.48,0.48 and 0.44 respectively. The number of ports n was changed from one to three. The depth of water in the channel was 140 to 180mm. The jet Reynolds number defined as $U_o d/\nu$ where ν is the kinematics viscosity of water was in range of 4000 to 14000.

Table (1): presents the details of experiments:

Exp. No	Diameter Jet d (mm)	No of Ports (n)	Spacing (S)	Jet Velocity U_o (m/s)	Channel velocity U (m/s)	$\alpha = U_0/U$	α d/D	Jet Reynolds num $R = U_o d/\nu$
D1	**8**	**3**	**8d**	**0.5**	**0.145**	**3.5**	**0.2**	**4004**

D2	**8**	**2**	**8d**	**0.725**	**0.145**	**5**	**0.27**	**5805**
D3	**8**	**1**	**8d**	**1.16**	**0.145**	**8**	**0.32**	**9289**
S1	**8**	**3**	**8d**	**1.2**	**0.151**	**8**	**0.41**	**9609**
S2	**8**	**2**	**8d**	**1.4**	**0.148**	**10**	**0.45**	**11211**
S3	**8**	**3**	**8d**	**1.68**	**0.14**	**5**	**0.40**	**13453**
S4	**8**	**2**	**16d**	**1.70**	**0.34**	**5**	**0.40**	**13613**
S5	**8**	**3**	**16d**	**1.11**	**0.14**	**8**	**0.42**	**8889**
S6	**10**	**2**	**16d**	**1.4**	**0.145**	**10**	**0.66**	**14014**
S7	**10**	**2**	**8d**	**0.950**	**0.12**	**8**	**0.53**	**9510**
S8	**10**	**3**	**8d**	**1.12**	**0.128**	**10**	**0.67**	**11211**
S9	**10**	**3**	**6d**	**0.725**	**0.145**	**5**	**0.42**	**7258**
S10	**10**	**2**	**6d**	**1.12**	**0.14**	**8**	**0.44**	**11211**

Concentration fields in the deflected jets were measured in the transverse direction y in the η direction as well as in the vertical direction z at different distances along the jet axis ζ. The concentration measurements covered a distance of x/d = 200 where x is the longitudinal distance down stream the diffusers. In terms of the transformed distance α x/d, the measurements covered a range from 8 to 1800. The concentration at any point C was normalized by the concentration at the nozzle C_o. Figure (2) shows the variation of C_o / C_m with α x/d for all three series of deep water jet experiments. The dilution results for this study were compared with those for circular jets in cross flow (Hodgson 1992 and Moawad 2001) for single and multiple deep case and Moawad (2005) for single shallow case. The measurements covered a range of α x/d from 10 to 1800.

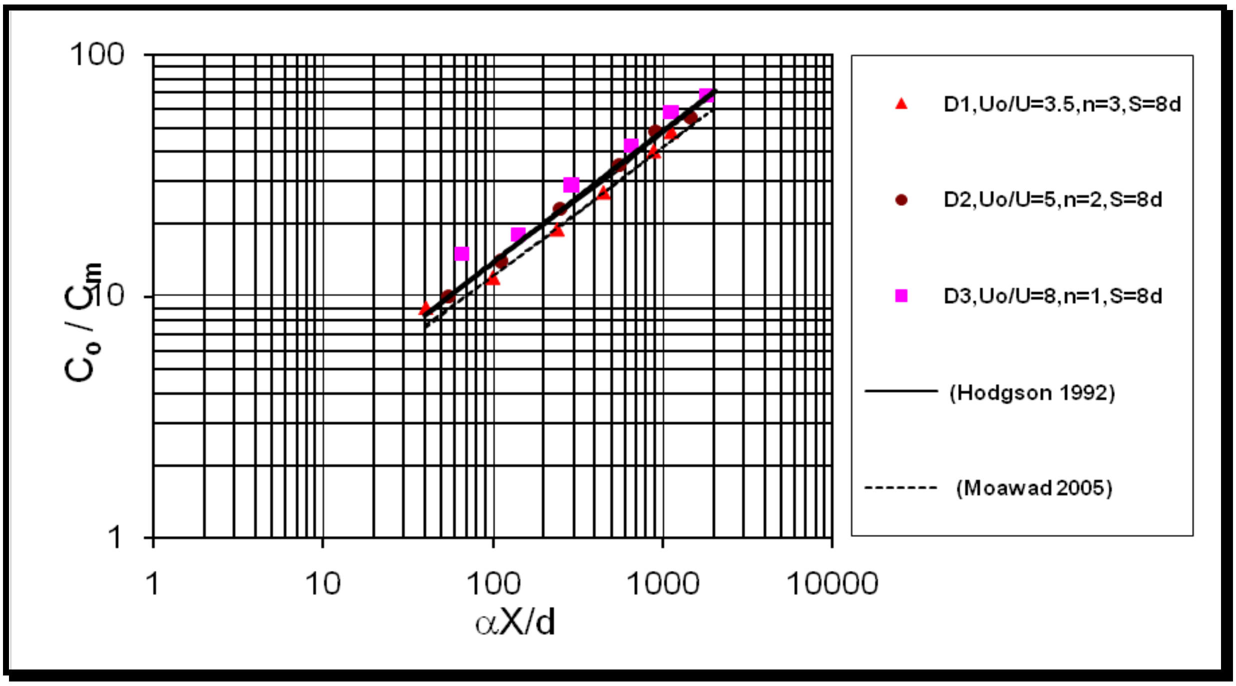

Fig .2: Variation of minimum dilution (C_o/C_m) with αx/d for all deep runs

Figure (3) shows the variation of C_o / C_m with α x/d for all series of experiments for shallow water jet. The results from this study on minimum dilution were compared with those for circular jets in cross flow (Hodgson 1992 and Moawad 2001) for deep case and Moawad (2005) for single shallow case. The measurements covered a range of α x/d from 40 to 2000.

To study the effect of increasing the spacing between the ports on minimum dilution, the observations from experiments of S1, S2, S3 and S7 are compared with that of S5, S6,S9 and S10 for α= 5,8 and 10.Variation of minimum dilution (C_o/C_m) with α x/d showing the effect of changing the spacing (see Fig 4).

Figure 5 shows the variation of minimum dilution (C_o/C_m) with α x/d to study the effect of changing the number of ports on minimum dilution, the observations from experiments of S1, S2 are compared with that of S7, S8 for α=8 and 10. Concentration measurements were performed in transverse direction at different longitudinal distances x from the nozzle varying from x= 40mm to 2000mm.

The variation of the minimum dilution with α x/d is affected by α (see Fig 6). The effect of α on the minimum dilution can also be noticed from the experiments in S with S3 and S8 at α x/d=900 for α=8,5 and 10 respectively, S2 with S7 at α x/d=320 for α=10 and 8 respectively, S4 with S6 at α x/d=530 for α=5 and 10 respectively.

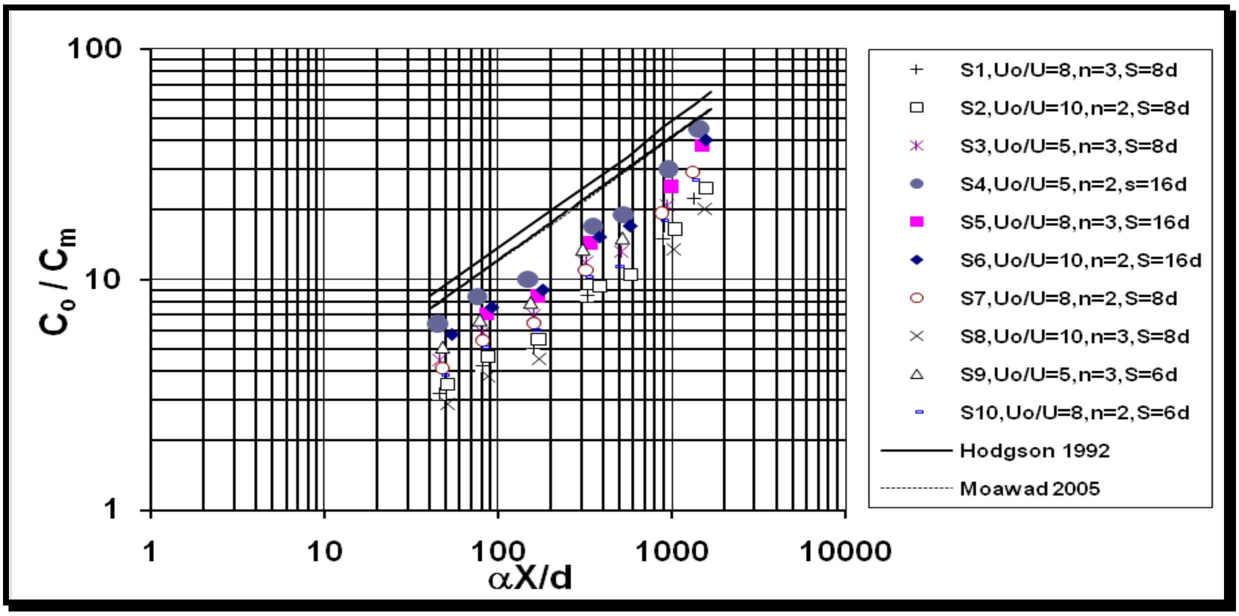

Fig. 3: Variation of minimum dilution (C_o/C_m) with αx/d for all runs Shallow

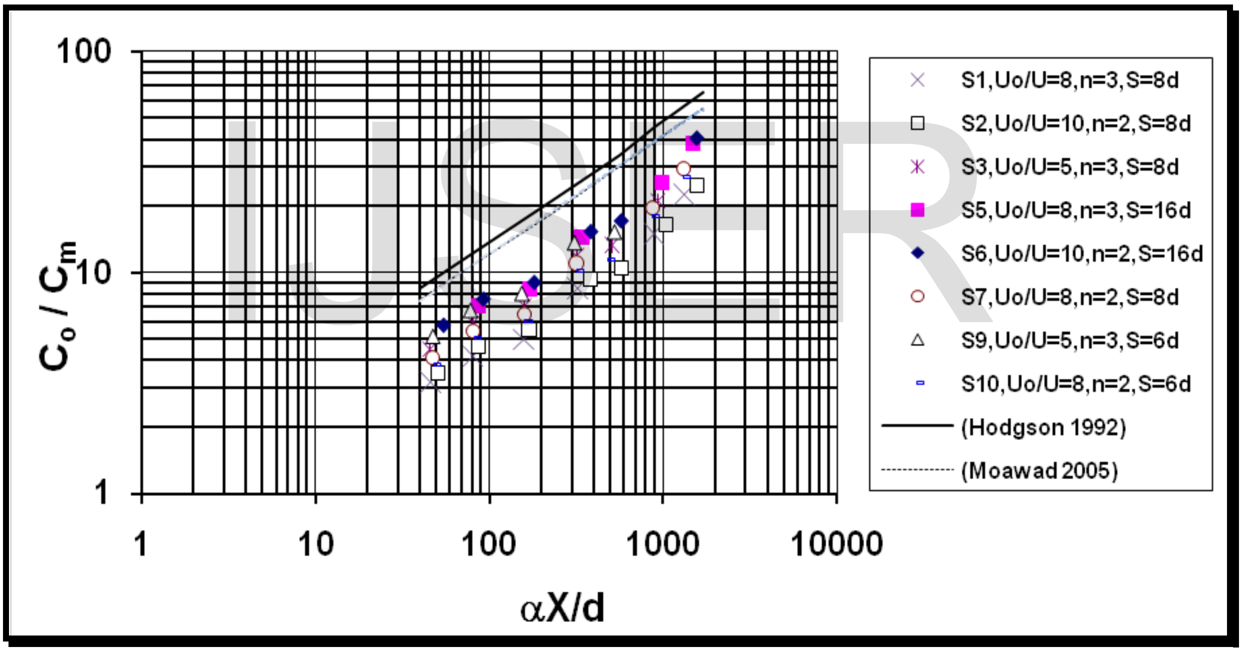

Fig. 4: Variation of minimum dilution (C_o/C_m) with αx/d showing The effect of changing the spacing

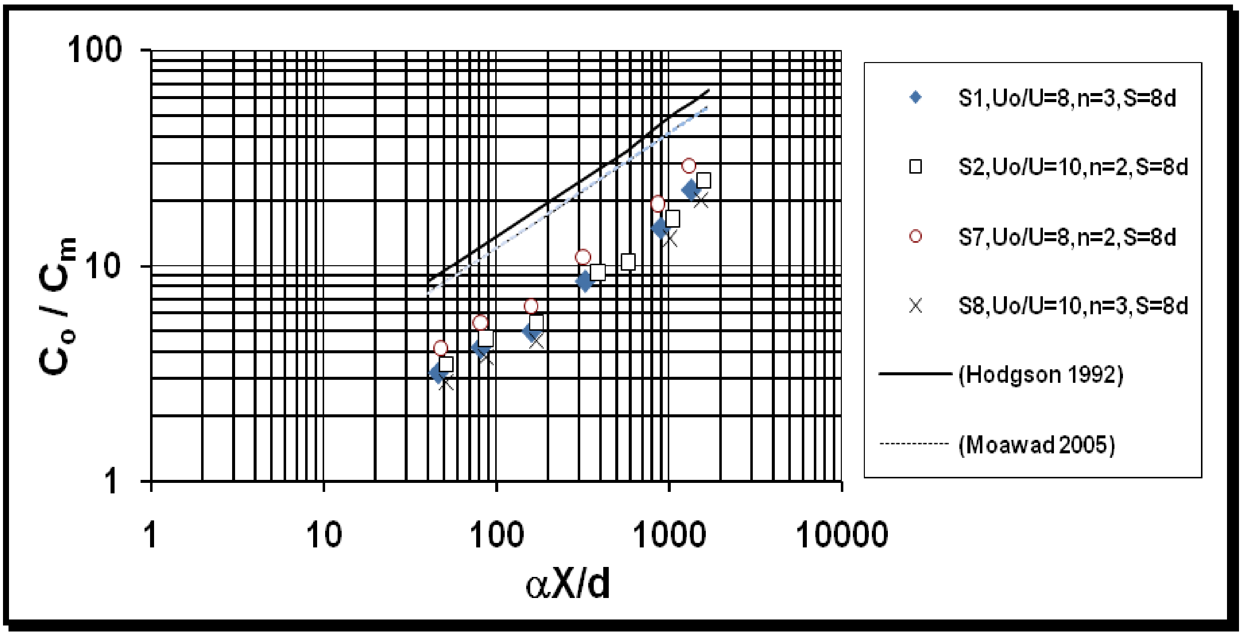

Fig. 5: Variation of minimum dilution (C_o/C_m) with αx/d showing The effect of changing the number of ports

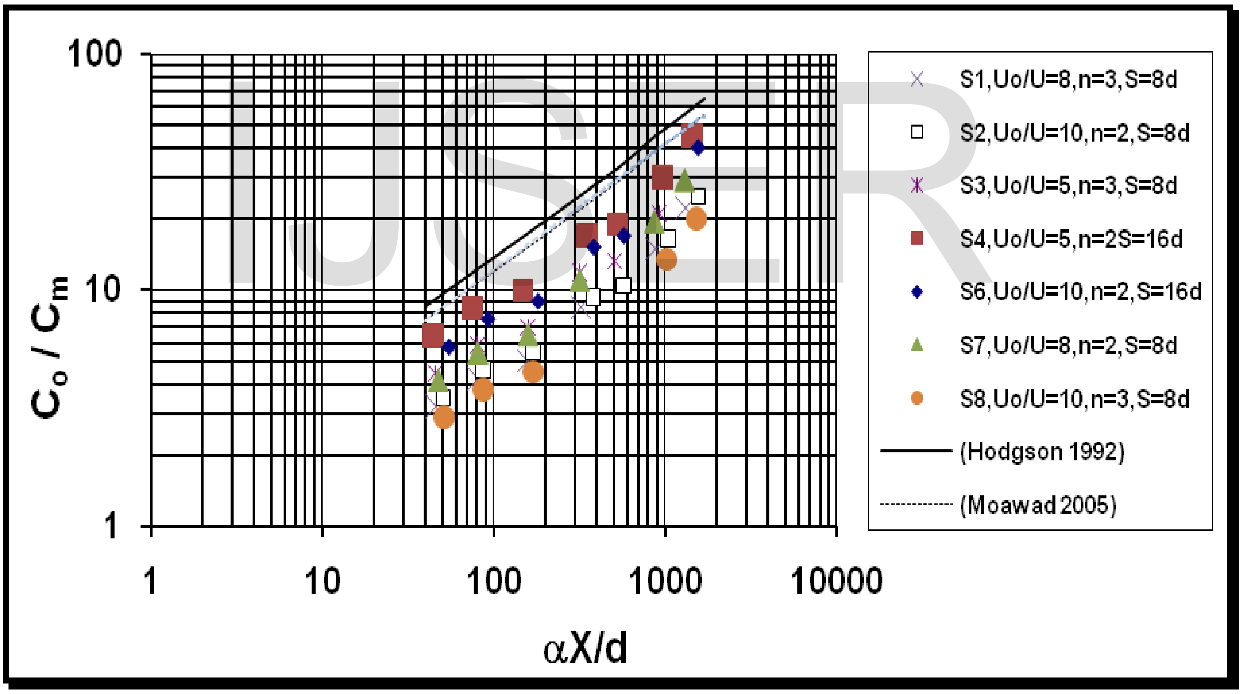

Fig. 6: Variation of minimum dilution (C_o/C_m) with αx/d showing The effect of changing the value of α

Fig 7(a-b) show the transverse concentration profiles for α=8 for three ports with spacing equal to 8d. A study of Fig 7(a-b) showed that the Concentration field had two peaks. It was noticed that the maximum concentration was near the water surface, after occurs the bifurcation. An increase of the distance X would be occurred decrease in the minimum dilution.

Figures 8 (a-b) show typical vertical concentration profiles for α=5 for two ports with spacing equal to 16d and α=8 for two ports with spacing equal to 6d. The bifurcation occurred to the jet with colored dye injection. It was found that at αx/d < 100 in MD NF region the maximum concentration was below the surface, while at αx/d > 100 the maximum concentration was near the surface.

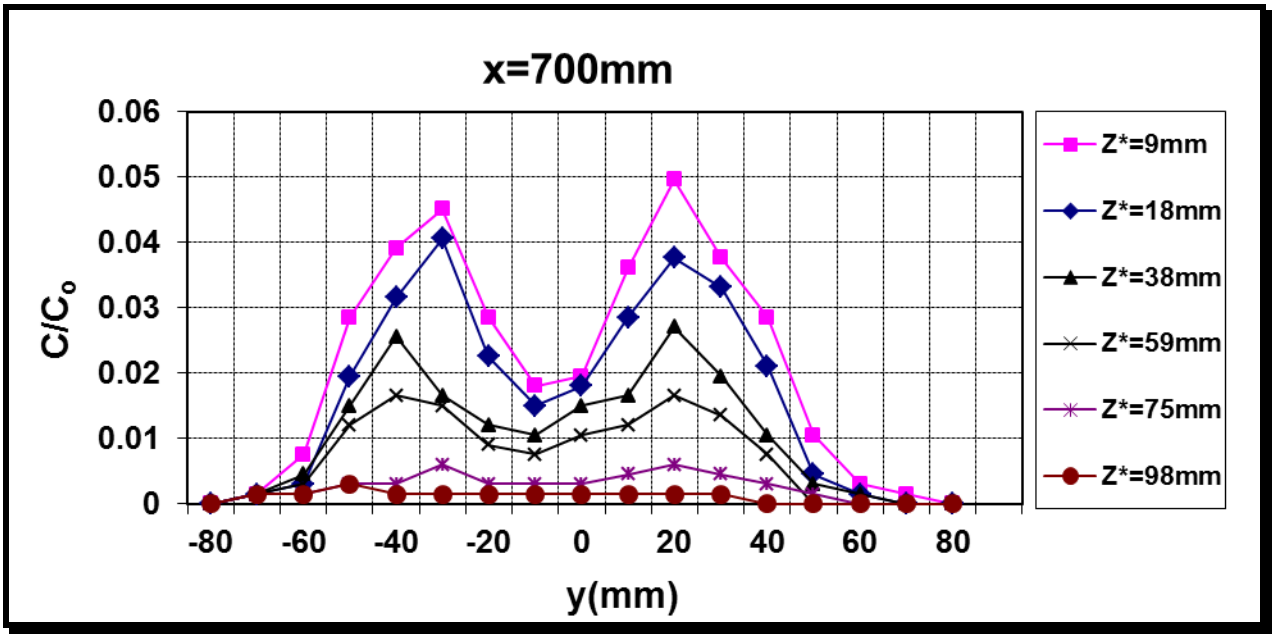

Fig. 7.a: Typical concentration profiles for the maximum transverse concentration planes

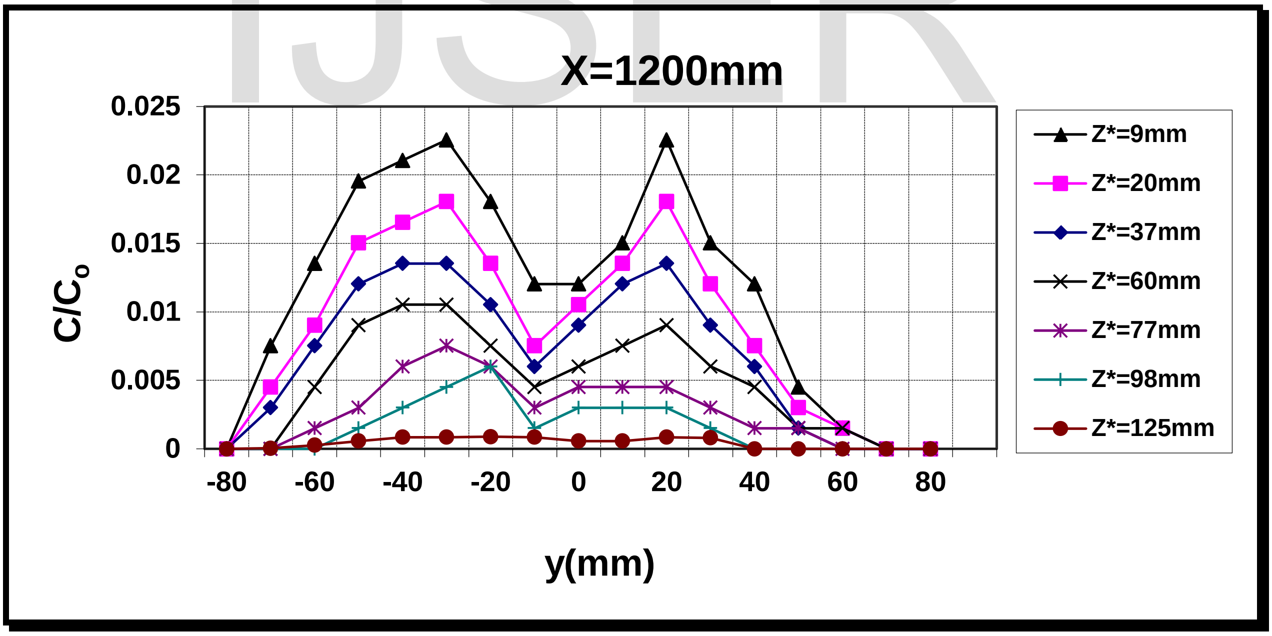

Fig. 7.b: Typical concentration profiles for the maximum transverse concentration planes

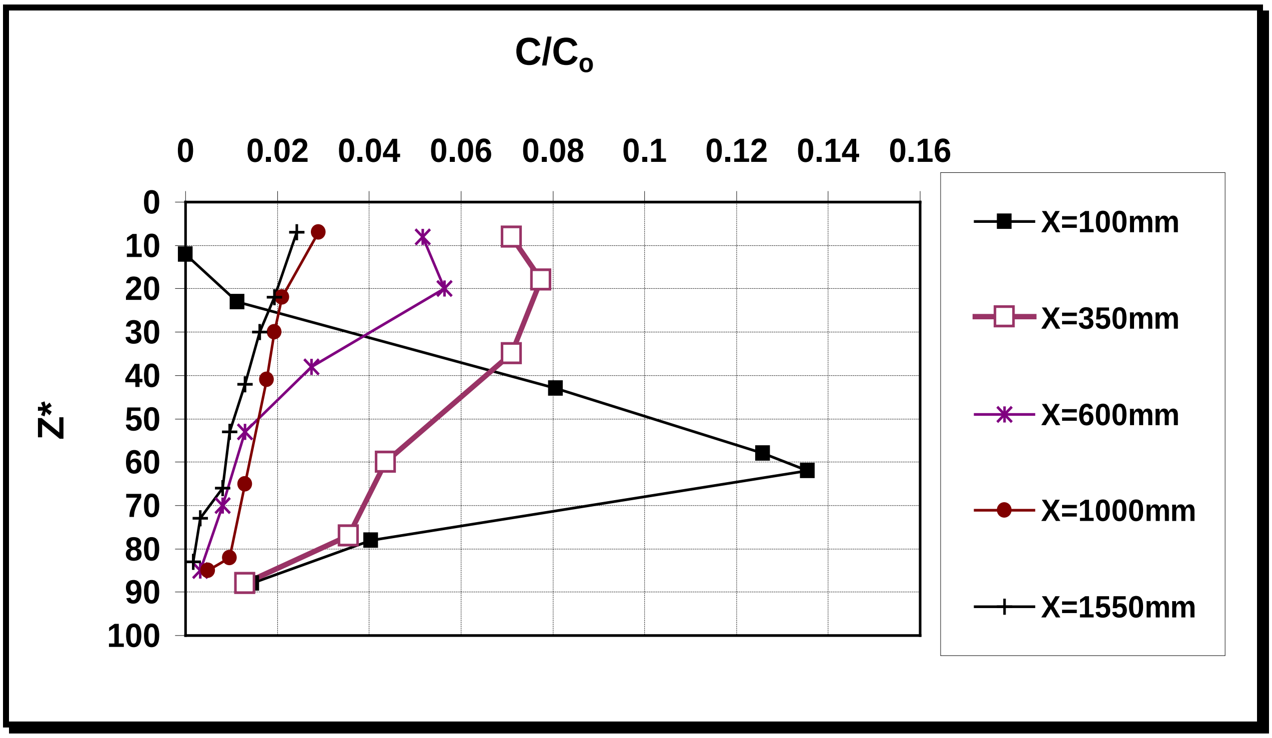

Fig. 8.a: Typical vertical concentration profile at different longitudinal distances, Expt. S4 (α=5, n=2 and S=16d)

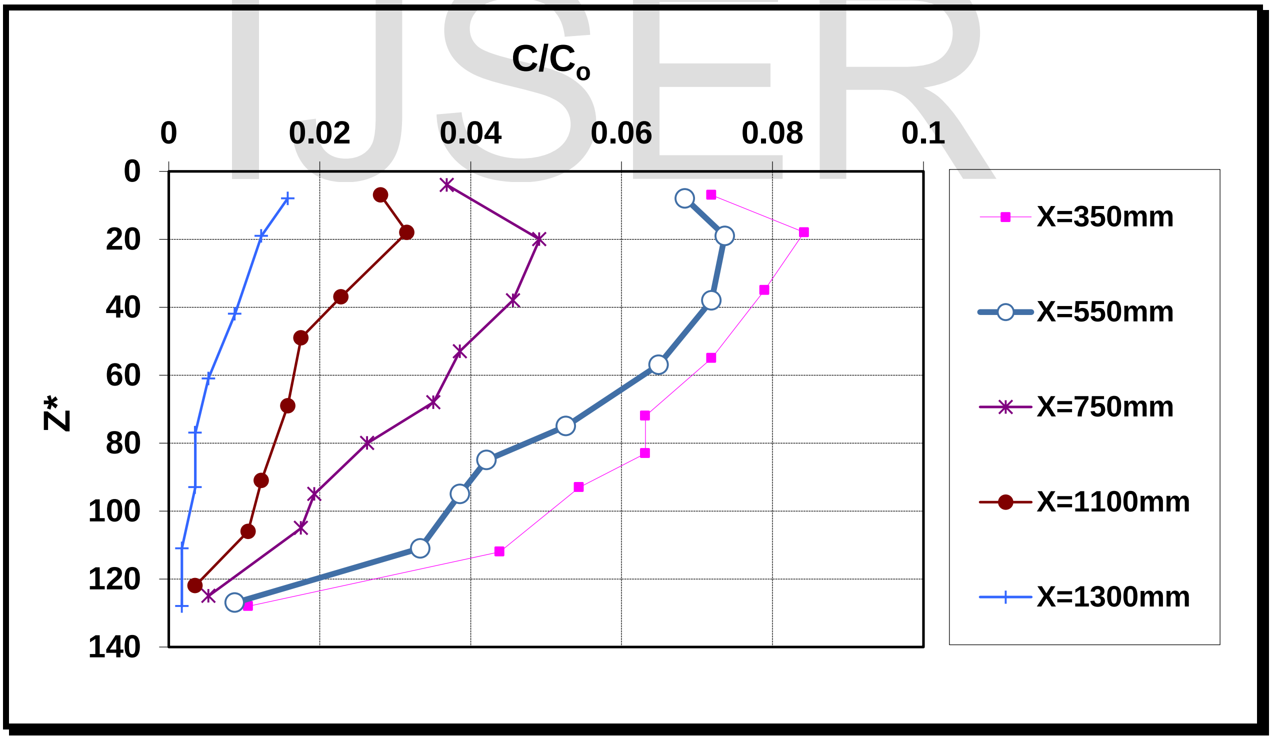

Fig. 8.b: Typical vertical concentration profile at different longitudinal distances, Expt. S10 (α=8, n=2 and S=6d)

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4. Analysis of the Experimental Result

4.1 Minimum dilution

The minimum dilution at any section is defined as the ratio of the concentration at the parts (C_o) in the terms of the maximum concentration at (C_m) that section. The maximum concentration (C_m) represents the maximum concentration at a section referred to the background concentration C_b (if the maximum value at the section measured is C_{max} then C_m is equal to (C_{max}- C_b).Following the work of Hodgson and Rajaratnam (1992) and Moawad (2001 and 2005), the variation of the minimum dilution C_o/C_m with the dimensionless distance□α x/d was studied for all experiments. The measurements covered a range of α x/d from 40 to 2000. According to Moawad (2001) for value of α equal to 5 and 8 at n=3, S=8d where a dilution of 17 and 15 respectively was obtained at a distance α x/d 170 and 200 while in this study at under the same condition for α 5 and 8 where a dilution of 8.4 and 6 respectively at a distance α x/d = 170 and 200.

To study the effect of increasing the spacing between the ports on minimum dilution, the observations from experiments of S1, S2, S3 and S7 are compared with that of S5, S6,S9 and S10 for α= 5,8 and 10.Variation of minimum dilution ($C_o/C_{\mathbf{m}}$) with α x/d showing the effect of changing the spacing (see Fig 4). For S1, S2, S3 and S10 respectively where a dilution of 8.6, 10.5, 13.2 and 27 obtained at a distance α x/d=340, 580, 500 and 1300 respectively. For larger values, the minimum dilution (C_o/C_m) tends to increase to 14.4, 17, 15.2 and 29.2 for (S5, S6, S9 and S10) respectively was obtained at the same distance α x/d respectively.

Figure 5 shows the variation of minimum dilution (C_o/C_m) with α x/d to study the effect of changing the number of ports on minimum dilution, the observations from experiments of S1, S2 are compared with that of S7, S8 for α=8 and 10. For value of α equal to 8 and 10 at n=3, S=8d where a dilution of 15 and 13.5 for S1 and S8 respectively was obtained at a distance α x/d=900 and 1000 respectively. The minimum dilution (C_o/C_m) tends to increase to 19.5, 16.5 for S7 and S2 respectively was obtained at the same distance for α =8 and 10 at n=2, S=8d.

The variation of the minimum dilution with α x/d is affected by α (see Fig 6). The effect of α on the minimum dilution can also be noticed from the experiments in S1 (16) with S3 (21) and S8 (12) at α x/d=900 for α=8,5 and 10 respectively, S2 (8.7) with S7 (11) at α x/d=320 for α=10 and 8 respectively, S4 (19) with S6 (16.7) at α x/d=530 for α=5 and 10 respectively.

4.2 Similarity of Concentration Profiles

The concentration profiles in the center plane were tested for similarity by using the maximum concentration Cm as the concentration scale and b* as the length scale. The length scale b* is defined as the distance where the concentration is half the maximum concentration (C_m) on either side of the jet axis. The outer scale is conventionally considered positive (+b*) and the inner scale negative (-b*). Fig 9 shows the non-dimensional transverse concentration profiles for different values of α for several sections .The measurements covered a range of x from 100 to 1300.All the runs were carried out for shallow conditions. A study of Fig 9, it was found that these distributions are approximately similar and some dispersion of the data along the centerline between the bifurcated jets was also symmetry between the two peaks.

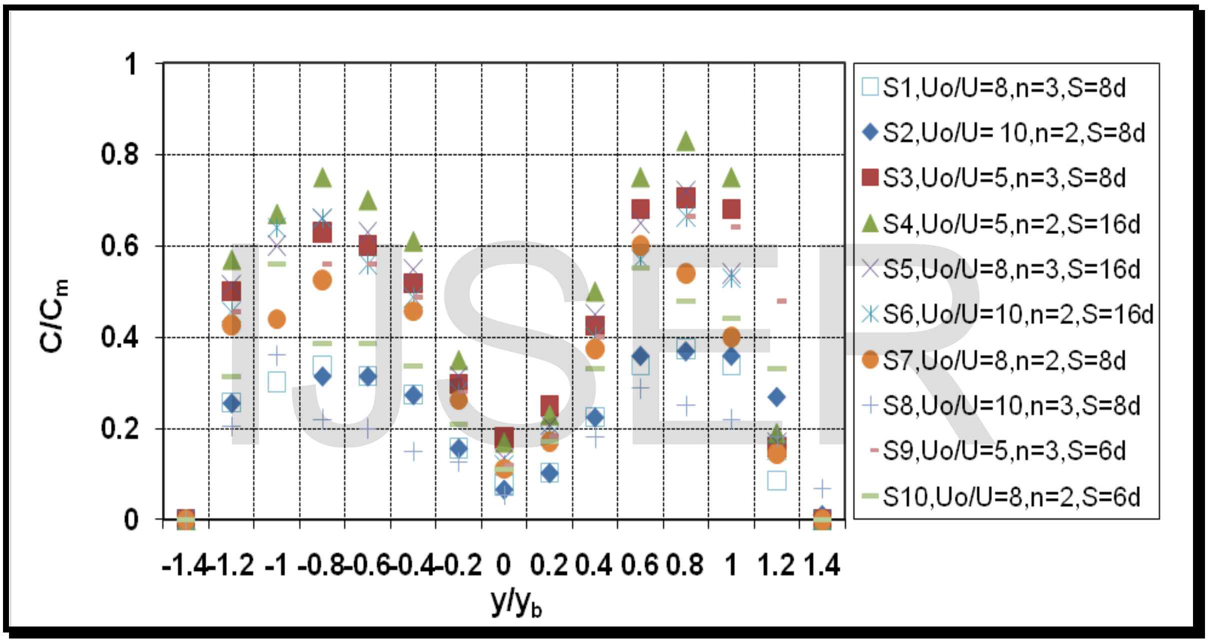

Fig.9: Similarity of transverse concentration profiles for all runs

The vertical concentration profiles were also experienced for similarity by equalizing the concentration with C_m and the distance measured along the η direction by b_z as the concentration was equivalent to one half the maximum concentration $C_{m.}$ Fig 10 show the non-dimensional vertical concentration profiles for all runs**.** It can be seen that the concentration profiles are approximately similar at different sections for different test conditions. It may be noticed that near the water surface, there is some dispersion of the data because of the occurrence of a concentration rising for the experiments near the water surface.

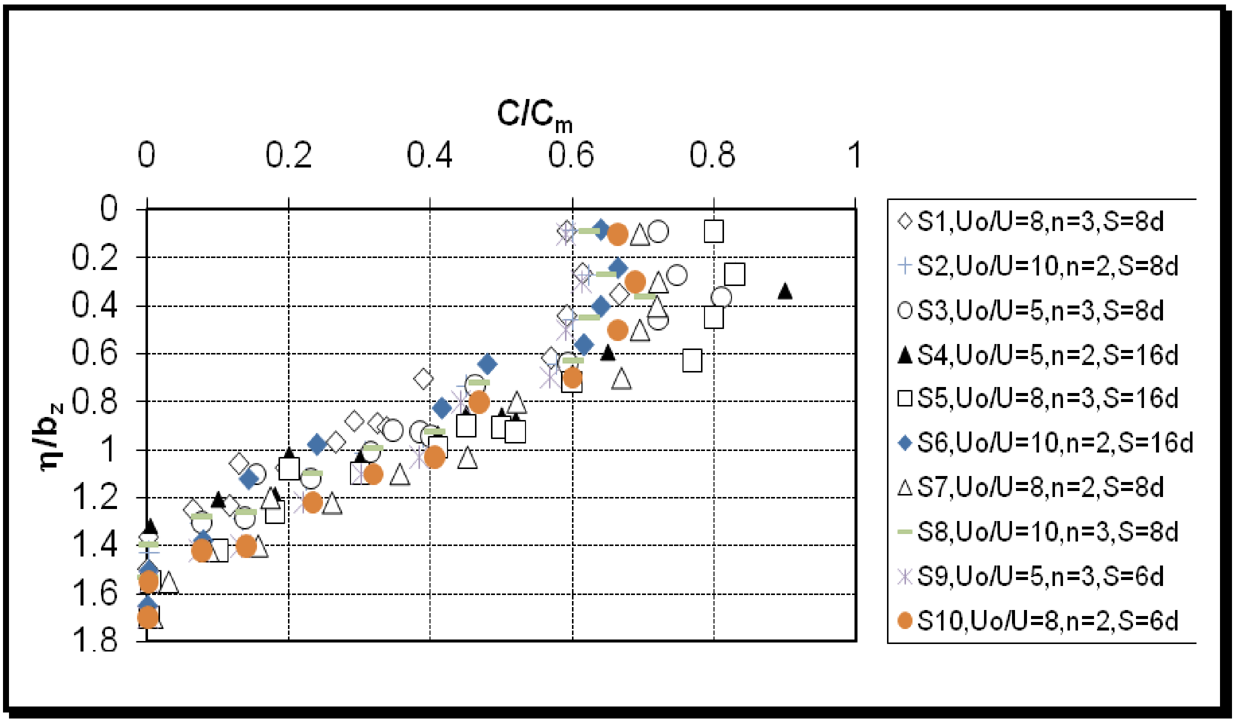

Fig.10: Similarity of vertical concentration profiles for all runs

4.3 Width of jets

The width of the jets Wy is defined as the distance measured along the y axis where the Concentration on either side of the jet centerline is 50% of the maximum concentration. Fig 13 shows the variation of $(W_y - L)/\alpha d$ with $x/\alpha d$ for all runs of shallow water jet experiments. The results of this study were compared with that of Moawad (2001) for multiple deep water jets. At $x/\alpha d = 9$ was $(W_y - L)/\alpha d$ for jets in shallow water was about 4.00 while the value for deep water jets was about 1.8.

4.4 Thickness of jets

The thickness of the jets W_z was determined as the vertical distance from the water surface at which the concentration at any vertical part was one-half the maximum concentration at that part .The growth of the jet thickness W_z in the vertical direction was normalized by αd and the results are plotted against the dimensional distance $x/\alpha d$ in fig 14. Results were compared to the single and multiple jets discharging in cross flows (Hodgson and Rajartnam 1992) and (Mowad 1998). The thickness of jets in deep water was more than that of the shallow water jets.

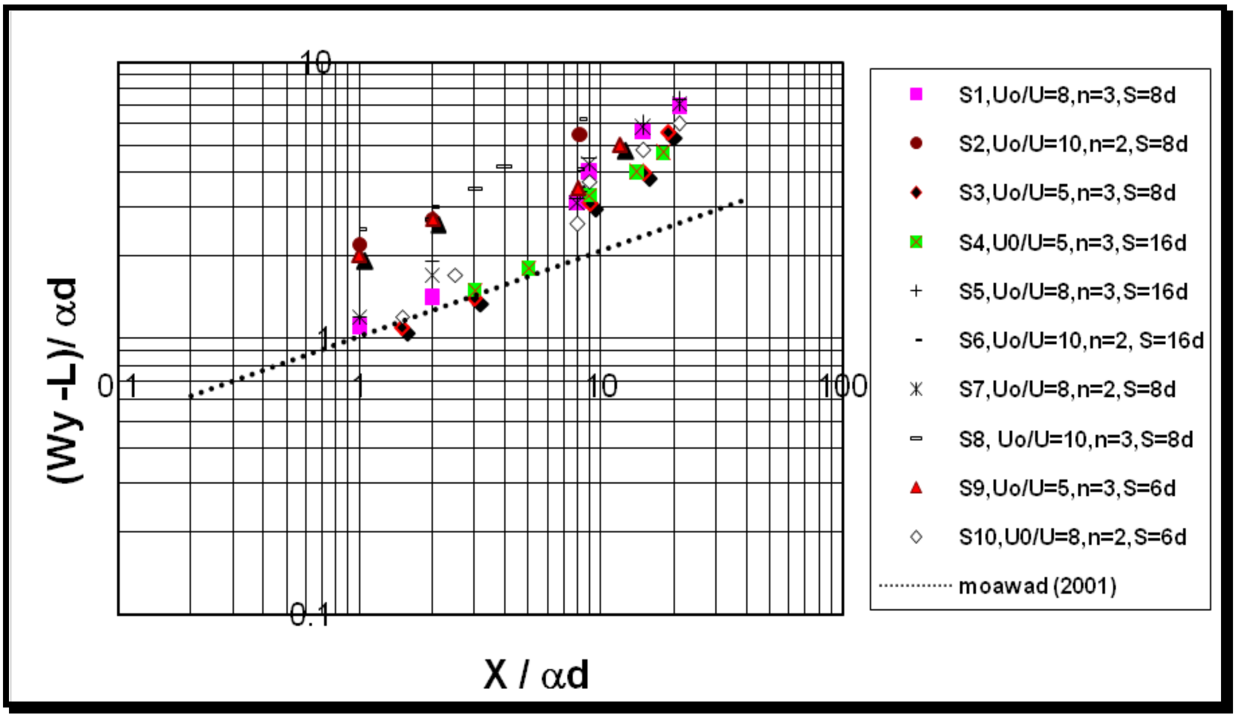

Fig.11: Variation of the growth of the normalized width with x/αd

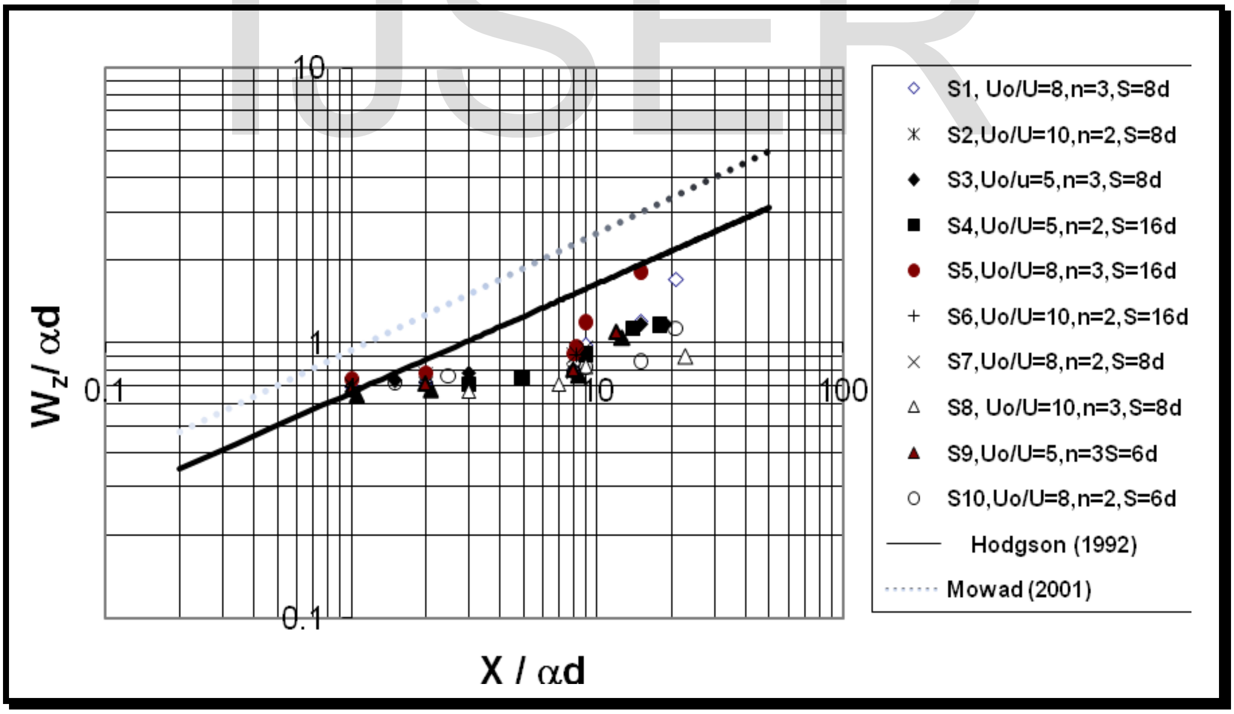

Fig.12: Variation of the growth of the normalized thickness with x/αd

5. Conclusion

From the previous analysis of the obtained results, the conclusions which have been reached are as follow:

- The minimum dilution at any section is the ratio of the concentration at the ports (C_o) in the terms of the maximum concentration at that section (C_m).
- From experimental results the minimum dilution for multiple shallow water jets were less than single shallow and deep water jets for single and multiple.
- Shallow water jets tend to surface and get separated to two distinct concentration peaks (bifurcation).
- The maximum concentration exists near the water surface, after occurs the bifurcation.
- The minimum dilution decreases with the increase in the number of ports (n) and the increase of the velocity ratio (α).
- An increase of the spacing between the ports (S) will cause an increase in the minimum dilution.
- The width of jets for the case of shallow multiple jets was more than that of the single jet for deep case.
- The thickness of jets in shallow water was less than that of the deep water jets.
- Finally, the results of this study show the growth of the width and thickness, also expressions are believed useful in the design of out falls in rivers.

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APPENDIX NOTATION

The following symbols are used in this paper:

C = concentration at any point in jet;

C_m = maximum concentration at section;

C_o= initial concentration at nozzle;

D = depth of flow;

d = jet diameter;

n = number of ports;

R = Reynolds number of the jet;

S = spacing between ports;

U = crossflow velocity;

U_o = velocity at the jet nozzle;

W_z = jet thickness;

W_y = jet width;

b_z= length scale for concentration profile;

x = longitudinal distance downstream from the jet nozzle;

z = vertical distance measured from the bed;

y = distance along the diffuser;

α = ratio of jet velocity to ambient crossflow velocity (U_0/U);

η= distance measured normal to ζ;

ν = kinematic viscosity of fluid; and

ζ = distance along axis of deflected jet.