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# Effect of Aspect Ratio, Friction Term and Ratio of Curvature to Hydraulic Radius on Dispersion Coefficient of Rivers

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**ABSTRACT :** Dispersion coefficient,  $D$ , measures the dispersive ability of flowing water bodies and is a primary quantity in water quality management and design of treatment units. It can be determined through equations derived from the geometric and hydraulic parameters of the flow regime. There are controversies about how some of these parameters namely, aspect ratio ( $B/H$ ) and friction factor  $U/U^*$  relate to  $D$ . This study is aimed at resolving this issue and to determine the effect of a new parameter,  $(R_C/R_H)$ , on dispersion. Tracer experiments were performed in six meandering channels and two straight cases and the resulting dispersion coefficient values regressed against  $B/H$ ,  $U/U^*$  and  $(R_C/R_H)$ . Result showed that all three parameters have strong relationship to  $D$  in meandering channels, but poorly related to it in straight cases. The higher the  $B/H$ , the less its effect on dispersion and the more the tendency to plug flow. As  $U/U^*$  increased, dispersion increased,  $U/U^*$  has slightly larger effect on dispersion than  $B/H$ . As  $R_C/R_H$  increased,  $D$  decreased. It is concluded that all three parameters increase the precision and accuracy of dispersion coefficient models contrary to report by some researchers. Accurate determination of  $D$  will improve water resources management and pollution control.

**KEYWORDS:** Aspect ratio, controversy, dispersion coefficient, friction term, accuracy, hydraulic radius, river channel.

## I. INTRODUCTION

Pollution of water courses is a serious environmental problem the solution of which requires good knowledge of the dispersive characteristics of the water body. Dispersion coefficient ( $D$ ) is an important parameter by which the dispersive capacity of such regimes may be measured. It is usually determined by tracer studies which are expensive and time consuming, hence many equations have been formulated for  $D$  to lower cost and time and to improve its accuracy. Two factors that have consistently appeared in many of those equations are aspect ratio,  $\left(\frac{W}{H}\right)$ , and friction term,  $\left(\frac{U}{U^*}\right)$  (Deng et al. [1]; Seo and Cheong, [2]; Sahay and Dutta, [3]; Amir and Milad, [4]; Wang and Huai, [5]; Sahay, [6]; Li et al. [7]). Yet, there are differences in research findings on how these factors affect dispersion (Ahmad, [8]; Nooriet al. [9]; Tayfur and Singh, [10]; Sahay and Dutta, [3]; Memarzadey, [11]; Iwasa and Aya, [12]; Kousis and Rodriguez-Mirasol, [13]; Etemad-Shahidi and Taghipour, [14]). With these arguments, accuracy of  $D$  is challenged and needs to be settled. Their effects can be measured by how they closely relate to and practically affect dispersion coefficient measurement in tracer studies. To achieve this, tracer experiments were performed in six channels and  $D$  calculated and regressed against the affected parameters. A new ratio, radius of curvature-to-hydraulic radius is also introduced and its effect determined in same manner.

The coefficient of dispersion is important in the design of wastewater treatment units such as waste stabilization ponds, design of intake works and spill modeling. Its accuracy will improve surface water quality and pollution control. Dispersion coefficient remains the major means of defining pollutant transport in rivers and streams (Goliatt et al. [15];Farzadkhoo et al. [16]) confirmed that accurate determination of D is essential to the engineer.

## II. LITERATURE REVIEW

Flowing rivers and streams have the characteristic of spreading out in the streamline direction, diluting a mass of pollutants introduced into them. This characteristic of the water body is called longitudinal dispersion and is measured by the parameter called dispersion coefficient (Goliatt et al, [15]). Longitudinal dispersion coefficient is the most significant parameter in water quality monitoring (Ukpaka et al. [17]; Ghaemi, [18]) and vital for strategic development of environmental systems for rivers (Gholami et al. [19]).

Of the three stages involved in the transport of pollutants in a flowing stream, longitudinal dispersion is the most dominant mechanism. Once the cross-sectional mixing (preceded by vertical mixing) is established, longitudinal dispersion sets in, erasing all longitudinal concentration gradients (Rutherford [24]). At this point the one-dimensional dispersion equation is applicable. In natural water bodies such as rivers, the main cause of longitudinal dispersion is the large width-to-depth ratio,  $\left(\frac{W}{H}\right)$  (Fischer, [21]). Fischer found that in such natural waters, longitudinal dispersion is the effect of depth averaged velocity gradient in the transverse direction because of the large width-to-depth ratio. The longitudinal dispersion caused by velocity gradient in the depth (ie vertical direction) can be neglected because it is short-lived compared to that caused by velocity gradient in the lateral direction. Thus velocity gradient in the width-wise direction is the major factor that causes longitudinal dispersion.

Fundamentally, there are dispersion side-wise, vertically and longitudinally, the predominant one being the longitudinal dispersion in the stream-wise direction. The reason is that while the vertical dispersion is small and short-lived, there is practically zero concentration gradient in the side-wise direction after complete mixing. This means that of the three directional dispersion coefficients,  $(D_x, D_y \text{ and } D_z)$  only  $D_x$  is important.  $D_y$  (in the vertical direction) is caused by the effect of initial momentum and buoyancy near the pollutant point of introduction terminating with full mixing in the vertical. The dispersion here is often neglected because of its very short duration. Dispersion in the lateral direction ( $D_z$ ) consisting of turbulent spreading through the cross-section, slowly evolves into the final longitudinal dispersion phase,  $D_x$ , which is then achieved when the tracer particles have sampled the entire transverse velocity distribution. The third stage of dispersion is the time when Taylor's (1954) asymptotic theory can provide coherent interpretation of the dispersion phenomenon (Panone, [20]).

Meanders influence longitudinal dispersion in two ways (i) concentration of high velocities on the outside of the river bends results in increased dispersion.(ii) River bends induce secondary currents which enhance transverse mixing. This implies that pollutant concentration is more uniform across the channel, thus reducing longitudinal dispersion (Deng et al, [1]).

Longitudinal dispersion coefficient (D) of a river depends on the geometry of the channel, velocity distribution, rate of transverse mixing and a dimensionless parameter that include the mean velocity and length of an average bend (Fisher [21]). A reliable estimation of longitudinal dispersion coefficient in natural streams is required for acceptable estimation of the rate of pollutant decay in natural streams.

Non-uniformity of vertical velocity profile and the presence of other non-uniformities such as dead zones, depth fluctuations, meanders etc, result in longitudinal dispersion dominance over other transport phenomena and pollutant mixing associated with channel flow. The non-uniform velocities (shear velocities) will cause a patch of tracer to advect downstream and get stretched due to the different advection velocities in the shear profile. The figure below shows the progressive effect.

Longitudinal dispersion coefficient is inversely proportional to transverse diffusivity transverse mixing coefficients. For meandering channels, there is strong longitudinal dispersion at the entrance of the bend which diminishes and beyond the apex if the meander. The combined effects of primary velocity gradients and secondary current produce significant effects on longitudinal dispersion within a meander length. Results show that longitudinal dispersion is significantly larger in the reach between a cross-over and an apex than in the reach between an apex a cross-over (Marion, and Zaramella, [22]).

Most of the equations that contain aspect ratio and friction factor were derived through regression analysis. Sahay and Dutta [6] applied genetic algorithm to 65 data sets and proposed,

$$\frac{D}{HU_*} = 2 \left(\frac{W}{H}\right)^{0.96} \left(\frac{U}{U_*}\right)^{1.25} \quad (1)$$

Where D is dispersion coefficient (m<sup>2</sup>/s) u and u<sub>\*</sub> are mean flow and shear velocities respectively in m/s, w is width of channel(m), H is channel depth of flow(m)

They stated that the most effective parameter for accurate prediction of the longitudinal dispersion coefficient is the  $\left(\frac{U}{U_*}\right)$  term (2)

Other dispersion coefficient models that contain aspect ratio and friction terms include Seo and Cheong [2] who used dimensional and regression analysis to derive

$$D = 5.915 \left(\frac{W}{H}\right)^{0.62} \left(\frac{U}{U_*}\right)^{1.428} (HU_*) \quad (3)$$

Deng et al. [1] considered transverse mixing coefficient in the derivation of their model for longitudinal dispersion coefficient and predicted,

$$\frac{K}{HU_*} = \frac{0.15}{8\epsilon_{ro}} \left(\frac{B}{H}\right)^{5/3} \left(\frac{U}{U_*}\right)^2 \quad (4)$$

$$\epsilon_{ro} = 0.45 + \frac{1}{3520} \left(\frac{U}{U_*}\right) \left(\frac{W}{H}\right)^{1.38} \quad (5)$$

$\epsilon_{ro}$  = Transverse mixing coefficient

Kashefipour and Falconer [23] used 81 data sets and by application of regression and dimensional analysis developed the following equation.

$$D = 10.612HU \left(\frac{U}{U_*}\right) \quad (6)$$

By combining their equation and that of Seo and Cheng and by trial and error, they obtained the following equation

$$D \left[ 7.428 + 1.775 \left(\frac{W}{H}\right) 0.62 \left(\frac{U}{U_*}\right) 0.572 \right] HU \left(\frac{U}{U_*}\right) \quad (7)$$

Amir and Milad [4] used MS model tree to derive equation for dispersion coefficient which they claim out performs other existing formulae. For a width to depth ratio less or equal to 30.6, they obtained

$$\left(\frac{KS}{HU_*}\right) = 2.75 \left(\frac{W}{H}\right)^{0.78} \left(\frac{U}{U_*}\right)^{0.11} (\sigma)^{04.04} \quad (8)$$

For width /depth greater than 30.60

$$\left(\frac{K}{HU_*}\right) = 8.6 \left(\frac{W}{H}\right)^{0.61} \left(\frac{U}{U_*}\right)^{0.85} (\sigma)^{1.78} \quad (9)$$

### 2.1: Width-to-depth ratio

The ratio of the width of the channel measured perpendicular to the direction of flow, to the flow depth is called aspect ratio (B/H). Generally, the geometry of the channel (i.e length, width and depth) affects its dispersion capacity.

Deng et al, [1] report that the main cause of longitudinal dispersion in natural rivers is the large width-to-depth ratio. Longitudinal dispersion coefficient changes even in the same stream as the flow depth or water level changes.

Fischer [21] showed that for a more natural cross-sectional geometry channel, D increases. Channel shape factor may be evaluated by  $\ln\left(\frac{B}{H}\right)$  Deng et al. [1]

A general form of dispersion coefficient equation as presented by several researchers is

$$D = \theta \left(\frac{U}{U_*}\right) \left(\frac{W}{H}\right) \quad (10)$$

Deng et al, [1] suggested that the impact of irregular variation on width-to-depth ratio on longitudinal dispersion coefficient increased its value by ten or more times. The term  $\left(\frac{B}{H}\right)$  should affect the longitudinal dispersion because

D is a result of the transverse difference of longitudinal velocity. Dispersion coefficient generally varies as width, depth, flow shear velocity and other geometric and hydraulic irregularities change. Zeng and Huai [23] suggested that equations containing B/H underestimates D when  $20 < B/H < 100$ .

Large width-depth ratio as experienced in natural rivers results in vertically well mixed pollutant injection at the near-field region long before it becomes transversely well mixed. Since this occurs in the short-lived region, vertical mixing resulting from rivers is usually ignored.

Rutherford [24] stated that transverse mixing coefficient is not influenced by channel aspect ratio because the overall trend of the data is horizontal. Aspect ratio may be used to classify rivers as wide and shallow on one hand and as deep and narrow on the other hand.

Linearising equation (4) yields

$$\log \frac{K}{HU_*} = \log a + b \log \left(\frac{W}{H}\right) + c \log \left(\frac{U}{U_*}\right) \quad (11)$$

It does appear from the above equations that  $\left(\frac{K}{HU_*}\right)$  would have a good correlation with both  $\frac{W}{H}$  and  $\frac{U}{U_*}$

Deng et al. [1] introduced shape factor as  $\ln\left(\frac{W}{H}\right) = \beta$  and Etemid-Shahidi et al. [14] referred to  $\beta$  as corresponding to  $\log\left(\frac{W}{H}\right)$ . It is thus safe to infer that a relationship exists between  $\beta$  and  $\frac{W}{H}$ . Deng et al. [1] defined narrow and deep channel as that with  $\frac{W}{H} \leq 30$ ,

And Wide and shallow as that with  $\frac{W}{H} \geq 30$

Transverse dispersion coefficient increases as aspect ratio increases.

### 2.2: Ratio of curvature to hydraulic radius

Curvature is the single most important factor that affects flow in meandering channels as it is the source of the helical motion that controls transversal mixing which in turn reduces longitudinal dispersion. High value of hydraulic radius

implies a reduction in effect of radius of curvature according to equation 11. A reduction in the effect of curvature will reduce transverse mixing and increase longitudinal dispersion. In water treatment reactors, when the objective is to enhance longitudinal dispersion rather than mixing, the ratio of radius of curvature to hydraulic radius should be optimized.

### 2.3: Friction factor $\left(\frac{u}{u_*}\right)$

The friction term ( $u/u_*$ ) can sometimes represent the effect sinuosity, shape factor, slope to the horizontal and channel roughness (Seo and Cheong, [2]). While larger aspect ratio and corresponding increase in the lateral velocity increased the rate of longitudinal mixing, larger variations in cross-sectional velocities can make the friction term the dominant factor on the rate of longitudinal mixing in large rivers.

The friction term evaluates the effect of roughness on dispersion. Pirsaraee and Tokaldany [25] report that diffusion coefficient increases with increasing friction factor but that there is no specific relation between diffusion and aspect ratio (B/H). Increasing roughness of channel boundaries provides additional flow turbulence, which in turn results in reducing perfect mixing length of pollutants.

## III. MATERIALS AND METHODS

### Study area

The study location is the engineering campus of Kenule Beeson Saro-wiwa Polytechnic, Bori. Bori is a town located in Khana local government area of Rivers State in southern Nigeria at latitude of  $4^{\circ}40'34.64''N$  and longitude  $7^{\circ} 21'54.68''E$

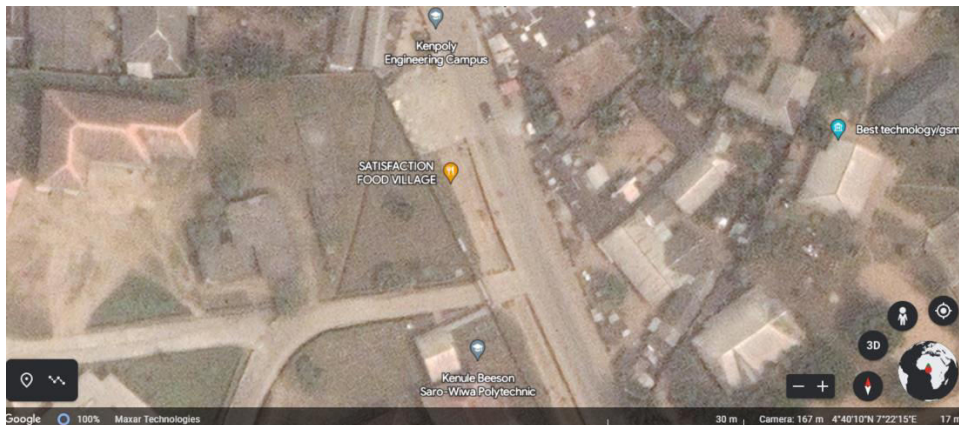


Figure 1. Google Map of Study Area

The materials used in carrying out this research include out-door channels constructed with sandcrete blocks, sodium chloride as tracer, current meter, steel tape, borehole, and chemistry laboratory.

### Experimental Setup

Equipment and material used include eight out-door channels each 15.0m long, 0.4m wide and 0.3m deep; a weighing balance; sodium chloride and a current meter. Six of the channels were S-shaped and two were kept straight. Salt weighing 400 grams was measured out and dissolved in 200 ml of water. The solution was introduced at the inlet of the channel with water flowing at a determined velocity. Samples were collected at outlet at varying times representing the theoretical detention time of the channel. This is the constant distance, variable time method. The experiment was repeated ten times for channel with bends and seven times for straight cases, at different velocities.

In determining the chloride concentration of tracer, samples collected were titrated against silver nitrate solution with potassium chromate as indicator according to standard methods. The predicted values of dispersion coefficient were calculated using Levenspiel and Smith [26] method and regressed against  $\left(\frac{U}{U_*}\right)$ ,  $\left(\frac{W}{H}\right)$  and  $\left(\frac{R_c}{R_H}\right)$  to obtain the correlation coefficients.

The channels were models of the Kaani river stretch from Yeghe in Gokana local council (4°39'35"N 7°16'57"E to Wiyaaakare in Khana local council (4°42'N 7°21'E) all in the Nigeria's south-south state of Rivers. The river has some bends along the stretch that are difficult to measure. The velocities, and hence water depth, were varied arbitrarily for the purpose of this study. The study area experiences frequent rains between March and late September causing frequent variations in velocity. The sand mining activities upstream also fluctuates velocity. The data obtained in these experiments can therefore compare favorably with those of natural streams of similar features.

Radius of curvature was determined from the design drawings of the channels. For ease of calculation, hydraulic radius was determined by considering the channel as having a rectangular section of perimeter

$$P = (W + 2H), \text{ Area, } A = WH \text{ and Hydraulic radius, } R_H = A/(W+2H)$$

W and H are width and depth of channel respectively.

#### IV. RESULTS AND DISCUSSION

The tables in appendix show generated field data for dispersion coefficient, flow velocity, width and flow depth of channel, calculated shear velocity, radius of curvature and the resulting aspect ratio, ratio of radius-hydraulic radius and friction factor. The plots in figures 1a to 3f were made from these tables. The table show how aspect ratio, friction term and ratio of radius-of-curvature-to-hydraulic radius practically affect dispersion.

##### 4.1: Effect of Aspect Ratio on dispersion coefficient

The range of coefficient of correlation(R) between aspect ratio and dispersion coefficient in the meandering channels is between 0.8963 and 0.7673 and the value of B/H is between 2.94 and 22.73. Deep and narrow channels have  $B/H \leq 30$  while shallow and wide channels have  $B/H \geq 30$  (Deng et al [1]). Therefore the channels in this study are classified as deep and narrow. The value of R for channel of 2 meanders is 0.8963 with B/H value range between 2.44 and 7.14 while for the channel of 7 meanders R is 0.7673 and B/H value was between 4.3 and 22.73. This implies that the higher the B/H value, the less the effect of it on dispersion. Therefore, for wide and shallow channels, the effect of B/H will be less or insignificant, such that high values of B/H would most likely result in secondary current that reduces longitudinal dispersion. The implication of this is that high aspect ratio indicates tendency to plug flow and reduction in longitudinal dispersion. Therefore for deep and narrow channels, effect of B/H will be high while it will be low for wide and shallow channels. Most equations have underestimated dispersion coefficient when  $20 < B/H < 100$  (Zeng and Huai [23]).

It is expected that maximum velocity will occur at the free surface of the channel regardless of radius of curvature at high value of B/H while velocity variation at low B/H occurs because of the walls. Increase in B/H causes a decrease in effect of secondary current because the effect of banks (side walls) decreases as the channel widens. For this reason dispersion coefficient becomes smaller as well. The plots in fig 4.23a – 4.13g show that aspect ratio is in inverse proportion to dispersion coefficient.

Table 4.5 shows that aspect ratio has slightly less effect on dispersion than the friction term. This contradicts the findings of Ahmad [8] and Noori et al. [9] who reported a higher effect than the friction term. Infact, Tayfur and Singh [10] did not see the need for inclusion of the term in dispersion coefficient equations. However, the results of table 4.5 is in agreement with the report of Sahay and Dutta [6] who reported higher influence of friction term. This work thus confirms higher



impact of friction term on dispersion than aspect ratio. Less impact of B/H is observed in straight channels as seen in table 4.15 where R is less than 0.5 compared to the meandering ones.

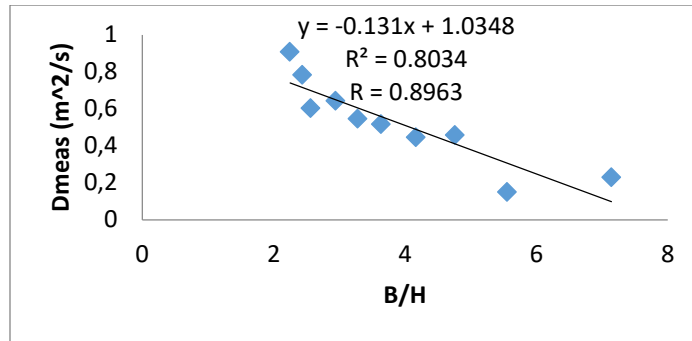


Fig 1a: Graph of D against B/H

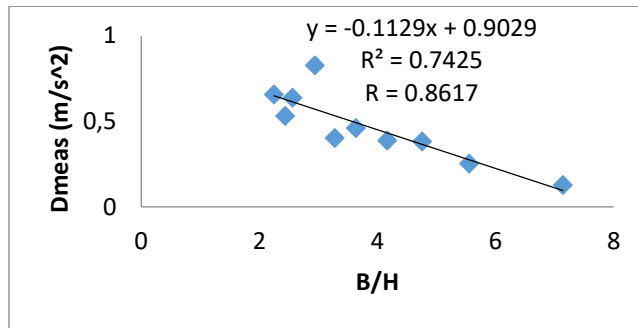


Fig 1b Graph of D against B/H

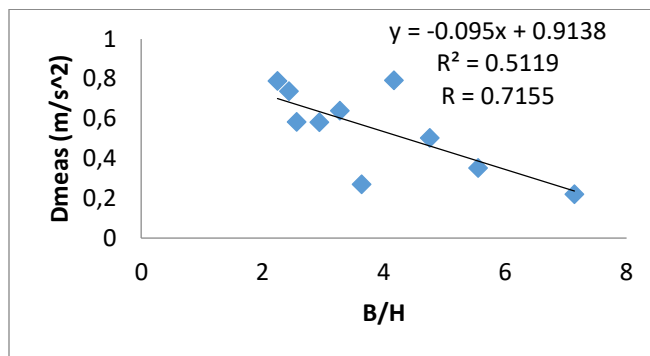


Fig 1c Graph of D against B/H



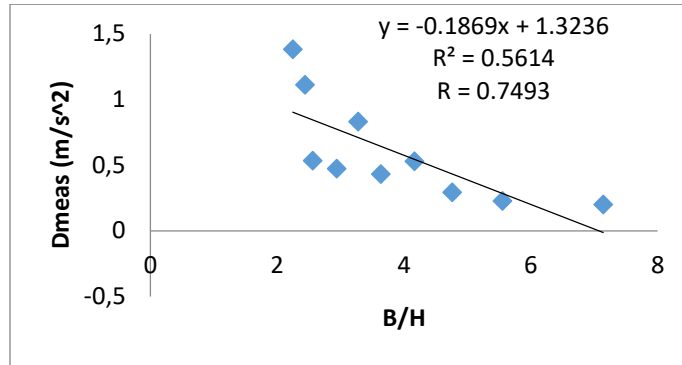


Fig 1d Graph of  $D_M$  against  $B/H$

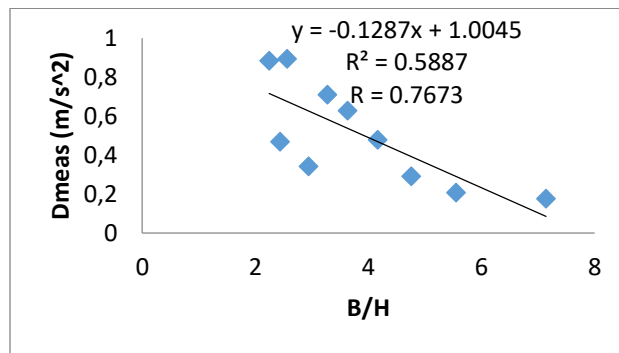


Fig 1e Graph of  $D$  against  $B/H$

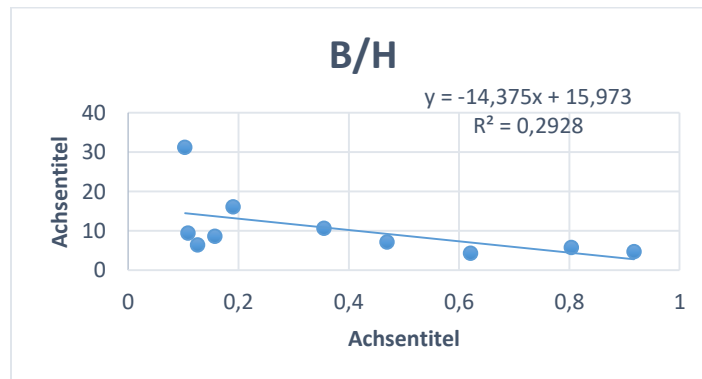


Fig 1f

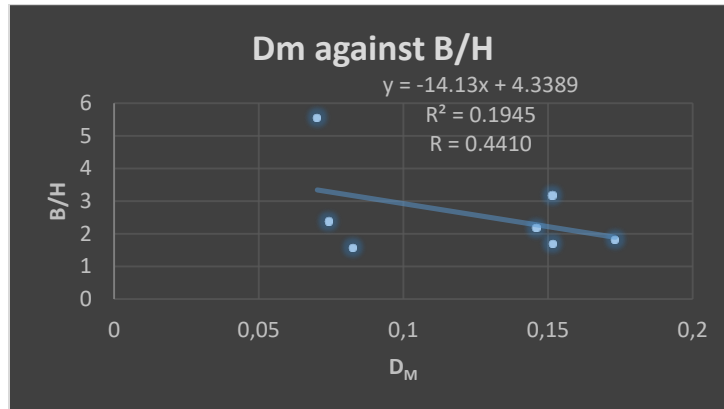


Fig. 1g: D against B/H S1

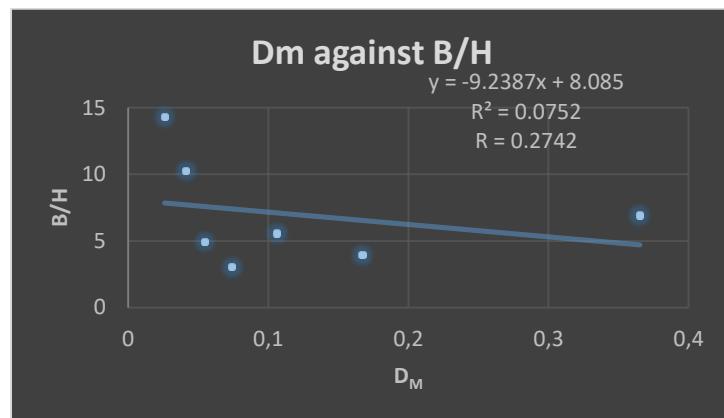


Fig. 1h: D against B/H S2

#### 4.2: Effect of friction factor ( $U/U_*$ ) on dispersion

The R values of between 0.95 and 0.75 for the regression between measured dispersion  $D_M$ , against  $U/U_*$  shows very good relationship between both parameters. This is in contrast to Memarzadeh [11] who reported that there is no effect of the friction term on longitudinal mixing in small rivers. Iwasa and Aya [12] and Kousis and Rodriguez-Mirasol [13] reported no effect of friction term on longitudinal mixing for both small and large rivers. However the results in this work agrees with the findings of Sahay and Dutta [6] who reported larger influence of  $U/U_*$  in small rivers. It also agrees in part with the report of Etemad-Shahidi and Taghipour [14] who reported a relationship between the terms for large rivers only. This work confirms that for both small and large rivers, friction term has significant influence on the accuracy of dispersion coefficient in meandering channels. However, the R values 0.35 and 0.0007 for straight channels is so insignificant that it can be affirmed that for straight rivers  $U/U_*$  and dispersion are poorly related and effect may be insignificant. This supports the reports of Fischer, Yotsukura and Sayre as reported by Rutherford, [24] who developed equations that suggest that there is no transverse dispersion in straight rivers. As insignificant as the effect of  $U/U_*$  may be on straight channels, it is still important to note that transverse dispersion exists in both types of channel, but that it is far more prominent in the meandering case. This study has shown that there is some secondary current and hence transverse dispersion in straight open channel flow.

From table 4.5, it is observed that  $U/U^*$  has the larger effect on dispersion than  $B/H$ . Again, this is in contrast to the reports of Noori et al. [9] who reported greater influence of aspect ratio. However, our findings agree with those of [9], who reported larger effect of friction term for large rivers. The channels used in this work can be classified as small because the aspect ratio is less than 30. It then follows that for both small and large rivers, friction factor influences dispersion significantly and has more effect than aspect ratio.

Less impact of  $U/U^*$  is observed in straight channels as seen in table 4.15 where  $R$  is less than 0.4 compared to the meandering cases. The obvious reason for this hinges on the fact that in meandering channels mixing is much higher than in straight channels because of the spiral motion created at the bends by centrifugal forces. Friction term also has less effect on dispersion than aspect ratio in straight channels.

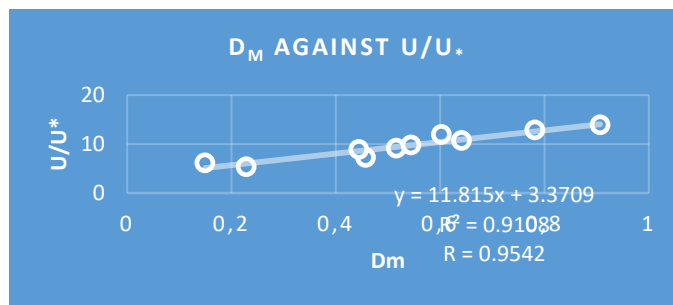


Fig. 2a:  $D_M$  against  $U/U^*$  for channel of 2 meanders

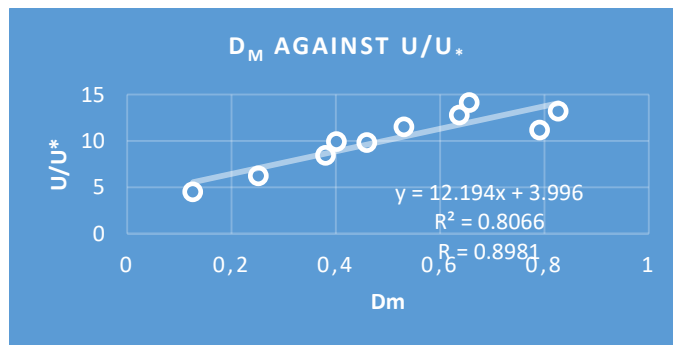


Fig. 2b:  $D_M$  against  $U/U^*$  for channel of 3 meanders

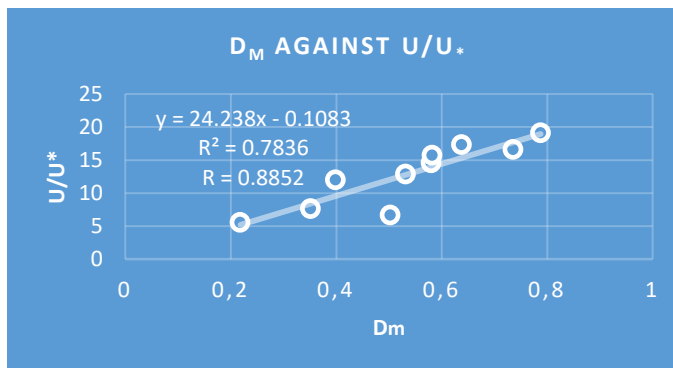


Fig.2c:  $D_M$  against  $U/U^*$  for channel of 4 meanders

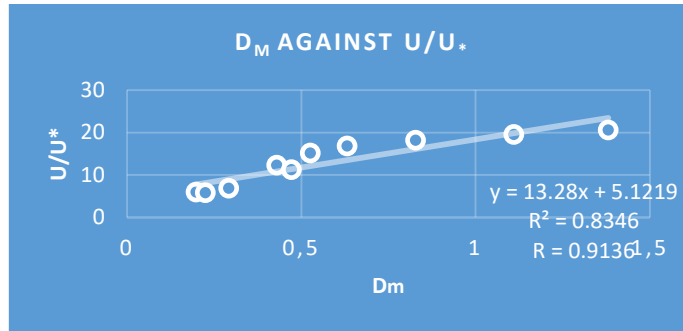


Fig. 2d: D<sub>M</sub> against U/U\* for channel of 5 meanders

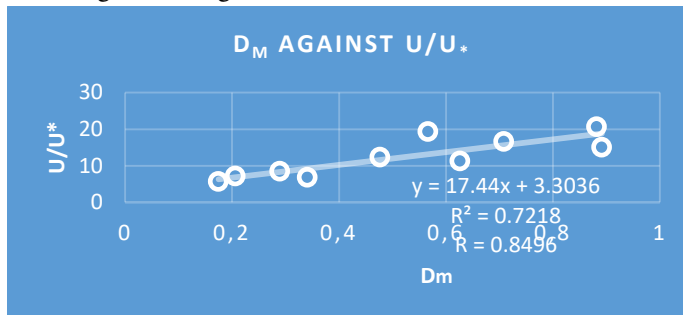


Fig. 2e: D<sub>M</sub> against U/U\* for channel of 6 meander

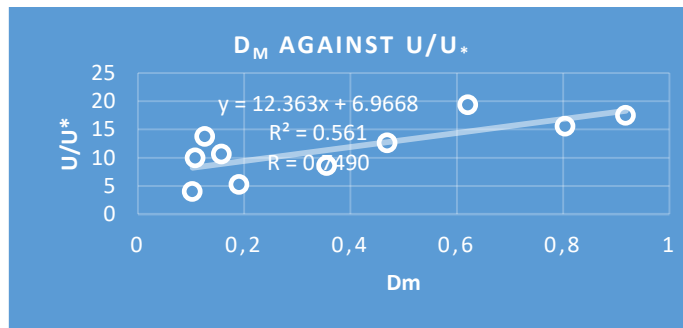


Fig. 2f: D<sub>M</sub> against U/U\* channel of 7 meanders

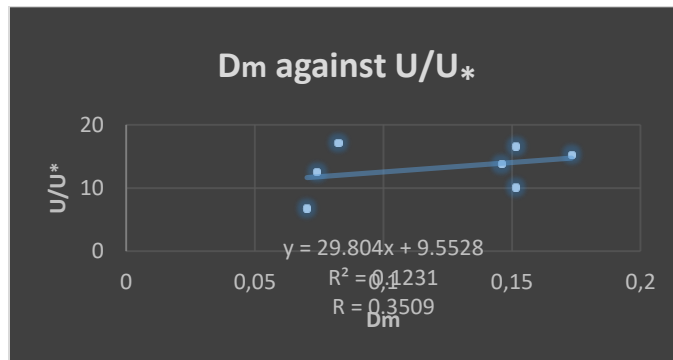


Fig. 2i: D<sub>m</sub> against U/U\* for straight channel 1

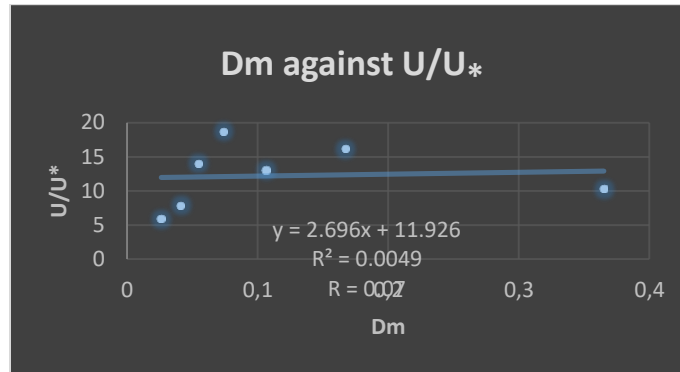


Fig. 2j: D against U/U\* for straight channel 2

**4.3: Effect of Ratio of Radius of Curvature to Hydraulic Radius on Dispersion**

Figures 3a – 3f show coefficient of correlation between  $R_c/R_h$  and  $D_L$  to be between 0.882 to 0.7721, implying good relationship. This puts it on the same pedestal of effect as aspect ratio and friction factor. The plots show that the relationship is in the inverse. This means that as  $R_c/R_H$  increases,  $D_L$  decreases as is evident in table 1. Hydraulic radius directly affects uniformity of flow, therefore it is expected that it will affect dispersion processes. Wide and shallow channels have larger wetted perimeter (implying more friction) and hence lower longitudinal velocity and higher lateral velocity. Narrow and deep channels have smaller wetted perimeter (implying less friction) and faster flow and hence improved dispersion. The higher the hydraulic radius the lower the amount of water in contact with the floor and the walls of the channel and hence the less the effect of friction, thus increasing flow and dispersion because of increase in velocity.

Table 1 shows that on the average the ratio of radius of curvature to hydraulic radius is on the average, better related with dispersion coefficient than aspect ratio. In this research, hydraulic radius is used in place of bed shape factor because it provides a measure of bed shape as it does in its use in Manning’s equation.

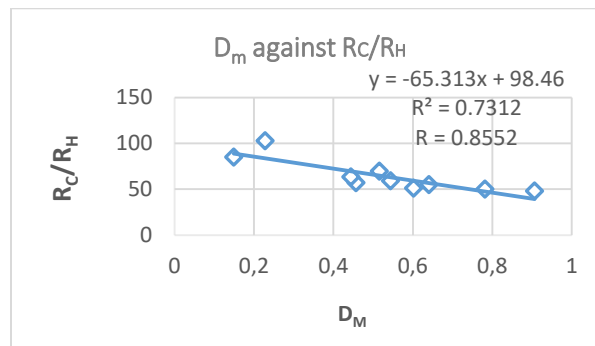


Fig.3a:  $D_M$  against  $R_c/R_H$  for 2 meanders

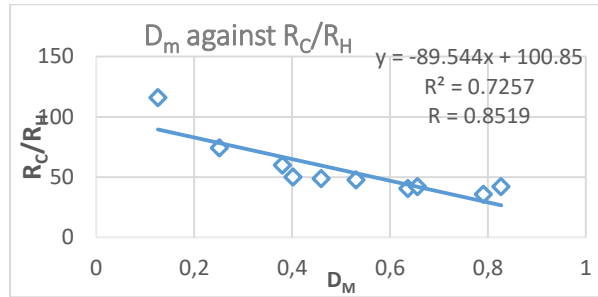


Fig. 3b:  $D_M$  against  $R_C/R_H$  for 3 meanders

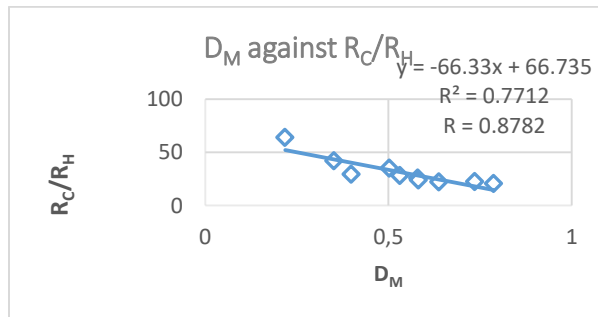


Fig 3c:  $D_M$  against  $R_C/R_H$  for 4 meanders

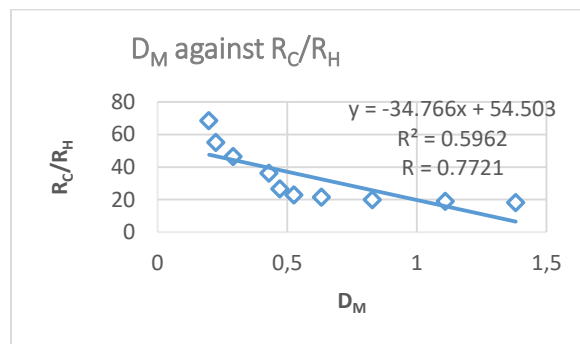


Fig. 3d:  $D_M$  against  $R_C/R_H$  for 5 meanders

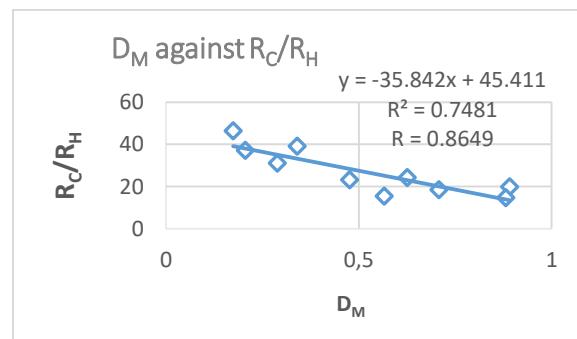


Fig.3e:  $D_m$  against  $R_C/R_H$  for 6 meanders

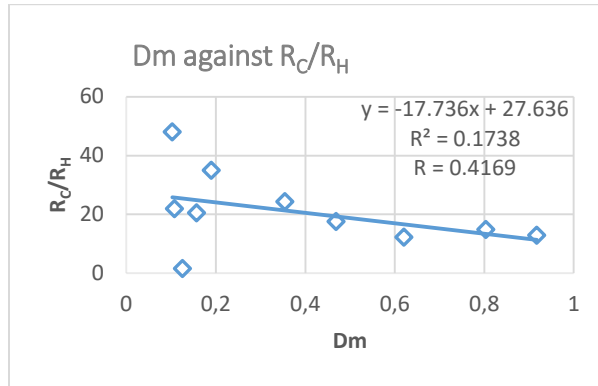


Fig 3f:  $D_M$  against  $R_C/R_H$  for channel of 7 meanders

**Table 1: Coefficient of correlation between  $D$  and  $U/U_*$ ,  $R_C/R_H$  and  $B/H$ ,**

Num. of meanders	$\frac{U}{U_*}$	$\frac{R_C}{R_H}$	$\frac{B}{H}$
2	0.9542	0.8552	0.8963
3	0.8981	0.8519	0.8617
4	0.8852	0.8782	0.7155
5	0.9136	0.7721	0.7493
6	0.8496	0.8648	0.7673
7	0.7400	0.4169	0.2928
S1	<b>0.3509</b>		<b>0.4410</b>
S2	<b>0.0007</b>		<b>0.2742</b>

## V. CONCLUSION

Dispersion coefficient is an indicator of the dispersive characteristics of a water body. Tracer experiments on out-door channels show that it is affected by aspect ratio, friction factor and ratio of radius of curvature to hydraulic radius. The range of coefficient of correlation ( $R$ ) between aspect ratio and dispersion coefficient in the meandering channels used for this study is between 0.8963 and 0.7673 and the value of  $B/H$  is between 2.94 and 22.73. The higher the  $B/H$  value, the less the effect of it on dispersion. For wide and shallow channels, the effect of  $B/H$  will be less or even insignificant.  $B/H$  significantly affects dispersion as high aspect ratio tends towards plug flow. This contradicts Tayfur and Singh [10] who did not see the need for inclusion of the term in dispersion coefficient equations. However, aspect ratio has somewhat insignificant effect on dispersion in straight channels.

The  $R$  values of between 0.95 and 0.75 for the regression between dispersion coefficient,  $D_M$ , against  $U/U_*$  shows good relationship between them. This is in contrast to Memarzadeh [11] who reported that there is no effect of the friction term on longitudinal mixing in small rivers. Iwasa and Aya [12] and Kousis and Rodriguez-Mirasol [13] reported no effect of friction term on longitudinal mixing of both small and large rivers. However the results in this work agrees with the findings of Sahay and Dutta [6] who reported larger influence of  $U/U_*$  in small rivers, and partly with the report of Etemad-Shahidi and Taghipour [14] who reported a relationship between the terms for large rivers only. This work confirms that for both large and small rivers, friction term has significant influence on the accuracy of dispersion coefficient equations. There is, however, very poor relationship between friction term and dispersion in straight channels.

Also,  $U/U^*$  has the larger effect on dispersion than does  $B/H$ . Again, this is in contrast to the reports of Noori et al [9] who reported greater influence of aspect ratio. However, our findings agree with those of Noori et al. [1], who reported larger effect of friction term for large rivers.

The coefficient of correlation of  $R_c/R_h$  to  $D_L$  was between 0.882 and 0.7721, implying good relationship. This puts it on equal stand with aspect ratio and friction term.  $R_c/R_h$  is inversely proportional to dispersion coefficient. This means that as  $R_c/R_h$  increases,  $D_L$  decreases.

The effects of aspect ratio, friction factor and a new parameter, ratio of radius of curvature to hydraulic radius, have been investigated. It is concluded that all three parameters highly affect dispersion in rivers.

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**Appendix:**

**Table 1a: measured dispersion coefficient and other data  
Channel of 2 meanders**

Expt.	D (m/s <sup>2</sup> )	U/U <sub>*</sub>	B/H	R <sub>C</sub> /R <sub>H</sub>
1	0.22867	5.3721	7.1429	102.7397
2	0.14925	6.1463	5.5556	84.9057
3	0.45732	7.2326	4.7619	56.8182
4	0.51615	9.1136	3.6364	69.4444
5	0.44446	8.9024	4.1667	63.3803
6	0.64146	10.7111	2.9412	54.8780
7	0.60265	11.9787	2.5641	51.1364
8	0.54451	9.7778	3.2787	59.2105
9	0.78204	12.8571	2.4390	49.8891
10	0.90693	13.9216	2.2472	47.7707



**Table 1b: Channel of 3 meanders**

Expt.	D (m/s <sup>2</sup> )	U/U <sub>*</sub>	B/H	R <sub>C</sub> /R <sub>H</sub>
1	0.12597	4.5106	8.70	115.6250
2	0.25158	6.2143	5.8824	74.0000
3	0.38032	8.4348	4.4444	59.6774
4	0.45961	9.8261	3.3333	48.6842
5	0.79092	11.1622	3.8462	35.5769
6	0.82692	13.1923	2.5641	42.0455
7	0.63678	12.7800	2.3810	40.2174
8	0.40172	9.9149	4.0000	50.0000
9	0.53074	11.5098	2.8986	47.4359
10	0.65603	14.1250	2.2727	42.0455

**Table 1c: Channel of 4 meanders**

Expt.	D (m/s <sup>2</sup> )	U/U <sub>*</sub>	B/H	R <sub>C</sub> /R <sub>H</sub>
1	0.2181	5.5238	15.3846	63.9130
2	0.35132	7.6190	9.5238	42.0000
3	0.50233	6.6833	7.5472	35.0000
4	0.39883	12.0000	6.0606	29.4000
5	0.53175	12.8571	5.6338	28.2692
6	0.58047	14.5455	5.0000	25.7895
7	0.58194	15.7273	4.5455	24.0984
8	0.63807	17.3333	4.0816	22.2727
9	0.73582	16.5909	4.1667	22.6154
10	0.7875	19.1304	3.6364	20.7042



**Table 1c: Channel of 5 meanders**

Expt.	D (m/s <sup>2</sup> )	U/U*	B/H	R <sub>C</sub> /R <sub>H</sub>
1	0.19836	5.9231	16.6667	68.1818
2	0.22486	5.8000	14.2349	54.8780
3	0.2918	6.7990	11.7647	46.3918
4	0.42999	12.2917	8.6957	36.0963
5	0.5264	15.1111	4.7619	22.8041
6	0.47212	11.1671	5.7971	26.4706
7	0.6322	16.7756	4.3478	21.4286
8	0.82884	18.1818	3.9216	19.8529
9	1.11002	19.5329	3.6036	18.9076
10	1.38112	20.5882	3.3613	18.0965

**Table 1e: Channel of 6 meanders**

Expt.	D (m/s <sup>2</sup> )	U/U*	B/H	R <sub>C</sub> /R <sub>H</sub>
1	0.174408	5.6145	16.1290	46.2963
2	0.205975	7.1585	12.5628	37.0920
3	0.289352	8.4242	10.4167	31.0174
4	0.626012	11.2234	7.5758	24.2248
5	0.476262	12.2861	7.2464	23.1054
6	0.340653	6.7582	13.8889	39.0625
7	0.891284	15.0485	5.9524	19.8413
8	0.708129	16.5721	5.3191	18.3824
9	0.56624	19.3180	4.2017	15.4321
10	0.881723	20.6220	3.9063	14.7059



**Table 1f: Channel of 7 meanders**

Expt.	D (m/s <sup>2</sup> )	U/U <sub>*</sub>	B/H	R <sub>C</sub> /R <sub>H</sub>
1	0.10287	4.0000	31.2500	48.0000
2	0.19049	5.2586	16.1290	34.9091
3	0.10838	9.9487	9.4340	21.8182
4	0.15753	10.6154	8.6207	20.4255
5	0.4694	12.6415	7.1429	17.4545
6	0.35528	8.5829	10.6383	24.2424
7	0.80379	15.5932	5.7471	14.7692
8	0.91765	17.5186	4.6729	12.8000
9	0.12611	13.7755	6.4103	1.4545
10	0.62111	19.3617	4.3103	12.1519

**Table 2a: Experimental Result for Straight Channel S1**

EXP	D	U	U <sub>*</sub>	B	H	R <sub>H</sub>	$\frac{U}{U^*}$	B/H
1	0.070213	0.385	0.0570	0.2	0.036	0.0206	6.790	5.5556
2	0.151518	0.504	0.0497	0.2	0.063	0.035	10.121	3.1746
3	0.074186	0.622	0.050	0.2	0.084	0.043	12.465	2.3810
4	0.145955	0.714	0.0517	0.2	0.092	0.046	13.810	2.1739
5	0.173227	0.803	0.0530	0.2	0.1101	0.050	15.266	1.8182
6	0.151559	0.878	0.055	0.2	0.118	0.054	16.597	1.6949
7	0.082511	0.901	0.053	0.2	0.127	0.056	17.129	1.5748

**Table 2b: Experimental Result for Straight Channels2**

EXP	D	U	U <sub>*</sub>	B	H	R <sub>H</sub>	$\frac{U}{U^*}$	B/H
1	0.026049	0.240	0.0409	0.40	0.028	0.25	5.864	14.2857
2	0.041163	0.328	0.0416	0.40	0.039	0.033	7.810	10.2564
3	0.365126	0.403	0.0393	0.40	0.058	0.045	10.255	6.8966
4	0.106353	0.550	0.0423	0.40	0.072	0.053	13.002	5.5556
5	0.054664	0.581	0.0415	0.40	0.081	0.058	14.000	4.9383
6	0.167162	0.662	0.0407	0.40	0.102	0.068	16.146	3.9216
7	0.074102	0.748	0.0401	0.40	0.132	0.080	18.653	3.0303



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