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Experimental study on different aspects Velocity of Density Current's in dealing with permeable obstacles

Seyed Mostafa Tabatabae [1], Hossein KhozeymehNezhad [2], Abolfazl Akbarpuor [3], Peyman Varjavand [4]

1. M.S.C in Water Resources Engineering, University of Birjand .Iran.
2. Assistant Professor, Department of Water Engineering, Faculty of Agriculture University of Birjand. Iran.
3. Associate Professor, Department of Civil Engineering Technical University of Birjand, Iran.
4. Research assistant professor of agricultural engineering research department, Khuzestan agricultural and natural resources research center, AREEO, Ahwaz, Iran.

***Corresponding Author email*:** Tabatabaei1984@yahoo.com

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 investigated different aspects velocity of density current's in dealing with permeable obstacles. The experiments of density current were performed in a channel length of 10 meters in three bed slope of zero, one and two percent by Six types permeable obstacles arrangement. covering Obstacles' was three meters. Concentration of density current was 40 g/l. Then density current velocity was measured in six and four sections 0.5 meters between and after permeable obstacles'. According to the results due to turbulence and mixing In the common region of density current and around water, In bed without obstacles, from 9 - 34% increases richardson numbers by advancing density curent along the channel. Increasing the bed slope to increase momentum and strengthen the stability of the density current. Permeable obstacles as a resistance force, decreases velocity of density current.Average velocity reduction in the slope of 0, 1 and 2% is 42 and 31% for similar convergent and Z(ed) form arrangement.The fitting velocity of the equation shows that S furthermore to the effect on hydrodynamics of density current, can be effective separately in the equation.**Keywords:** Experimental model, Density Current, permeable Obstacles', River bed

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).

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, $\Delta\rho$ is the density difference between the two fluids. Froude number is an important parameter in density current investigation(Equation 2). According to equation (3) investigation mixing intensity of density curent used the Richardson number equation.

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

$$F_{r_D} = \frac{U}{\sqrt{g' \times h\, cos\theta}} \quad (2)$$

$$R_i = \frac{1}{{fr_d}^2} \quad (3)$$

The development Velocity is the progress rate of current toward the area which is calculated by means of simple hydraulic calculations (Turner., 1973). (Tsihrintzis and Alavian, 1966) have shown that the density current develop in length as a result of four forces: gravity, floating (buoyancy), inertia, and friction. they have introduced these forces in the continuation of bed in Table 1, Relations. In these relations, $\Delta\rho$ 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.

Table 1. Development of density current

Force	force Gravity	buoyancy force	inertia force	friction force
Relation	$F_g \sim \Delta\rho gbhl\, sin\theta$	$F_{bx} \sim \Delta\rho gbh^2\, cos\,\theta$	$F_{ix} \sim \frac{\rho bhl^2}{t^2}$	$F_{dx} \sim \frac{\rho vbl^2}{ht}$

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.

(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.

The study studied different aspects of density current. the first flow studied onto the substrate without barriers. then studied velocity of density currnt after colliding with permeable obstacles. Experiments was three sloping bed and six types of obstacles arrangement. So far, has not been studied velocity of density current in dealing with different arrangement of permeable obstacles.

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 one densities (40 g/l) .

In order to survey the effect of obstacles' arrangement on the (development) Velocity of the 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. 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, 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. 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 2.

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. Figure 1 Plan arrangement of obstacles and In Figure 2, there is presented a simulated scheme for density current. In Figure (3) shows Schematic diagram of the head and example of density current in the laboratory environment.

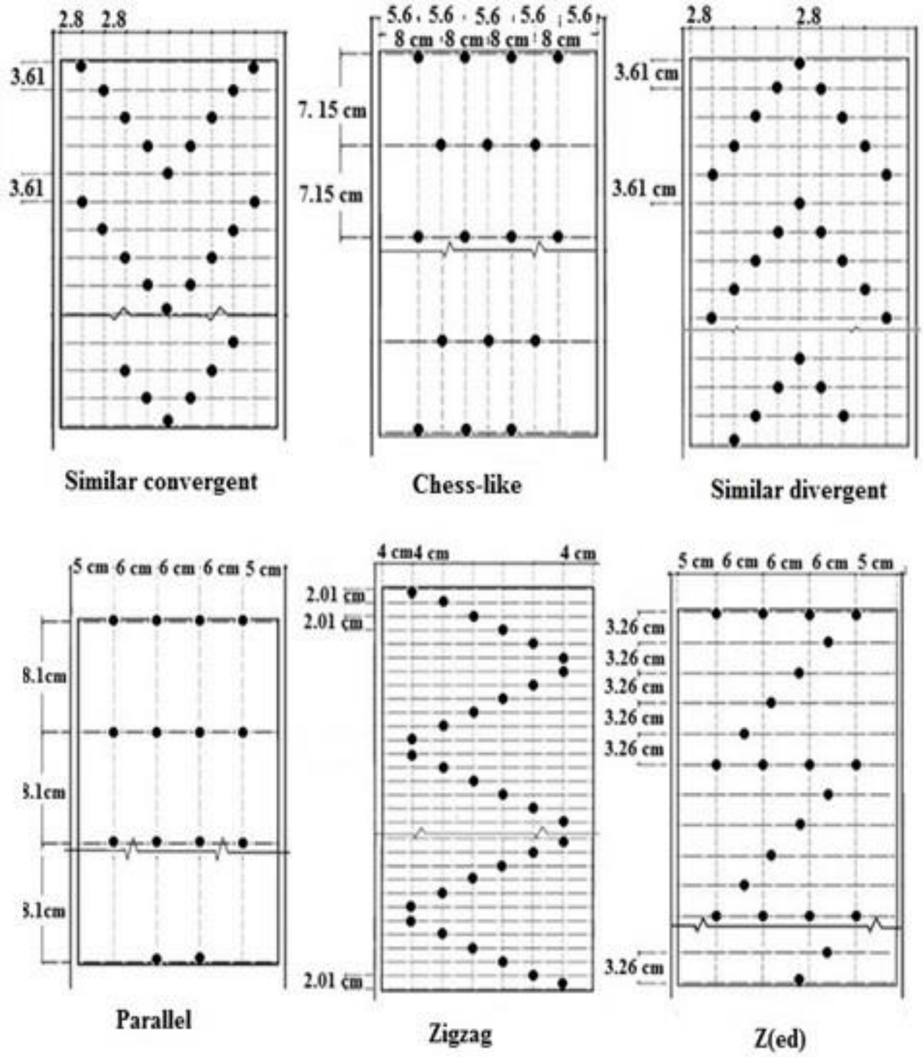


Figure 1. Plan of Arrangement Obstacles

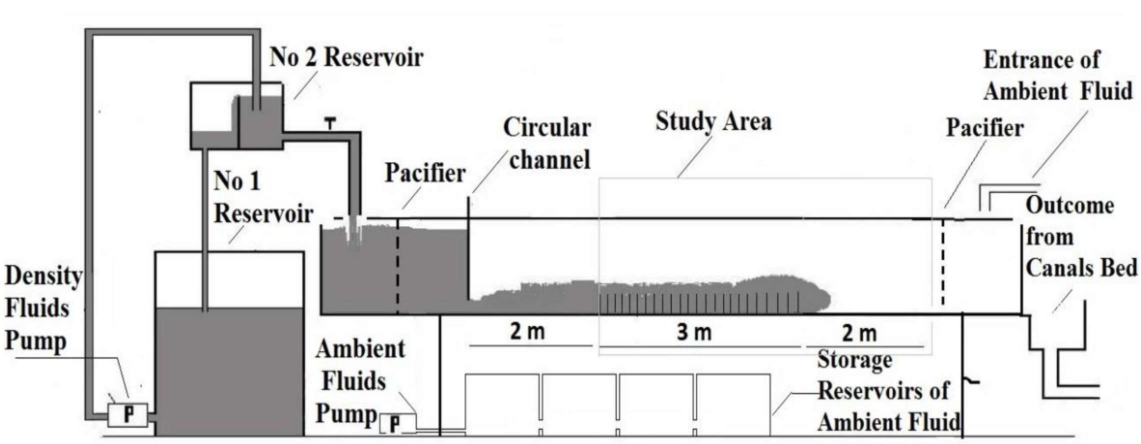


Figure 2. A Scheme for Simulator of Density Current

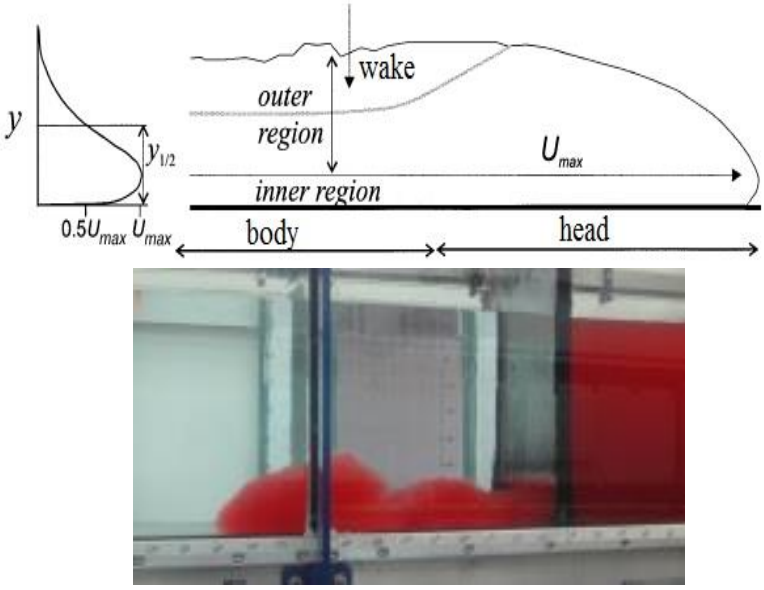


Figure 3. Schematic diagram (Kneller and Buckee, 2000) and example Density Current's in the laboratory of present Study

Table 2. Summarized test

Number of tests	Bed Slope (%)	Δρ	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

RESULTS AND DISCUSSION

Investigating of Density Current in the substrate without obstacles

As motin density current on the substrate the Subscribe area of density current with around water reduced of density difference in between the two fluids of common area. Thus, as shown in Figure 3 increases Richardson number to advance along the channel. This figure shows changes of Richardson number in length dimensionless (dividing point on the whole length). Changes of Richardson number are different for three bed slope. in during the channel without bed slope (S= 0), has increased Richardson number amount 34 percent. By increasing the bed slope (S= 2), this amounts to 9 percent. with increasing Richardson number along the channel, increases height of density currnt. Changes height of density currnt in the length channel relative to bed slope is shown in Figure 5. And according to in a situation that S=0% The height has increased 20 percent and in a situation that S=2% the height has increased 20 percent.

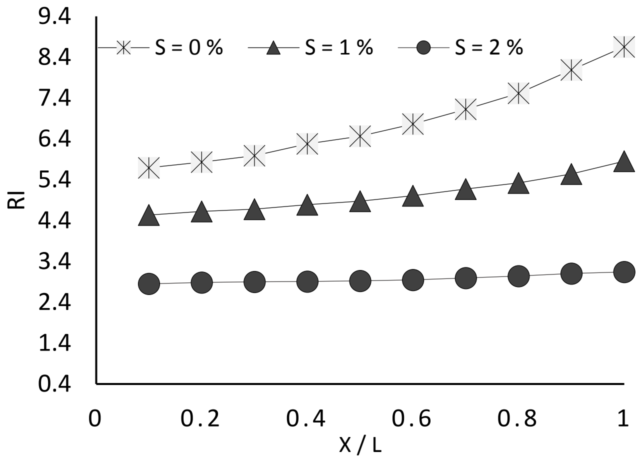


Figure 4. Changes of Richardson number in Length

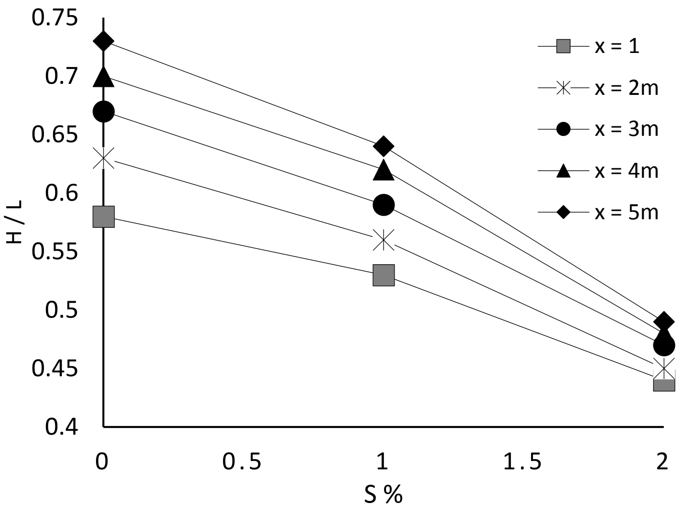


Figure 5. Changes Height of Density Current’s in the bed slope

By advanced density current along the channel and incorporation of the water with density current is reduced the density difference two fluid that is move the main factor.So proportional to the increase Richardson number along the channel reduced velocity of density current along the channe. Figure 6 and 7, shows velocity change in front of the Richardson number in the two slope. The slope of zero changes shows the amount 8 percent velocity of density current relative to the Richardson number. This amount in the bed w slope of two to less than 2 percent.

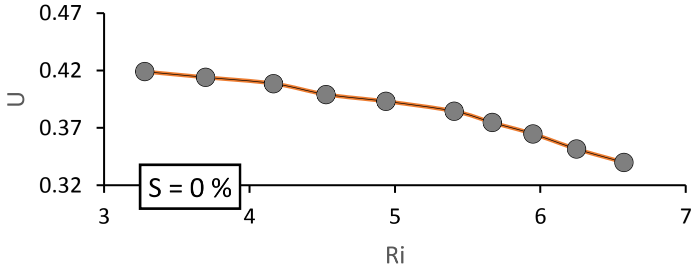


Figure 6. Changes velocity of Density Current’s in the Richardson numbers (S =0)

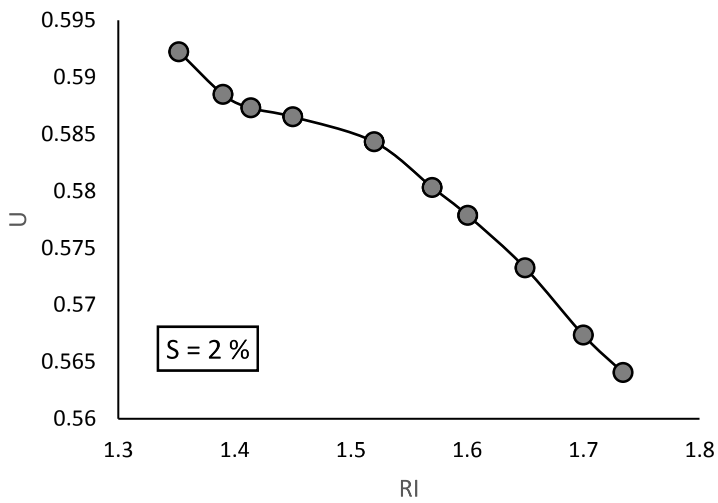
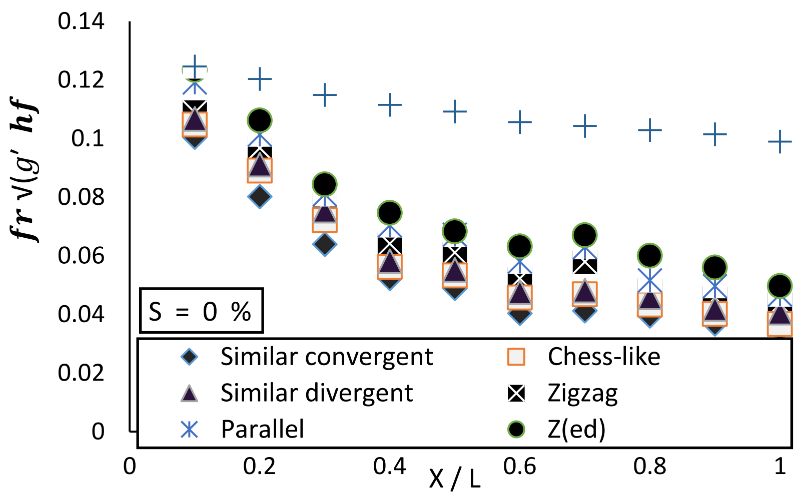
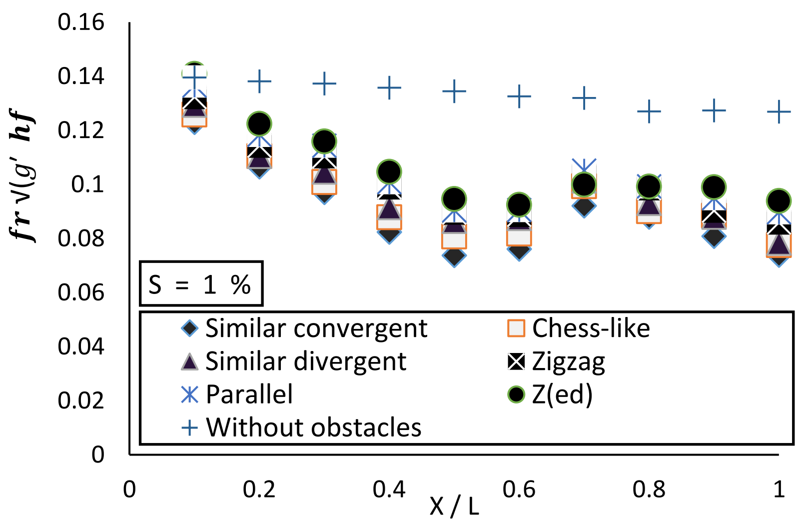


Figure 7. Changes velocity of Density Current's in the Richardson numbers (S = 2%)

Investigating velocity of density current in the substrate with Permeable obstacles

Figure 8, shows changes velocity of density current's in tree slope along the channel.





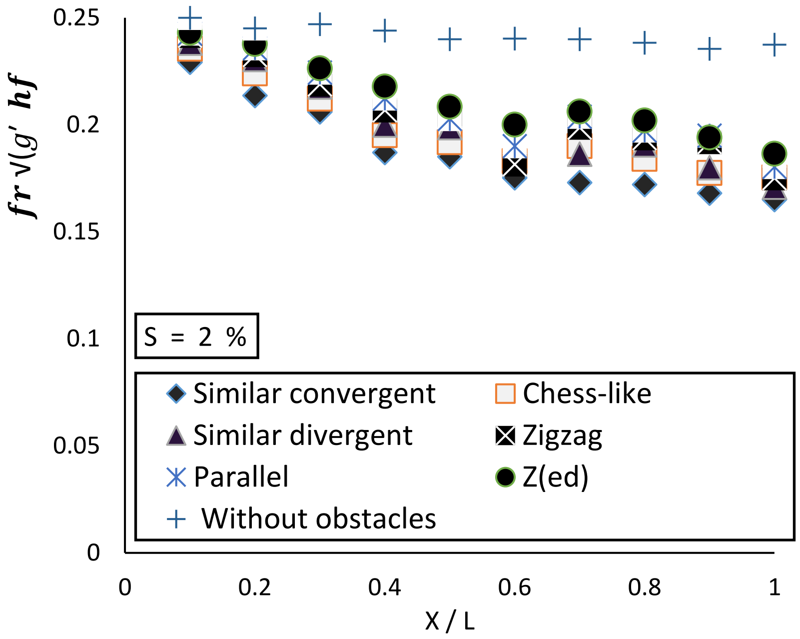


Figure8. Changes velocity of obstacles arrangement in slope of 0, 1 and 2%.

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, is the lower the stability.

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 8, 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. The average effect of Velocity reduction and Arrangement envelopment obstacles has been shown in Table 3.

Table 3. Effective of obstacles to Reduce the Velocity of dencity current

Slope (%)	Similar Convergent	Chess-Like	Similar Divergent	Zigzag	Parallel	Z	difference between the arrangements	Average Reduction
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

Finally, Order to predict head velocity density current equations were fitted using SAS statistical softwar (Based on the reduced gravity, height and bed slope). Results are shown in table 4.

Table 4. velocity predicted using SAS statistical software

Arrangement	Equation
Free-obstacles	$U_f = 0.25986 - 0.60046\,(g'H_f)^{0.5} + 0.01097(S)$
Similar Convergent	$U_f = -0.23845 + 1.56705(g'H_f)^{0.5} + 0.04995(s)$
Chess-Like	$U_f = -0.22621 + 1.46869(g'H_f)^{0.5} + 0.05051(s)$
Similar Divergent	$U_f = -0.25580 + 1.61533(g'H_f)^{0.5} + 0.05416(s)$
Zigzag	$U_f = -0.33331 + 1.98428(g'H_f)^{0.5} + 0.05649(s)$
Parallel	$U_f = -0.36497 + 2.10344(g'H_f)^{0.5} + 0.06223(s)$
Z-(form)	$U_f = -0.40221 + 2.25667(g'H_f)^{0.5} + 0.06580(s)$

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 the bed slope of the density currents is will an increase in velocity of density current. Permeable obstacles Acts against velocity of density current as a resilient force, and reduces velocity of density current. 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 current. As the slope in canal's bed increases, besides the hydraulic gradient, the bed's slope also affects the velocity of density current. By increasing the bed slope from zero to two, velocity of density current reached from 0.12 to 0.14 at the starting point. By continuing motion of density current in 2% slope,Permeable obstacles have Less effective on the velocity of density current. for example velocity dropped the amount 19% in 2% slope for Chess-Like arrangement. Similarly that amount in a 0% slope is 63% to the same arrangement. Therefore, with the increase of slope to 2 %, are reduced changes in Richardson numbers.Performance arrangement of Similar Convergent was better than the other arrangements. So that Changes Richardson number in arrangement of similar convergent more than as other permeable obstacles arrangement. And had the best effect on velocity reduction of density current.

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.

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