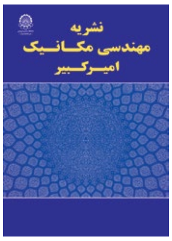

Amirkabir Journal of Mechanical Engineering

Amirkabir J. Mech. Eng., 53(1) (2020) 1-3
DOI:

Numerical Simulation of Three-Dimensional and Bi-Disperse Particle-Laden Turbidity Current in an Experimental Channel in the Presence of an Obstacle

S. Teymouri and E. Khavasi*

Department of Mechanical Engineering, University of Zanjan, Zanjan, Iran

ABSTRACT: In the present study, the propagation of a continuous three-dimensional, in collision with obstacle and bi-disperse particle-laden turbidity current with a large eddy simulation method was modeled using the OpenFOAM numerically. Due to the presence of a large number of suspended particles, the Eulerian-Eulerian method has been used and for each particle a concentration equation, which the particles settling velocity has been added to, is solved. The results show that before the obstacle, there is no significant change in the current velocity profiles in with and without obstacle state, but the presence of an obstacle decreases the maximum velocity by 10%, also the number of suspended particles on the obstacle decreases in channel width. In the final semi-stable state, the maximum concentration of 15.3% is reduced compared to the without obstacle state. By increasing the particle diameter to 20 and 30 microns, maximum concentration is increased by 12.5% and 22.3%, the number of suspended particles also decreases by 68% and 21%, respectively. As a result, particles with larger diameter precipitate more and rapidly. Changing the inlet concentration in the case of smaller diameter particle increases the number of suspended particles by 11.2% and current will have more capability for carrying suspended particles.

Review History:

Received:
Revised:
Accepted:
Available Online:

Keywords:

Density continuous current
Obstacle
Turbidity
Particles
Large eddy simulation

1- INTRODUCTION

In this paper hydraulic jumps, instability along the common boundary of two fluids, turbulent structures along the wall, the distribution of turbulent quantities and instabilities in the current are well illustrated. The Eulerian-Eulerian method for density current contains small particles is the best choice because acceptable results are obtained with the lowest possible computational cost.

In this paper, we tried to investigate the density current behavior and the sedimentation of particles in the encounter of topographic changes by putting obstacle. In the present study, a density current of bi-disperse particle-laden is simulated and the analysis emphasizes the effects of an obstacle to the dynamics and density current turbulence and the particle sedimentation. Current contains particles and the particles diameter effect on the current front location and the number of suspended particles are studied.

2- PROBLEM INFORMATION

In the present study, the diffusion of density current bi-disperse particle-laden is modeled in a three-dimensional channel. The physical field specification in this study is been chosen in accordance with the conditions employed in Garcia experimental experiments [1]. In order to consider the slop effect 1%, gravity acceleration components are defined as g = (0.098055, -9.8, 0). This problem is considered to be quasi-steady state, and y^+ is about one in this study.

*Corresponding author's email: khavasi@znu.ac.ir

3- GOVERNING EQUATIONS

In this study, Large Eddy Simulation (LES) method was used to simulate the current. This method is able to calculate three-dimensional and unsteady quantities instantaneously so that the methods of Navier Stokes equations are not able to calculate by Reynolds Average Navier-Stokes (RANS) method [2].

The final equations governing for this current are filtered in this section. In this research, a three-dimensional box filter or "cubic root of cell volume" filter (which is equivalent to averaging over volume) has been used and to ensure better results along the wall, the Van driest damping function is proposed by Moin and Kim [3], has been used. With respect to the continuity equation, we can write [2]:

$$\frac{\partial}{\partial x_k}\left(\nu_{SGS}\frac{\partial u_l}{\partial x_k}\right)=\frac{\partial}{\partial x_k}\left(2\nu_{SGS}S_{lk}\right) \tag{1}$$

where S_{lk} is filtered strain rate. Using Eq. (1) in the momentum equation, the continuity, momentum, and concentration equations are presented in the following form [2]:

$$\frac{\partial u_k}{\partial x_k}=0 \tag{2}$$

$$\frac{\partial u_l}{\partial t}+u_k\frac{\partial u_l}{\partial x_k}=\upsilon_w\frac{\partial^2 u_l}{\partial x_k\partial x_k}+\frac{\partial}{\partial x_k}\left(2\upsilon_{SGS}S_{lk}\right)-\frac{1}{\rho_w}\frac{\partial_p}{\partial x_l}-g'c\delta_{21} \tag{3}$$

$$\frac{\partial c_n}{\partial t}+u_k\frac{\partial c_n}{\partial x_k}=\alpha\frac{\partial^2 c_n}{\partial x_k \partial x_k}+\frac{\partial}{\partial x_k}\left(\alpha_{SGS}\frac{\partial c_n}{\partial x_k}\right) \tag{4}$$

where ρ_w and ν_w are the density and viscosity of the environmental current (water). Also, gravity is in the opposite direction of y or i=2. In the above equations, Boussinesq approximation is used for concentration.

The driving force of motion is the density difference, this type of currents after a while is stopped and depreciated with the loss of particles due to sedimentation and zeroing its density difference. To correct this equation, the settling term is added to the concentration equation, the Stokes relationship has been used to get the settling velocity. This relationship is as follows:

$$v_f = g\,D_p^2\frac{\rho_p-\rho_w}{18\mu} \tag{5}$$

In this equation, the fluid viscosity is μ that considered to be approximately equal to the water viscosity and the effect of particles on it is ignored and D_p is the average diameter of the particles.

$$\frac{\partial c_n}{\partial t}+u_k\frac{\partial c_n}{\partial x_k}=\alpha\frac{\partial^2 c_n}{\partial x_k \partial x_k}+\frac{\partial}{\partial x_k}\left(\alpha_{SGS}\frac{\partial c_n}{\partial x_k}\right)+\upsilon_{f_n}\frac{\partial c_n}{\partial x_k}\delta_{2k} \tag{6}$$
$$n=1,2,\ c=c_1+c_2$$

As seen in Eq. (5), the diameter of the particles influences the particle settling velocity and the settling velocity on the concentration equation. Diameter of particles is based on the average diameter for kaoleen particles that usually used for turbidity current experiments [4, 5]. The dynamics of dynamic Smagorinsky method presented by Lilly [6] is used to solve the equations.

To solve this problem, Open FOAM with open source code is used, which is specific for the Linux environment and in C++. The used solver is prepared by adding two concentration equation and the settling velocity parameter to the PisoFOAM solver. Also, a 12-core computer with a processor of 3.6 GHz and a 16-GB RAM was used to perform simulations. Each run takes about 5-6 days.

4- SEDIMENTATION IN TURBIDITY CURRENT

The number of suspended particles is calculated from the following equation [7]:

$$q_s=\int_0^\infty u(y)\,c(y)\,dy \tag{7}$$

Fig. 1 shows the number of suspended particles for channel without and with obstacle along the channel's length and width. The number of suspended particles decreases along the plain channel, without obstacle due to the deposition of particles but in the channel with obstacle, the two-part current and lateral deviation by the obstacle increase the sediment and thus reduce the number of suspended particles on the obstacle.

Fig. 2 shows the effect of increasing diameter on number of suspended particles. According to the figure, it can be said that the number of suspended particles decreases with increasing particle diameter. In other words, larger particles will sediment sooner and fine particles are transported to more distances by flow. The amount of suspended particle decreases by increasing the diameter of the particles for 30 and 20 microns in diameter by 68% and 21%, respectively.

Fig. 3 shows two states that the entrance concentration of the particle with a smaller diameter and the particle with a greater diameter is not equal. In the case where the entrance concentration of the particle with a smaller diameter is greater (linear curve), the number of suspended particles is increased by 2/11% and the flow has more suspended load capacity.

Fig. 4 shows the number of suspended particles in the middle of the channel (z = 0) and near the side wall (z = 0.11). The number of suspended particles in the middle and near the wall are nearly equal before the obstacle but with approaching the obstacle and the flow becomes dual, in the middle of the channel, the number of suspended particles decreases further. After passing the obstacle and creating the front head, the particles are deposited on the sides, and in the middle of the channel, the number of suspended particles increase.

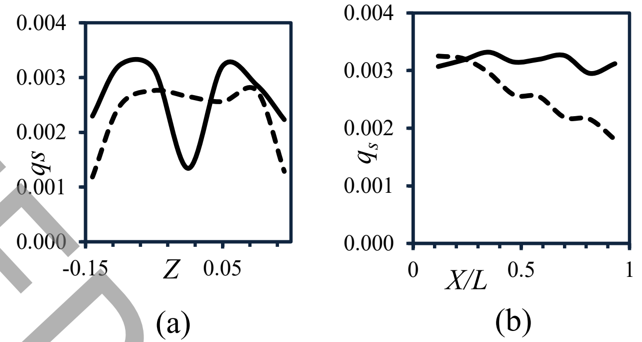

Fig. 1: The amount of suspended particle for plain channel without obstacle (dashed line) and channel with obstacle (line) a) along the channel (x) at z = 0 and b) in width of the channel (z) at x = 71.5h.

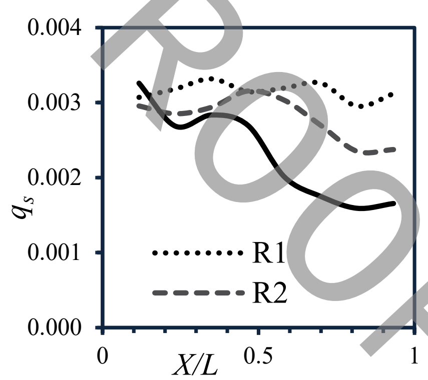

Fig. 2: The number of suspended particles for *R1*, *R2*, and *R3* along the channel

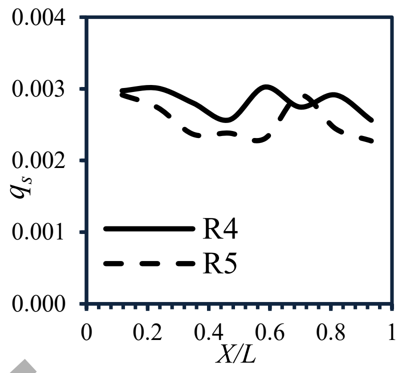

Fig. 3: The number of suspended particles for *R4* and *R5* along the channel

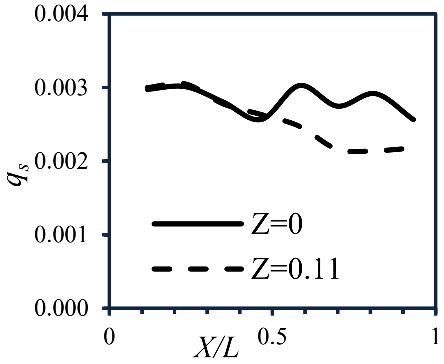

Fig. 4: The number of suspended particles in the middle of the channel (line) and near the walls (dashed line)

5- CONCLUSIONS

Density current after passing the obstacle and collision with the channel floor, with a change of phase from the supercritical region to sub-critical, has a hydraulic jump. The velocity profiles almost coincide with each other before the obstacle, it is indicating that before the obstacle the current behavior is almost the same as the channel without obstacle. Also, the presence of obstacle has reduced the maximum velocity of current by 10%. Also, the difference in maximum velocity of particles after the obstacle is greater.

The general figure of the concentration profile in the presence of obstacle is similar to the no obstacle state and the difference is generally at the current height. In the final steady-state, after current through the obstacle, the maximum concentration is compared with the no obstacle state by 15.3%. The concentration and the number of suspended particles increases and decreases with increasing particles diameter, respectively, and particles are transported to a greater distance by current. When the entrance concentration of the particle with a smaller diameter is greater, the number of suspended particles is greater and the current has a more suspended load capacity. By decreasing the entrance concentration, the particle deposits later. By decreasing the concentration, the instabilities on the common boundary increase and make it more intense in the environmental fluid entrainment and turbulence in the dense layer. Since turbulence is the main mechanism of suspension of particles, thus reducing concentrations, increasing the number of suspended particles and decreasing sediment rates.

REFERENCES

[1] M. H. Garcia, Hydraulic jumps in sediment-driven bottom currents, *J. Hydraul. Eng,* 119(10) (1993) 1094–1117.

[2] S. Abbaszadeh, *Large Eddy Simulation of Continuous Density Current impinging on Obstacles*, PhD Thesis, Department of Mechanical Engineering, Sharif University of Technology, Tehran 2014. (in Persian)

[3] J. Kim, and P. Moin, Numerical investigation of turbulent channel flow, *J. Fluid Mech* 118 (1982) 341–377.

[4] J. Zordan, C. Juez, A. J. Schleiss, and M. J. Franca, Entrainment, transport and deposition of sediment by saline gravity currents, *Advances in Water Resources* 115 (2018) 17-32.

[5] E Khavasi, M. Oshaghi, S. M. A. Mousavi, V. Zarei, M. Ghenaatpishe, B. Firoozabadi, and H. Afshin *Experimental investigation of the effect of obstacle on turbidity currents*, in Center of Excellence in Energy Conversion, School of Mechanical Engineering, Sharif University of Technology, Tehran, Iran 2012.

[6] D. K. Lilly, A proposed modification of the Germano subgrid-scale closure method, *Phys. Fluids A Fluid Dyn* 4 (3) (1992) 633–635.

[7] E. Khavasi, *Experimental study of sediment behavior of the particle laden density current,* Master's Thesis, Department of Mechanical Engineering, Sharif University of Technology, Tehran 2009. (in Persian)