Investigating the Effects of Obstacles' Arrangement on the Development of Hed Density Current

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Abstract
Density currents are determined as the main factors threatening the water resources and dams' reservoirs. As they can reduce both the volume of dam's reservoir and the volume of flood control, they can also affect the quality of water so that they cause reduction in economic efficiency as well as efficiency of electricity production. In this research, the effects of six arrangements on the development speed of the front of density current were investigated. Because the factors such as bed slope and current's concentration have influence on the development velocity of density current's front, the experiments have been repetitively conducted on 0 %, 1 %, and 2 % slopes, and with two densities of 40 g/l and 80 g/l. In sum, 42 experiments have been carried out. The results show if there are obstacles in front of density currents, the speed of the front reduces consequently. The arrangement of obstacles are effective in improving the performance of obstacles. By increasing the slope of the bed of the impact of reduced barriers make maximum impact is made and obstacles up 16% and in makeup was similar convergent.

Keywords: Density Current, Obstacles' Arrangement, Bed Slope, Dam Reservoirs, Water Resources Management.

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 Farl (1892), a Switzerland scholar, at Geneva Lake. Keulegan (1958) did his research based on the density current of salt-water solutions in a flat canal (without any slope). He presented a relation for calculating the speed of the front of density current. In terms of investigating the form of density current's front, Middleton (1966) has reported that the front's height is double of the body's height; and the speed of the front is lower than the speed 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 speed of the front 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 front's height in the sedimented density currents is higher (faster to some point) than the density current of saline solutions on the same slope. 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. 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 regard, 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 development of density current. Thus, the novelty of this research stands for the influence of obstacles' arrangement on controlling the development rate of the density current.

Developing the Model through Dimensional Analysis

In order to simultaneously consider the impact of effective factors on the speed of the front (head) of density currents, dimensional analysis was carried out by Buckingham Method. The effective parameters in dimensional analysis are shown in to Relation (1). In this relation, P determines the arrangement of obstacles; S for bed's slope, C for average concentration of density fluid behind the gate; L for the length of all obstacles; h_f for the height of the front; h_a for the average height of ambient fluid; $\mu_{d.c}$ for dynamic viscosity of density current; and g' for the reduced acceleration of gravity.

$$f\left(P, S, C, l, h_f, h_a, \mu_{d.c}, g'\right) = 0 \tag{1}$$

Considering the height of ambient fluid (h_a), the speed of the front 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 (2). 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 front, Reynolds Number and Densimetric Froude Number in density current.

$$A^* = f^*\left(P, S, \frac{C}{\rho_a}\ \frac{l}{h_a}, \frac{h_f}{h_a}, \frac{\mu_{d.c}}{v\times h_a \times \rho_a}, \frac{\mathrm{uf}}{\sqrt{g' \times h_a}}\right) \tag{2}$$

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.

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 front 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).

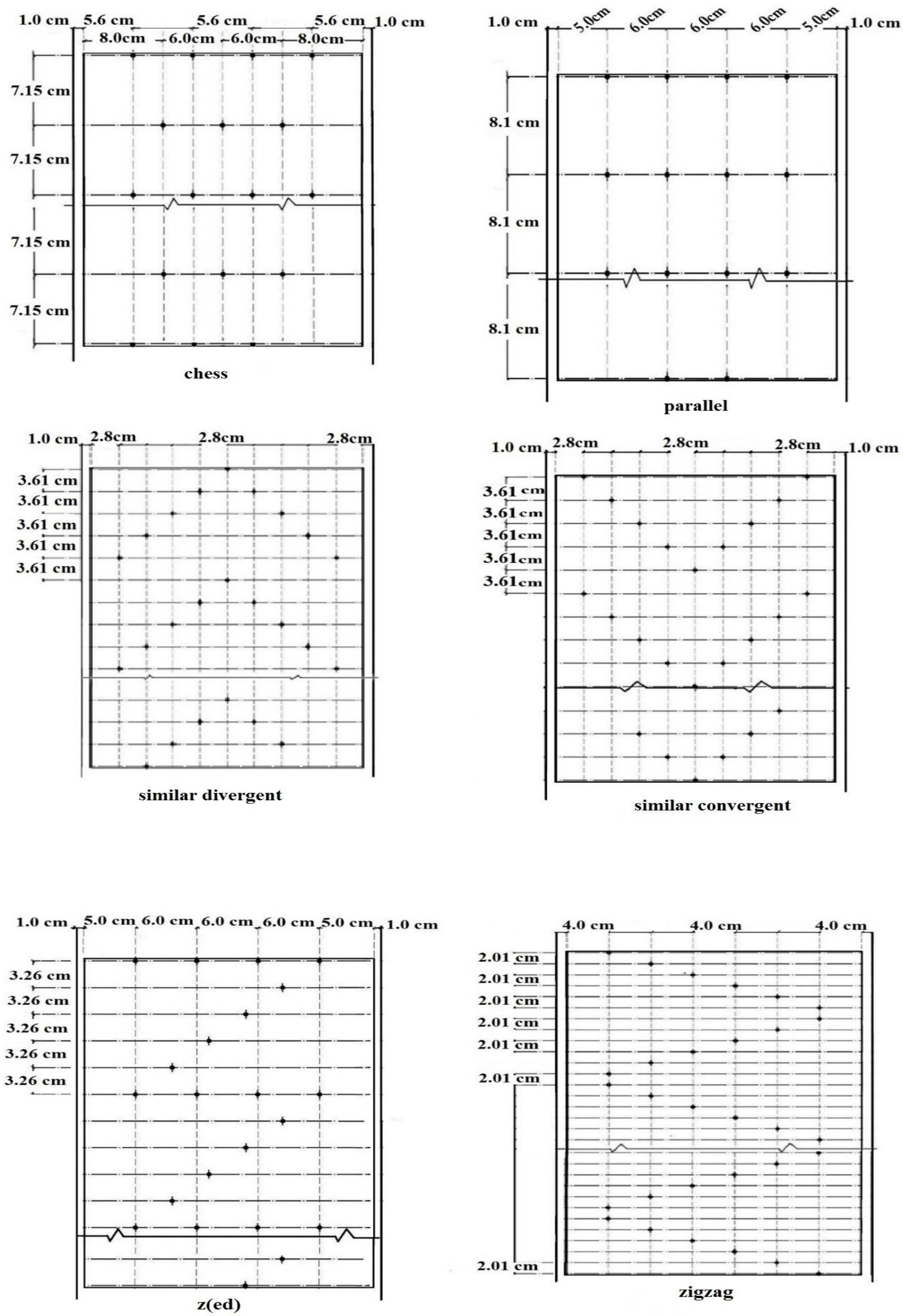

Figure (1): Arrangement of Obstacles

In order to survey the effect of obstacles' arrangement on the (development) speed of the front 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. $\Delta\rho$ refers the difference between the density of ambient fluid (ρ_a) and density fluid. $\Delta\rho$ is 27.3 in concentration of 40 g/l and 55.3 in concentration of 80 g/l. g' is for the reduced acceleration of gravity and its amount is 0.268 in concentration of 40 g/l and 0.543 in concentration of 40 g/l. h_a refers to the ambient fluid's height inside the canal and its amount is 33cm in 0% slope, 32cm in 1% slope, and 29cm in 2% slope. 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. Frd stands for Densimetric Froude Number in control treatments and Re is the average Reynolds Number of density currents in the control treatments (Table 1).

Table (1): Frd and Re Numbers

Slope (%)	Frd in 40 g/l concentration	Frd in 80 g/l concentration	Re in 40 g/l concentration	Re in 80 g/l concentration
0	0.402	0.344	41832	54307
1	0.459	0.455	47016	71307
2	0.587	0.623	57236	92638

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.

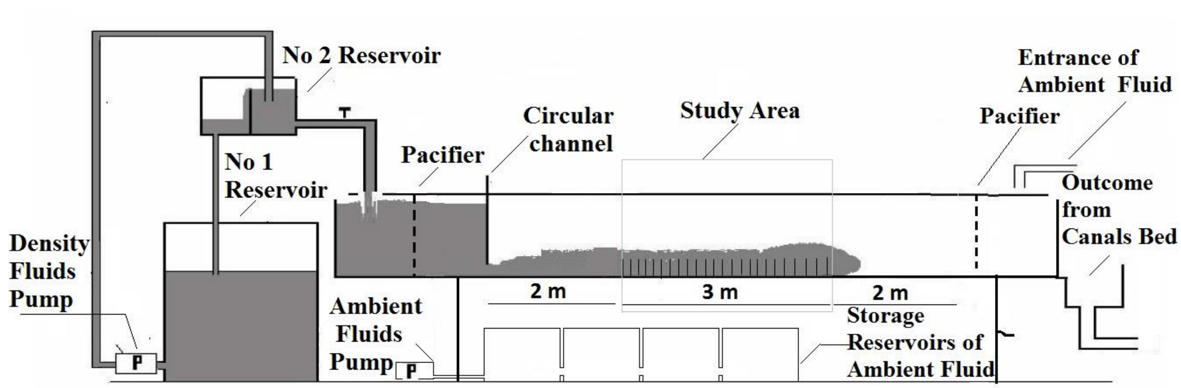

Figure (2): A Scheme for Simulator of Density Current

Results and Discussion

Investigating the Height of Front of Density Current

The front of density current has a rounded nose and unsteady state. Due to the existence of friction in the bed and non-slippy current in the bed, the front of current moves toward higher than the bed and behaves differently with the body of current. The balance between mass rate and momentum in the front is different from that of the body of current (Huppert and Simpson, 1980). The height of current's front is the highest point in the density current which is disorder in contrast to the body. This area is very active and turbulent as a result of mixing of the density current with the ambient fluid (Turner, 1973). Surveying the front of currents is very important in terms of the friction and sedimentation processes because the most friction takes place in the density current by means of the current's front. In Figure 3, the height of density current's front is shown with two concentrations of 40 and 80 g/l in the condition of free-obstacles.

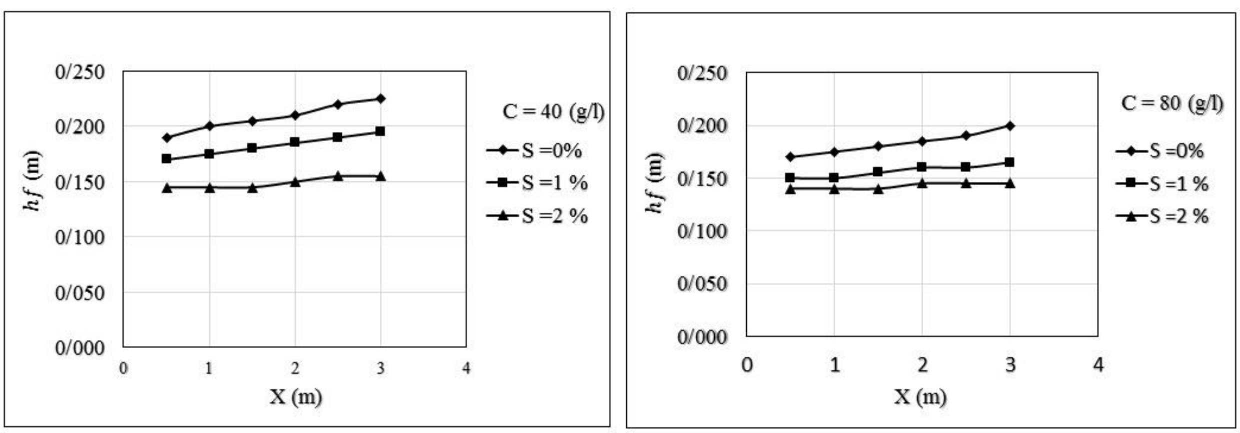

Figure (3): Changes in Height of Front in Free-obstacle Condition.

Based on the Table 3, as moving away from the canal's entrance, the ambient fluid enters into the density fluid and consequently the propulsive force reduces. As a result, the height of the front is increasing along the canal. On 0 % slope, hydraulic gradient in the system is due to the balance difference in the surface of density fluid. As the slope in canal's bed increases, besides the hydraulic gradient, the bed's slope also affects the current. Therefore, the increase of front's height is high on the 0 % slope. In the constant sections, increase in the concentration cause the increase in density difference between the density current and ambient fluid which consequently increase the volumetric concentration of the current. Finally, the speed of current increases and consequently the current's height reduces.

The Height of Density Current's Front in the Presence of Obstacles

In Figure 4, the effective parameters on the front's height are presented. In this Figure, the non-dimensional height of density current's front was drawn in contrast to that of the non-dimensional length. In this Figure, the average height of the front is considered without accounting the turbulent area of two fluids.

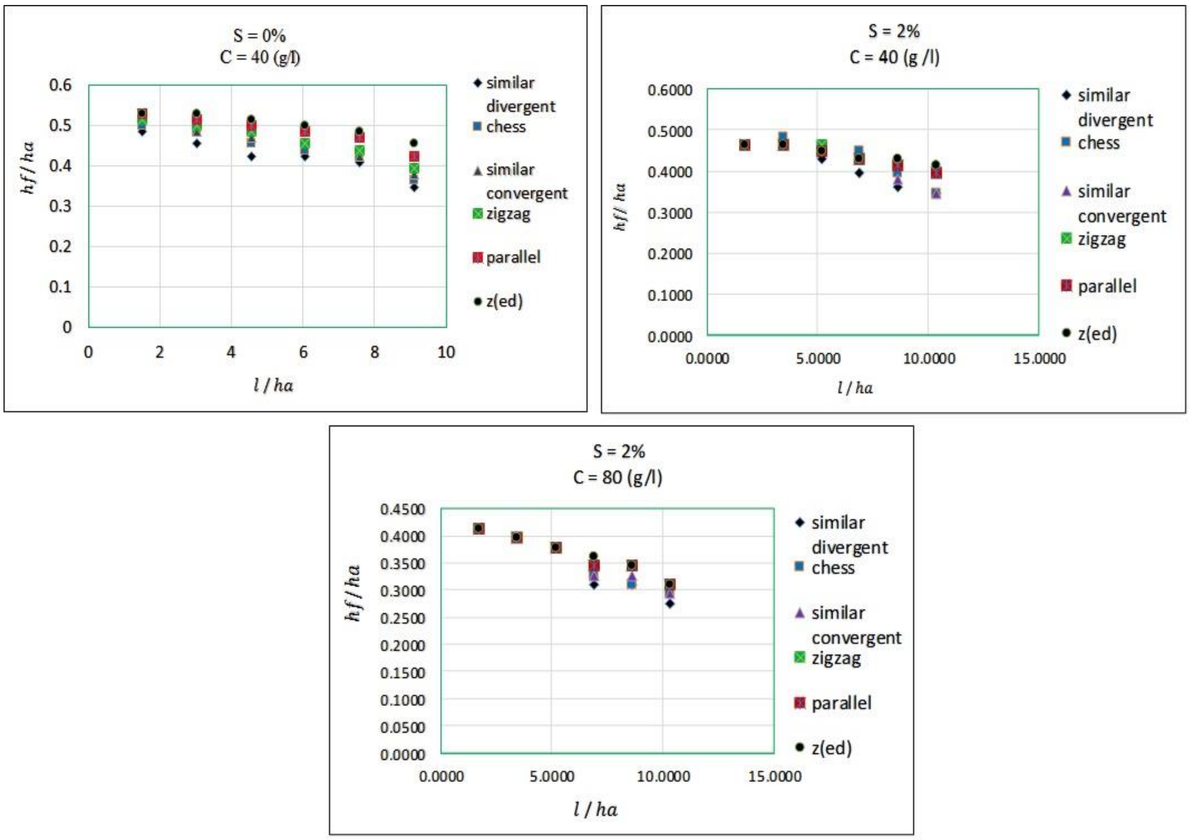

Figure (4): Changes of Non-dimensional Height of Density Current's Front in Contrast to Non-dimensional Length

After collusion of density current's front with the obstacles, the viscous tensions are increased in the above boundary of the front and brought about the horizontal vortexes and Kelvin–Helmholtz instability. With the refraction of Kelvin–Helmholtz instability, the turbulence of density fluid with the ambient fluid increases. Thus, the height of turbulent area between two density and ambient fluids increase. As the concentration increases, the reduced acceleration of gravity and effects of obstacles increases. Due to the high friction, more intramixing phenomenon on the 0 % slope, and the increase of gravity acceleration as a result of increased concentration, the highest turbulent height among the ambient and density fluids is related to the similar convergent arrangements on the 0 % slope and 80 g/l concentration. In both of the 40 g/l and 80 g/l concentrations, with the increase of slope to 2 %, the effect of presence of obstacles decreases and the density current is accelerated and the front's height reduces. This reduction in height may reduce the effect of obstacle's height on increasing the turbulence of the density current. In the 40 g/l concentration, the relative height of obstacles is reduced to the extent of 9 % (bed's slope increases from 0 % to 2 %). On the 2 % slope, the height changes are so small in the beginning of the obstacles due to the large extent of propulsive force in proportion of the conservative forces. The propulsive force reduces as the continuation of currents among obstacles. Then, the turbulence of current fluid with ambient fluid increases.

Average Development Speed of Density Current's Front

The development speed is the progress rate of current toward the front area which is calculated by means of simple hydraulic calculations (Turner, 1973). Based on the Relation 3, the speed of the current's front is obtained in the various distances from entrance by dividing the longitudinal distance into the elapsed time.

$$U_f = \frac{dx}{dt} \quad (3)$$

Tsihrintzis and Alavian (1966) have shown that the density current expands in longitude as a result of four forces of gravity, floating (buoyancy), inertia, and friction. They have introduced these forces in the continuation of bed in 4, 5, 6, and 7 Relations.

$$F_g \sim \Delta\rho g b h l \sin\theta \quad (4)$$

$$F_{bx} \sim \Delta\rho g b h^2 \cos\theta \quad (5)$$

$$F_{ix} \sim \frac{\rho b h l^2}{t^2} \quad (6)$$

$$F_{dx} \sim \frac{\rho v b l^2}{h t} \quad (7)$$

In these relations, F_g is gravity force, F_{bx} is buoyancy force, F_{ix} is inertia force, F_{dx} is friction force, $\Delta\rho$ is the difference of density between density and ambient fluids, h is current's height, b is current's width, t is the elapsed time, l is the length of development, v is kinematic viscosity of density current, and θ is the bed's slope.

Speed of Density Current's Front in Free-Obstacle Position

The propulsive force for the front 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 5 refers to the values of development speed for density current in three slopes and two concentrations.

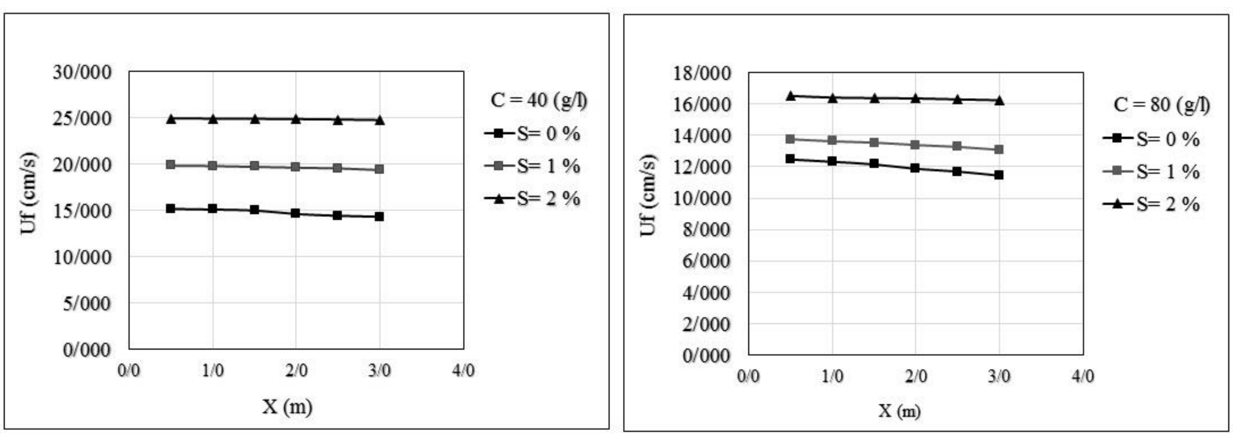

Figure (5): Development Speed for Density Current's Front in Free-obstacle Position in 40 g/l Concentration

Figure 5 shows the values of development speed for density current's front 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 speed 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 speed 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 speed increases ($g' = g\left(\frac{\rho_d-\rho_a}{\rho_a}\right)$; g for accelerated gravity of earth, P_d for average density of density current, and P_a for ambient fluid's density). The relative reduction in the development speed 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 speed reduces 12 % along the canal; although this extent is 20 % for increasing slope from 1 % to 2 %.

The relative reduction in the speed of density current's front 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 speed reduces 25 % along the canal; although this extent is 22 % for increasing slope from 1 % to 2 %. The value of intramixing and turbulence is in the same for density fluid and stability-related ambient fluid. The reduction in this stability cause the increase in turbulence and intramixing phenomenon. As the increase in current's concentration continues in the low height. It seems that the maximum point of development speed gets closer to the bed. As a result, density current wit high density streams in the lower height with higher speed. Although the slope and concentration increases cause the increase in the speed of current's front, the buoyancy force increases in contrast to the friction force by increasing the bed's slope in the constant concentration. In this case, the current along the canal drops so small. On the other hand, the current accelerates as a result of increased concentration in the constant slope, although the friction force causes the reduction of buoyancy (floating) along the canal.

Development Speed of Density Current's Front in Obstacle Position

In this research, the creation of obstacles in the arrangement of similar convergent have had the better performance (yield). The speed changes of the front has been shown in various arrangements in Figure 6.

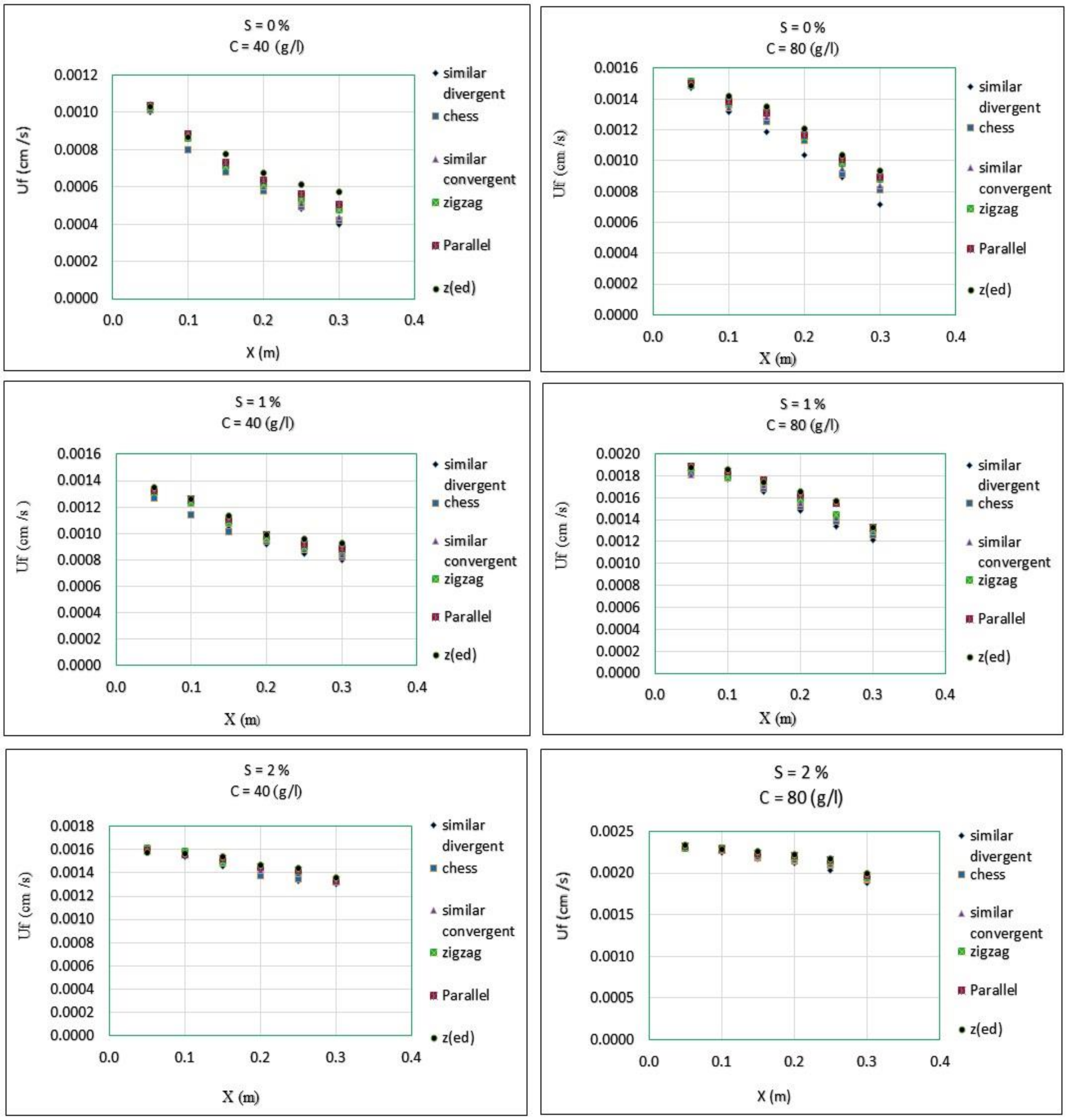

Figure (6): Changes of Front's Speed between Obstacles

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 front 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 speed of current reduces significantly in contrast to that of the free-obstacle position. As the bed's slope increases, the current's speed 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 speed 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 6, the longitudinal slope of the speed 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 speed reduction increases between obstacles and gets convex. By comparing two concentrations, it can be stated that the speed 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 speed 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 speed reduction becomes mild for 40 g/l concentration in the end of obstacles, although the slope of speed 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 speed reduction of the current's front would be higher with 80 g/l concentration in contrast to 40 g/l concentration.

Investigating Effect of Densimetric Froude Number on Obstacles' Arrangement

The arrangement and decoration of obstacles have impact on the Froude number of density current's front. In all treatments of this study, the influence of the arrangement of obstacles in reducing the Froude number of the density current is respectively shown in the Similar Convergent, Chess, Similar Divergent, Zigzag, Parallel, and Z form. The amount of this influence is not the same in various slopes and concentrations. For 40 g/l concentration, as the slope increases from 0 % to 1 %, the influence of obstacles on Froude number decreases 41 %. This amount is 48 % when form 1 % slope toward 2 % slope. Similarly, these values are 21 % and 33 % for 80 g/l concentration. In Table 2, the effect of obstacles on reduction of Densimetric Froude Number is presented by percentage.

Table (2): Obstacles' Effect on Reduction of Densimetric Froude Number by Percentage.

Concentration (g/l)	Slope (%)	Similar Convergent	Chess-Like	Similar Divergent	Zigzag	Parallel	Z	Obstacles Arrangement	Frd 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

Based on Table 2, the effect of obstacles' arrangement decreases as the bed's slope increases. Due to the great density difference in 40 g/l and 80 g/l concentrations, it does not seem that the increase in density can significantly increase the effect of obstacles' arrangement. There is much place for researching on the subject of concentrations with lower density difference.

Investigating Relations of Speed for Density Current's Front and Comparing them

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 (8) for speed (velocity) of density current's front.

$$v = C\sqrt{(m.s.d)} \tag{8}$$

In relation 8, *v* is velocity of the front, *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 front is introduces as a subject to the front's height and reduced gravity acceleration. Keulegan (1958) has proposed Relation 9 for the velocity of the density current's front. In this relation, *Uf* is velocity of the front, *C* is empirical coefficient, g' is reduced gravity acceleration, and *Hf* is the height of the density current's front.

$$\mathrm{Uf} = \mathrm{C}\,(g'\,\mathrm{Hf})^{0.5} \tag{9}$$

The calculation of *C* is obtained when the velocity of the density current's front (*Uf*) and the cutting densitometric velocity (g' Hf) are at hand. Other researchers have introduced some coefficients for *C*. The conditions and coefficients of the treatment have been presented in Table 3.

Table (3): Conditions and Coefficients of the Treatment by Various Researchers

C	Type of Current	Slope (%)	Researcher
0.75	Saline	S > 4	Keulegan, 1958
0.75	Saline	0 < S < 4	Middleton, 1966
√ 2	Sediment	0	Turner, 1973, 1979
0.68	Sediment	1.5	Denton, 1985
0.63	Saline & Sediment	0 < S < 2.9	Altinakar et al., 1990
0.75	Saline & Sediment	0.635	Ghomeshi, 1995

Altinakar et al. (1990) have compared their data with those of Middleton and Turner and suggested the coefficient 0.63. This coefficient is the lowest value amongst others which indicates that the velocity of density current's front is approximately constant along the canal and its relative changes is less than 1 %. Turner has used the body height of current density in order to calculate the volumetric cutting velocity, however others have used the height of current's front. To this reason, the Turner's coefficient (C) has the highest value amongst others. Due to the different laboratory conditions, it is seen that the coefficients (c) are similar in the treatments of Keulegan, Middleton, and Ghomeshi.

In Figure 7, instead of the values of volumetric cutting stress, the front's velocity (in this study) is presented to compare the other works.

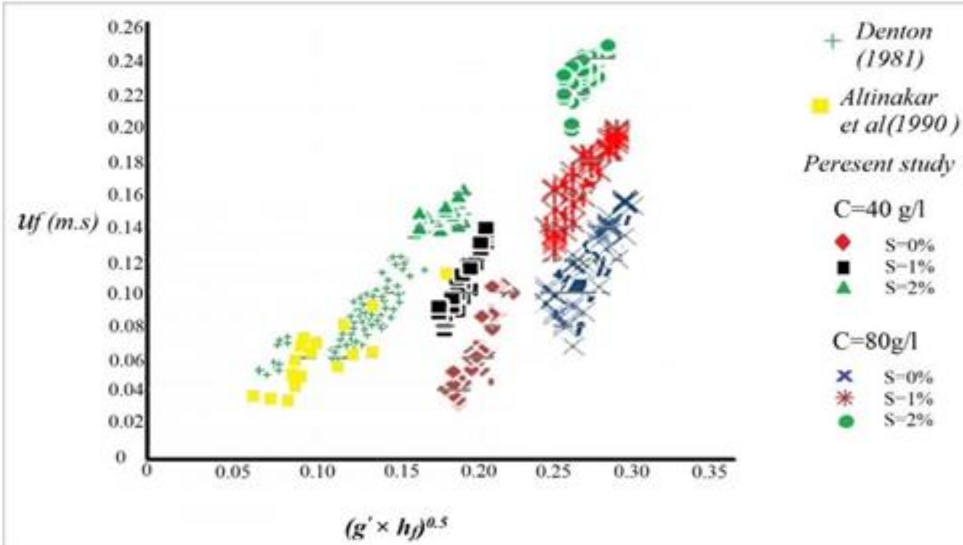

Figure (7): Values of Volumetric Cutting Stress and Velocity of Front

Based on Figure (7), the highest values for velocity of density current's front is located in the 80 g/l concentration on the 2 % slope. Therefore, it can be stated that as a result of increase in the bed's slope or the concentration of the density current, the volumetric cutting stress increases which consequently leads in increasing the velocity of the current's front.

Ghomeshi (1995) has proposed the Relation 10 for determining Keulegan's coefficient in terms of bed's slope.

$$C = 1.0403\, S^{0.0303} \tag{13}$$

Putting the value of 0.635 (Ghomeshi used this slope too) in Relation 10, the value of 0.89 is obtained which is estimated a little above the coefficient of 0.75 presented by Ghomeshi. In this present research, based on this Relation in the free-obstacle condition, the C coefficient is 0.73 on 0 % slope, 0.9 on 1 % slope, and 0.92 % on 2 % slope which is estimated higher the C values. It seems that this Relation can estimate the better values on the small slopes.

The calculated coefficients of C in this research have been presented for various arrangements of obstacles as well as correlational coefficient (Table 4).

Table (4): Coefficients in Various Slopes and Arrangements

C		Slope (%)
0.49	Control	0
0.38	Similar Convergent	
0.40	Chess-like	
0.43	Similar Divergent	
0.45	Zigzag	
0.43	Parallel	
0.44	Z-form	

0.66	Free-obstacles	1
0.57	Similar Convergent	
0.58	Chess-like	
0.59	Similar Divergent	
0.60	Zigzag	
0.62	Parallel	
0.63	Z-form	
0.88	Free-obstacles	2
0.88	Similar Convergent	
0.81	Chess-like	
0.82	Similar Divergent	
0.83	Zigzag	
0.84	Parallel	
0.84	Z-form	

Based on Table 4, increase in bed's slope cause to increase the values of C coefficient. The amount of this value is higher in free-obstacle condition than the condition of existence of obstacles. In this study, the provided coefficient on 0 % slope is lower than that of the other researchers'. On the 1 % slope, it is closer to the coefficient of Altinakar et al. and Denton. It sounds that this similarity is due to the similarity between bed's slopes. On 2 % slope, the provided coefficient is 0.88 in this study which is higher than that of others. In addition, it seems that this increase is due to the high concentrations (40 & 80 g/l) and buoyancy of the current as well. The C coefficient is not the same in the various arrangements of the obstacles. However, the similar convergent arrangement has had a better yield in controlling the current's development, the C coefficient in the similar convergent arrangements has the lower value on three slope (in contrast to the free-obstacle state). The difference of C amount reduces in the free-obstacle condition in contrast to the condition of various arrangements, as the bed's slope increases. For instance, the difference between two conditions in similar convergent arrangement are 0.11, 0.09, and 0.08 on the 0 %, 1 %, and 2 % slopes respectively.

Conclusion

Controlling the density currents plays an important role in maintaining the life expectancy of dams' reservoirs. The velocity of this current depends on the current's height, reduced gravity acceleration, and the primary conditions of entering current into the reservoir. The results of this research show that the movement velocity of density current has a reducing progress and the height has an increasing progress along the canal in the free-obstacle condition. As the bed's slope and current's concentration increase, the velocity of current increases and on the other the height of current decreases. For 40 g/l concentration on 0 % and 2 % slopes, the creation of obstacles, on average, cause reducing 59 % and 18 % for the Densimetric Froude Number. 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.

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 front, 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.

Resources

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