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Investigating Effects of Obstacles' Arrangement on the Velocity of Density Current's in Experimental Conditions

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Abstract

Density Currents reaching the reservoir dam reduces the shelf life and reducing or even eliminating the amount of water regulate and loss of profits caused by power generation and flood control. One method of density current control is creating obstacles before the reservoir dam. In this study Six types effect of obstacles arrangement: similar convergent, similar divergent, parallel, z(ed) shape, zigzag and chess-like studied the density current control is completed. The experiments were performed in a channel length of 10 meters. Made of plastic and the covering Obstacles' was three meters. Then density current velocity was measured in 6 and 4 sections 0.5 meters between and after covering obstacles'. Experiments with 3 bed Slope 0, 1 and 2%, with a salt concentration of 40 and 80 g/l was repeated. The results show if there are obstacles' in front of density currents, the velocity of the front reduces consequently. Covering obstacles' leading to reduce velocity average 21-59 of percent density current. Arrangement covering obstacles 3-16 %. Was effective on the velocity of density current. The similar convergent arrangements have the better yield in contrast to those of other arrangements. After crossing of obstacles, in one section increases velocity of density current. But this velocity is not impressive. And Density current also affected by covering obstacles. Therefore, controlling the density current on the slopes can be effective in controlling and increase the effects of obstacles arrangement.

Keywords: Bed Slope, Dam Reservoirs, Density Current, Obstacles' Arrangement

Introduction:

Building the structures such as a dam can disturb the natural balance of input and output sediments of the rivers. Therefore, it brings about the reservoir which increase the efficiency of sediments' trapping. The reservoir loses its storage capacity as time passes. Thus, that causes the reduction in volume of water's regulation (even it completely vanishes), loss of benefits from controlling flood, use of water, and energy production (Graf., 1984). Density current often composes during flood; it goes down to the reservoir's water in the plunge point and composes in the bed of reservoir. Although the slope of the bed would be high (higher than 0.001) or its width would be low, it continues its direction and movement (Firoozabadi et al., 2003). With the continuation of the movement, sedimentation is created in the vicinity of dam and consequently disturbs the yield (performance) of impoundments as well as the outcome of the bed (Toniolo et al., 2007). In general, the density currents are streamed due to the density difference between two or more various fluids, as a result the propulsive force from that under the condition of reduced gravity (Altinakar et al., 1990). Density currents are divisible into two clusters of conservative currents (or devoid of particles such as saline density current) and non-conservative currents (or having suspending particles) both of which are idiomatically called turbidity current (Huppert and Simpson., 1980). In fact, the difference between conservative and non-conservative currents is subjected to the difference between floatingness and density fluctuations.The earliest research has been related to (Farel, 1892) a Switzerland scholar, at Geneva Lake.

Density current is unsteady forehead. And according to relations 1, factor its motion, gravity is the result of differences in the density of the fluid. In this equation, ρ_d density of density current. ρ_a is Fluid density environs, Δρ is the density difference between the two fluids. The development Velocity is the progress rate of current toward the area which is calculated by means of simple hydraulic calculations (Turner., 1973).

$$g' = g(\rho_d - \rho_a)/\rho_a = g(\Delta\rho/\rho_a) \quad (1)$$

(Keulegan, 1958) did his research based on the density current of salt-water solutions. He presented a relation for calculating the Velocity of the of density current. In terms of investigating the form of density current's , (Middleton, 1966) has reported that the 's height is double of the body's height; and the Velocity of the is lower than the Velocity of the body of density current. (Altinakar et al, 1990) have investigated the effects of bed's slope and granolometry of sedimentations on the form, height, and the Velocity of the of sedimented density currents. Then, they have compared the results in the similar conditions with the density current of salt-water (saline) solutions. Their results show that the value of growth for the 's height in the sedimented density currents is higher (faster to some point) than the density current of saline solutions on the same slope. (Biton and colleagues, 2008) studied density current formation and flow dynamics in the northern Gulf of Eilat, Red Sea, and demonstrated how the intrinsic nonlinearity of density currents, which is poorly represented in the general circulation model, affects properties of simulated density currents. (Oehy and Schleiss, 2007) have analyzed the effects of various methods such as construction of permeable obstacles for water jet in the 45 and 90 degrees on the control the turbidity (here, density) currents in dams' reservoirs. (Lamb et al, 2006) have conducted some

experiments on the efficiency of trapping of sediments through a physical model. Their results show that both of the granolometry of crossed sediments after tinier obstacles and the density reduce not only significantly but remarkably. (Cortes and colleagues, 2014) developed a theory to predict the partition of the buoyancy flux into the interflow and underflow and how a gravity current splits in two upon reaching the sharp density step. Two dimensional hydrodynamic models were developed to study density current by assuming that the density current does not participate in the dynamics of heating and mixing; rather, the entrainment takes place from the ambient reservoir into the downflow . (Chen and Fang, 2015) In a study, Studied and examined sensitivity analysis of flow and temperature distributions of density currents in a river-reservoir system under upstream releases with different durations. Their study results showed that DRLRs lasting for at least 4 h maintain lower water temperatures at Cordova. When the 4-h and 6-h DRLRs repeat for more than 6 and 10 days, respectively, bottom temperatures at Cordova become lower than those for the constant small release (2.83 m3/s). These large releases overwhelm the mixing effects due to inflow momentum and maintain temperature stratification at Cordova. In research of (Fathi Moghadam et al, 2008) experimentally evaluated the effects of the reach degree of expansion on the density current head velocity.Experiments were conducted in a 6.0-m-long, 0.72-m-wide flume. The head velocity was measured at three expansion degrees (8; 12; 26) and two slopes (0.009; 0.016) for various discharges. For the same slope and discharge, the results illustrated that the head velocity increases in the reaches expanded up to 20 degrees, compared to that for a uniform cross-section reach. As anticipated, the velocity head increased directly with the bed slope. (Toniolo et al, 2007) have analyzed the efficiency of trapping in the reservoirs of dams. In terms of numerical simulation, they have shown that the efficiency of obstacle's trapping reduces as time passes and as a result, more sediments can infiltrate through the obstacle.

In this studyregard, six types of obstacle arrangement have been used with three slopes (0 %, 1 %, and 2 %) and two densities (40 g/l and 80 g/l). in terms of the reviewed literature, no study has been so far reported in dealing with the influence of arrangement of obstacles on the velocity of density current. Thus, the novelty of this research stands for the influence of obstacles' arrangement on controlling the Velocity of the density current.

Developing the Model through Dimensional Analysis

In order to simultaneously consider the impact of effective factors on the Velocity of density currents, dimensional analysis was carried out by Buckingham Method. the effective parameters in dimensional analysis are shown in to relation 2,. In this relation, P determines the arrangement of obstacles; S for bed's slope, C for average concentration of density fluid behind the gate; x for the length of all obstacles; hf for the height of the ; ha for the average height of ambient fluid; $\mu_{d.c}$for dynamic viscosity of density current; u_f the Velocity of the front of density currents in the constant sections; and g' for the reduced acceleration of gravity.

$$f\left(P, S, C, x, h_f,\ \mu_{d.c}, u_f,\ g'\right) = 0 \qquad (2)$$

Considering the height of ambient fluid (h_a), the velocity of the of density currents in the constant sections (uf), and the height of ambient fluid (ρ_a) as three repetitive parameters, the non-dimensional relations were obtained in terms of relation 3,. In this Relation, non-dimensional parameters respectively

refer to the arrangement of obstacles, bed's slope, the relative concentration of the current, the relative height of the, Reynolds Number ($\frac{u_f \times \rho_a \times h_f}{\mu_{d.c}}$) and densimetric Froude numberin density current, ($\frac{u_f}{\sqrt{g' \times h_f}}$). Whereas in the treatments of this research, the values of Reynolds Number of density current are always involved in the boundary of the turbulent current, the calculation of it (Re) is overlooked.

$$A^* = f^*\left(P, S, \frac{C}{\rho_a}, \frac{h_f}{h_a}, \frac{x}{h_a}, R_{e\ d.c}, F_{r\ d.c}\right) \qquad (3)$$

Materials and Methods

This research has been conducted in Hydraulic Laboratory of Agriculture Faculty at the University of Birjand, Iran. The experiments were carried out in the slope-allowed canal which has 10 meter length, 0.3 meter width, and 0.48 meter height. The aim of this study was to investigate the effect of obstacle's arrangement and the slope of bed on the development of the of density current as well as to propose the appropriate strategies for avoiding the potential damages of these currents. In so doing, six types of obstacles' arrangement were taken into account of experiment in three slopes (0 %, 1 %, and 2 %) and two densities (40 g/l and 80 g/l) (Figure 1 View from above).

In order to survey the effect of obstacles' arrangement on the (development) Velocity of the of current, the cylinder-like obstacle was used with the features of 8.5 mm diameter, the constant height of 20 cm, and 3 m length in all experiments, i.e. the concentration of obstacles' arrangement were constant in this research. To form and stabilize the density current, the first obstacle was put 2 meters distant from the gate. C refers to the concentration of density current behind the gate and its amounts are 40 g/l and 80 g/l. S refers to the slope of canal's bed and its amounts are 0 %, 1 %, and 2 %. ρ_d is for the density of density current and is 1027.3 in concentration of 40 g/l, and 1055.3 in concentration of 80 g/l. ρ_a refers to ambient fluid's density and is taken equal with 1000. Δprefers the difference between the density of ambient fluid (ρ_a) and density fluid. h_a refers to the ambient fluid's height inside the canal and its amount is 31cm The maximum difference between the ambient fluid and density fluid is 0.5 ˚ C. The average temperature of the laboratory was 15˚. H refers to the opening height of circular channel which is located in the entrance of density current toward the ambient fluid. H is 5 cm for all experiments. Therefore, the inlet flow was constant. A summary of the tests are shown in Table 1.

After reaching the same heights for the ambient fluid and density fluid, the circular channel was opened 5 cm. Therefore, the density current entered into the ambient fluid through the inlet flow. Moreover, a controller is installed in order to prevent the occurrence of turbulences as a result of entrance of ambient fluid at the end of the canal where was the entrance of ambient fluid. Another controller was installed in the place of entrance of density current (number 2 reservoir) for preventing the effects of turbulences. In Figure 2, there is presented a simulated scheme for density current.

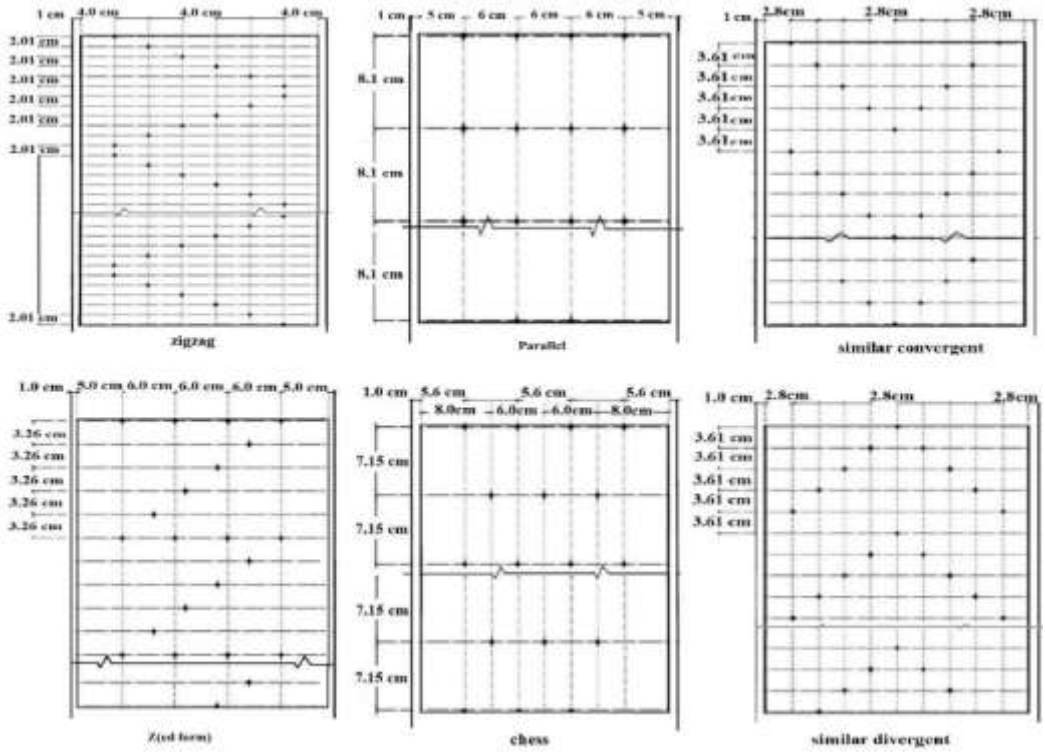


figure 1: Plan of Arrangement Obstacles

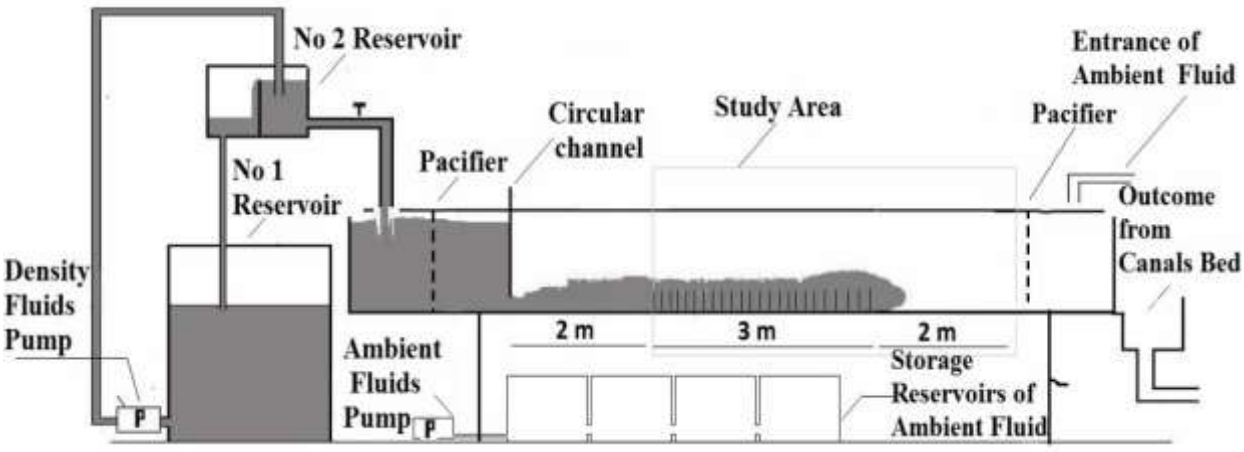


Figure 2: A Scheme for Simulator of Density Current

Table 1: Summarized test

Number of tests	Bed Slope (%)	$\Delta\rho$	g´	Arrangement	*Froude Number*	Reynolds Number $\times 10^4$
3	0, 1, 2	27	0.268	Free-obstacles	0.392 - 0.887	0.398 – 0.574
3	0, 1, 2	27	0.268	Parallel	0.266 - 0. 852	0.174-0.569
3	0, 1, 2	27	0.268	Chess-like	0.201 – 0.839	0.140 - 0.569
3	0, 1, 2	27	0.268	Similar Convergent	0.191 - 0.841	0.139 - .0570
3	0, 1, 2	27	0.268	Z-form	0.283 – 0.857	0.147 - 0.569
3	0, 1, 2	27	0.268	Zigzag	0.248 – 0.846	0.167 - 0.568
3	0, 1, 2	27	0.268	Similar Divergent	0.226 – 0.849	0.154 - 0.569
3	0, 1, 2	55	0.543	Free-obstacles	0.562 – 1.287	0.463 - 0.931
3	0, 1, 2	55	0.543	Parallel	0.546 – 1.268	0.332 -0. 863
3	0, 1, 2	55	0.543	Chess-like	0.441 – 1.253	0.303 - 0.863
3	0, 1, 2	55	0.543	Similar Convergent	0.380 – 1.245	0.267 - 0.863
3	0, 1, 2	55	0.543	Z-form	0.565 – 1.272	0.349 - 0.864
3	0, 1, 2	55	0.543	Zigzag	0.510 – 1.263	0.327 - 0.865
3	0, 1, 2	55	0.543	Similar Divergent	0.486 – 1.257	0.313 - 0.863

Results and Discussion

Velocity variations at sections without obstacles

The propulsive force for the in one density current is, in fact, the pressure of gradient which is the result of density difference between density current and ambient fluid (Graf, 1984). Figure 3, refers to the values of development Velocity for density current in three slopes and two concentrations.

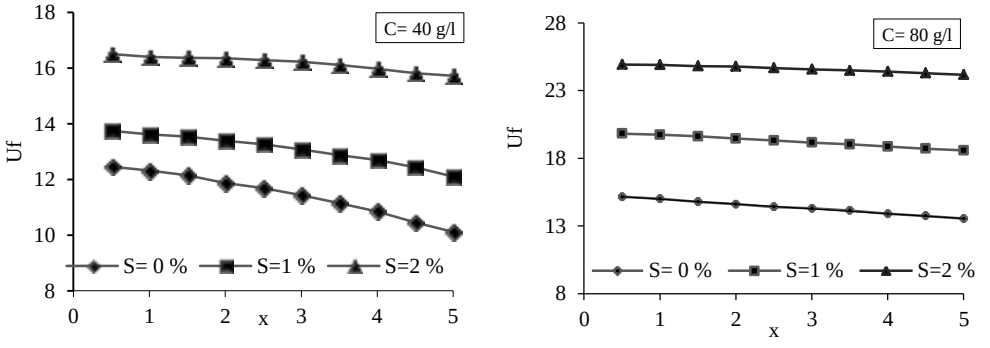


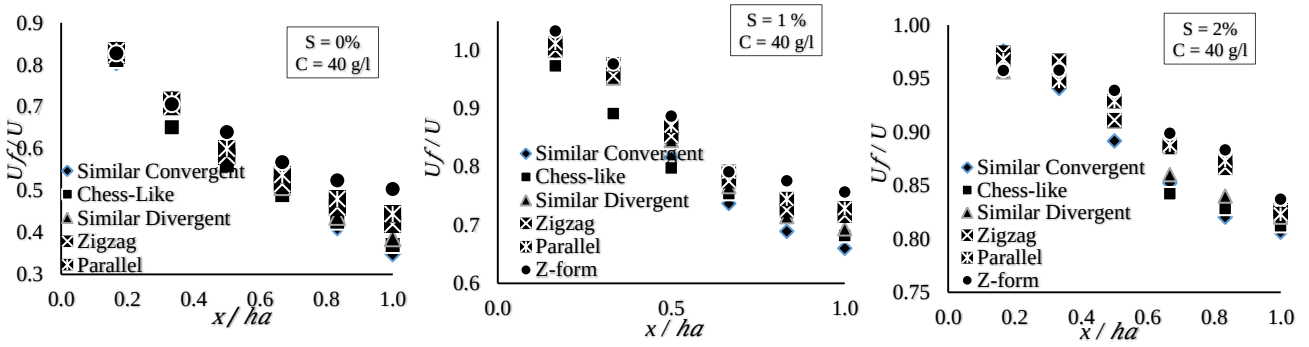
Figure 3: Development Velocity for Density Current's in Free-obstacles

Figure 3, shows the values of development Velocity for density current's on three slopes (0 %, 1 %, 2 %) along the canal. In the beginning of the canal, the current's development factor is the inertia and gravity forces although the friction force is so small. As moving away from the entrance gate of density current, the density difference reduces and finally the only current's development factor becomes gravity force. Therefore, the density fluid firstly accelerated due to the existence of the large gravity force, and then the acceleration and Velocity of the current reduce because of moving away from the entrance and reducing gravity force. In the constant sections, as the bed's slope and current's concentration, the Velocity values increase, that is, the g' increases and the bed's slope increases and as a result the driving component of apparent weight increases so that the current's Velocity increases. The relative reduction in the development Velocity of the density current along the canal for 40 g/l concentration on 0 %, 1 %, and 2 % slopes is 8 %, 5 %, and 2 % respectively. As the bed's slope increases from 0 % toward 1 %, the reduction extent of Velocity reduces 12 % along the canal; although this extent is 20 % for increasing slope from 1 % to 2 %.

The relative reduction in the Velocity of density current's is 6 %, 3 %, and 1 % on three slopes of 0 %, 1 %, and 2 % along the canal, respectively. By increasing the bed's slope from 0 % to 1 %, the reduction extent of Velocity reduces 25 % along the canal; although.

Velocity variations at sections obstacles

In this research, the creation of obstacles in the arrangement of similar convergent have had the better performance (yield). The velocity changes of the has been shown in various arrangements in Figure 4 , And in Figure 5, has been shown the change velocity in four section of 0.5 meter after the obstacles



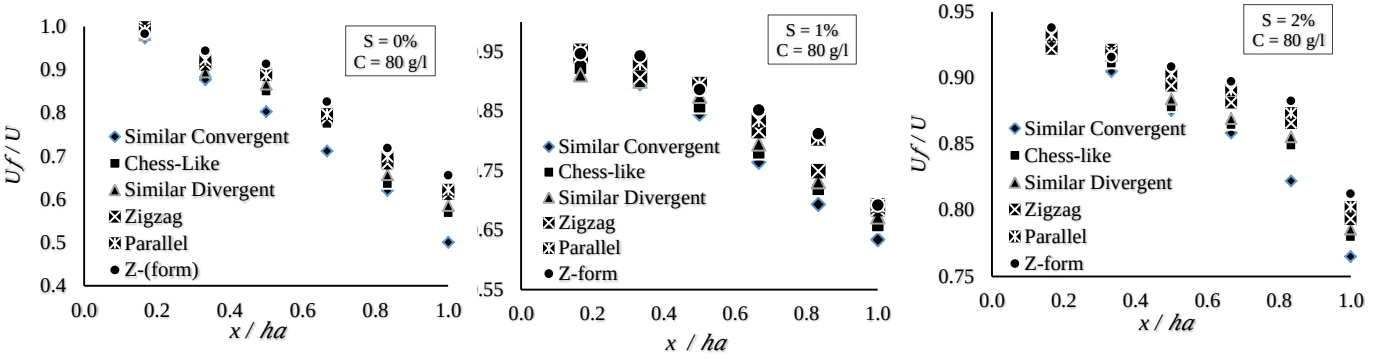


figure 4: Changes of 's Velocity between Obstacle

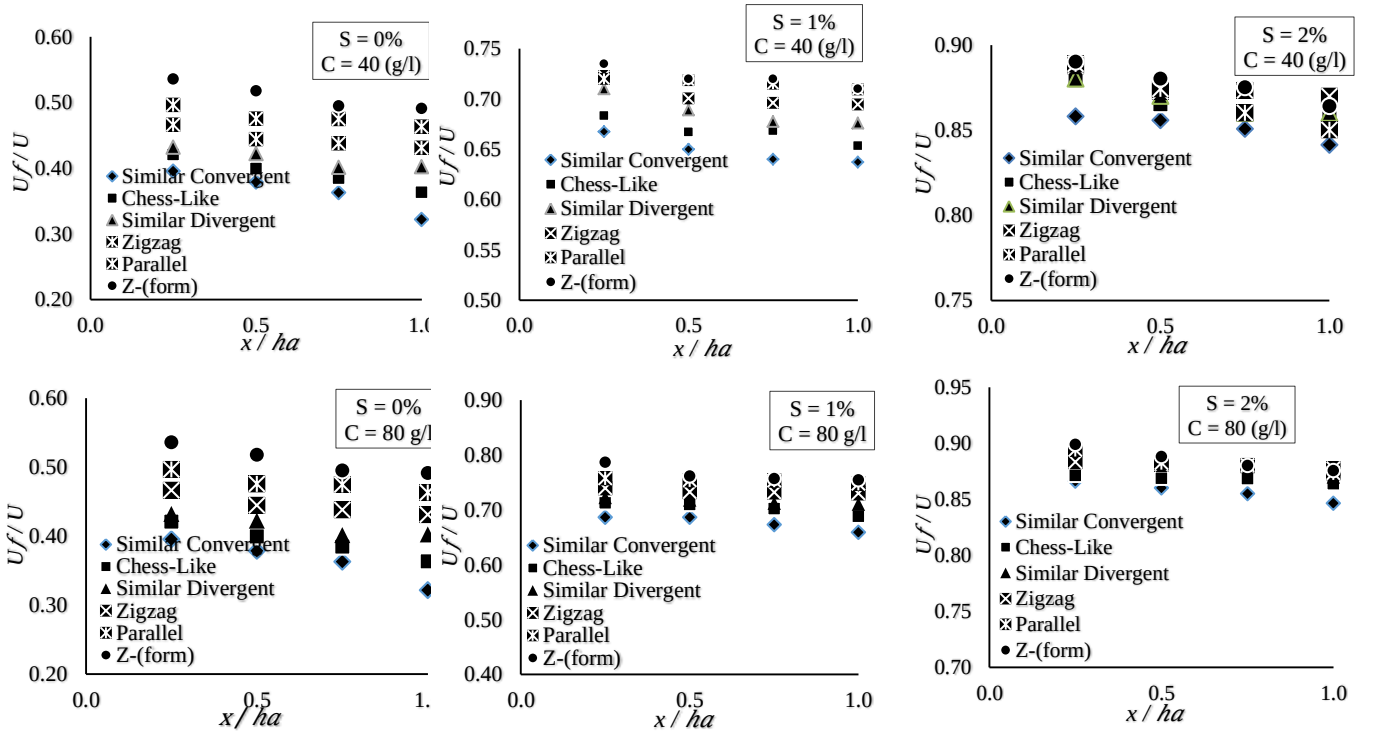


Figure 5: Changes in flow velocity after the envelopment obstacles

In the absence of obstacles, with the continuation of current along the canal, the current's energy reduces and conservative force will be increasing and accordingly the turbulence of ambient fluid with

density fluid increase. As a result, density difference between the density fluid and ambient fluid which is the main factor in movement, reduces. The existence of obstacles in the of the current increases the conservative force and also cause the much dissipation of energy in that the intensity of turbulence of ambient fluid with density fluid increases. Therefore, as a result of reduction in density, the Velocity of current reduces significantly in contrast to that of the free-obstacle position. As the bed's slope increases, the current's Velocity increases that leads to increase in momentum of current. In this condition, the effect of resistance decreases and the intensity of turbulence of ambient fluid with density fluid decreases so that the stability increases. The extent of stability between two fluids of ambient and density is the function of cutting stress and hydrostatic pressure gradient perpendicular to the joint point of these fluids. This means that the higher the stress, the lower the stability is.

As the hydrostatic pressure gradient becomes higher, the stability gets higher because it creates consistence in the joint area of two fluids. On the one hand, and hydrostatic pressure gradient perpendicular to the joint point in these fluids, in itself, is subjected to the component of reduced accelerated gravity in the direction of perpendicular to the current, i.e. $g'cos\theta$. Therefore, the higher the $g'cos\theta$, the higher the hydrostatic pressure gradient perpendicular to the current, and consequently the more stability is obtained, so that the intramixing and turbulence are less. On the other hand, the extent of cutting stress in the joint area of two fluids is dependent on the component of reduced accelerated gravity in the direction of perpendicular to the current, i.e. $g'sin\theta$. The higher the $g'sin\theta$, the density's current is accelerated toward the downstream. Thus, with the incidence of current with the obstacles, the Velocity change happens in the joint area of two fluids, so the cutting stress increase and accordingly the instability, turbulence, and intramixing phenomenon increases.

Bases on the Figure 7, the longitudinal slope of the Velocity reduction increases on the 0 % slope. This longitudinal slope becomes mild as the bed's slope increases. As a result of increase in concentration between obstacles, the cutting stress increases and the linear slope of the Velocity reduction increases between obstacles and gets convex. By comparing two concentrations, it can be stated that the Velocity has higher values in the 80 g/l concentration in the end of obstacle rather than that of the 40 g/l concentration. In all of the arrangements of obstacles, the reduction value of Velocity is higher in 80 g/l concentration from the beginning to the end of obstacles rather than that of the 40 g/l concentration. The progress of Velocity reduction becomes mild for 40 g/l concentration in the end of obstacles, although the slope of Velocity reduction (between obstacles) is higher in the 80 g/l concentration. It seems that if the length of obstacles was more than 3 meters, the effect of Velocity reduction of the current's would be higher with 80 g/l concentration in contrast to 40 g/l concentration. The average reduction Velocity of density current At the end obstacles and the effect Obstacles Arrangement is shown in Table 2, And after the obstacles, flow velocity a smaller value after the envelopment obstacles proportional of without obstacles. And by increasing the bed slope, this difference is reduced. The average effect of Velocity reduction and Arrangement envelopment obstacles has been shown in Table 3.

Table 2: Effective of obstacles to Reduce the Velocity

C (g/l)	Slope (%)	Similar Convergent	Chess-Like	Similar Divergent	Zigzag	Parallel	Z	Obstacles Arrangement	Average Reduction
40	0	65	63	61	58	55	50	15	59
	1	39	37	36	33	32	29	10	34

	2	19	19	18	17	17	16	3	18
80	0	50	43	41	39	38	34	16	40
	1	35	33	31	30	30	29	6	34
	2	23	22	21	21	20	19	4	21

Table 3: The average relative decrease velocity after envelopment obstacles

C (g/l)	Slope (%)	Obstacles Arrangement	Average Reduction (%)
40	0	17	59
	1	10	32
	2	7	13
80	0	20	38
	1	11	28
	2	7	13

Review and compare density current velocity of Equation

(Daly, 1936) has stipulated that the existence of many valleys in the depth of seas and oceans is due to the existence of density currents and to the friction effect of them. Then, he proposed the Relation 4, for Velocity of density current's .

$$v = C\sqrt{(m.s.d)} \qquad (4)$$

In this relation v is Velocity of the , m is medium hydraulic depth, s is bed's slope, d is special mass difference between ambient and density fluids. In a few of works, the development Velocity of the density current's is introduces as a subject to the 's height and reduced gravity acceleration.(Keulegan, 1958) has proposed Relation 5 for the Velocity of the density current's . In this relation, Uf is Velocity of the , C is empirical coefficient, g′is reduced gravity acceleration, and Hf is the height of the density current's .

$$\mathrm{Uf} = \mathrm{C}\sqrt{g'\,\mathrm{h_f}} \qquad (5)$$

The calculation of C is obtained when the Velocity of the density current's (Uf) and the cutting densitometricVelocity $(g'\,Hf)^{1/2}$ are at hand. And the diagram shown in Figure 6, (As an example of this and other researchers).

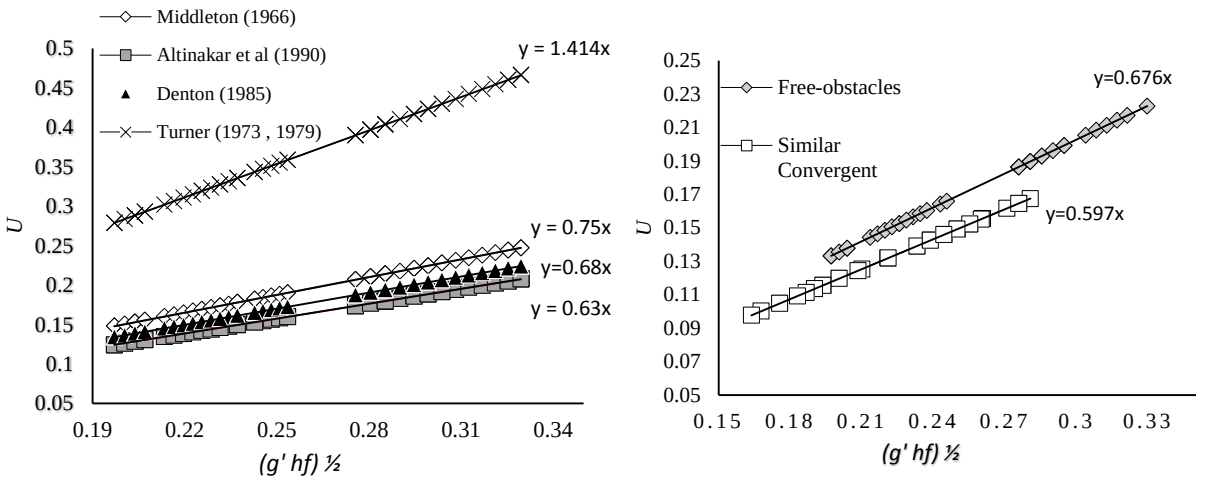


Figure 6: *C* determine the coefficient of the graph

Conclusion

Controlling the density currents plays an important role in maintaining the life expectancy of dams' reservoirs.The Velocity of density current depends on the reduced gravity acceleration, and the primary conditions of entering current into the reservoir. Increasing thebed slope and increase the concentration of the density currents is will An increase in velocity of density current. For 40 g/l concentration on 0 % and 2 % slopes, the creation of obstacles, on average, cause reducing 59 % and 18 % for the velocity of density current.Similarly, these values are 40 % and 21 % for 80 g/l concentration. On average, the obstacles' arrangement is 3-16 % effective for improving the performance of obstacles.Performance arrangement of Similar Convergent was better than the other arrangements. These findings indicate that bed's slope (in rivers) is the most significant factor in the development Velocity of density currents.

Due to the important role of slopes in increasing the Velocity, erosion of current's , and supporting the density current on the steep slopes, it is recommended that the watershed operations be done on the steep slopes of rivers to prevent the erosion, to prevent the increase in concentration and the Velocity of density currents. Furthermore, construction of obstacles seems necessary for downstream and upstream areas of rivers where there are some steep slopes. In order to improve the performance of the obstacles and justify this proposal economically, the similar convergent arrangement can be used. It is better that the obstacles be permeable in order not to store the water behind the obstacles in the times of water deficit in reservoir. To do so, the vegetation coverage of each area is a proper choice because it dost not need any repair and maintenance and also does not destroy the environment. Moreover, using vegetation coverage on the steep slopes can be an appropriate strategy for controlling the density current and erosion of a river's bed.

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