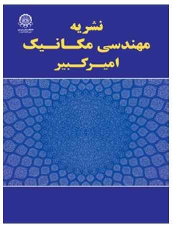

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Numerical Study of Lock Exchange Turbidity Current Depositional Behavior in Stratified Environment

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ABSTRACT: In this paper, three-dimensional numerical simulation was conducted to study the lock exchange turbidity current depositional behavior in a stratified environment. Simulations are carried out using Large Eddy Simulation method. The obtained results in stratified case are in good agreement with experimental data. Also, the presence of stratified environment reduces the current velocity, so that the front location is reduced by 57%, but does not have any significant effect on the sedimentation pattern. In addition, the results showed that increasing the slope to 12 degrees increases the sedimentation rate by 15 and 40 percent compared to the slopes 9 and 6 degrees. It was also observed that increasing the particle diameter reduced the momentum and the current sedimentation increases 0.75 and 3.7 times higher. For more accurate representation of the particle interaction, the particle settling velocity also varies with concentration. The results of this analysis indicate that assuming the variable settling velocity in the early stages of the current progression leads to insignificant change in the front velocity, but when the current propagates more, the faster front velocity will be predicted. In variable velocity case, the current separation location increases by 22%..

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1- Introduction

In the previous researches, density current in stratified environment studied experimentally without considering the effect of the particle existence [1]. In the present study, numerical simulation of the sedimentation behavior of lock-exchange turbidity current in a stratified environment has been carried out. In this simulation, using a large eddy model, modeling and studying the density current in a rectangular channel with a sloping bed, in non-particle states and in the presence of particle is discussed. To investigate the interaction between particles, simulation in a particle-laden current has been performed in two modes: the constant velocity settling velocity and particle variable settling velocity with concentration which is one of the innovations of this article. This research studies the effect of channel slope and stratified environment on numerical simulation results and comparing it with the experimental results of He et al. [1], it has been shown that this method is in good agreement with experimental results. It should be noted that by simulating this issue it is possible to study the natural currents more accurately.

2- Problem Formulation and Numerical Model

The lock exchange simulation in a rectangular reservoir with a 15 cm width, 280 cm length and 34 cm height has been performed. The gate height at the entrance is kept at 4 cm. The lower, upper and side plates are intended as wall, as well as the end of the channel has wall condition.

In the first case, the fluid inside the channel has a constant density and its density does not change with the location, hence the initial conditions of the problem will be homogeneous. In the second case, the fluid density of the channel environment is changed by a linear relationship with the location and layers the channel environment with different densities, Therefore, in this case, the density of the problem has a non-homogeneous initial condition, while the initial conditions for the parameters of velocity and pressure are homogeneous and constant by changing of spatial coordinates.

The next step is the stratified environment, the particle are added to it. For current containing particle, it is assumed that all particles have the same diameter and are Kaolin of density $\rho_p = 2650 \mathrm{kg/m^3}$ For all simulations, the input concentration is $c=(\rho_m-\rho_w)/(\rho_{max}-\rho_w)=0.78$, where ρ_m is average densities of the mixture of water and particles at the input, ρ_w is the clean water density and the maximum current density is ρ_{max}.

In all numerical simulations, the Reynolds number is $\mathrm{Re}=\sqrt{g'_0 h_1}.h_1/\nu$ (g'_0= initial reduced gravity, h_1= block rise height, ν = kinematic viscosity of water) greater than 3000, which ensures turbulence of the stream [1] as well as y^+ of this article is about one.

3- Governing Equations

A large Eddy simulation method provides a detailed description of turbulent current movements that hold most of the current energy (movements in longer dimensional scales).

In this study, simulations are carried out using large Eddy simulation method, three-dimensional box filter, dynamic

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Smagorinsky method and Van driest damping function [2]. According to the continuity equation, we can write [3]:

$$\frac{\partial}{\partial x_k}(\upsilon_{SGS}\frac{\partial u_l}{\partial x_k}) = \frac{\partial}{\partial x_k}(2\upsilon_{SGS}S_{lk}) \quad (1)$$

Where S_{lk} is filtered strain rate. Using the Eq. (1) in the momentum equation, the continuity equations, momentum and concentration (for mono-disperse particle-laden current) respectively, are determined using the relationships of continuity equation, momentum and concentration in the filtered form in the following form [3]:

$$\frac{\partial u_k}{\partial x_k} = 0 \quad (2)$$

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

$$\frac{\partial c}{\partial t} + u_k\frac{\partial c}{\partial x_k} = \alpha\frac{\partial^2 c}{\partial x_k \partial x_k} + \frac{\partial}{\partial x_k}(\alpha_{SGS}\frac{\partial c}{\partial x_k}) + v_s\frac{\partial c}{\partial x_k}\delta_{2k} \quad (4)$$

$$\frac{\partial c_2}{\partial t} + u_k\frac{\partial c_2}{\partial x_k} = \alpha\frac{\partial^2 c_2}{\partial x_k \partial x_k} + \frac{\partial}{\partial x_k}(\alpha_{SGS}\frac{\partial c_2}{\partial x_k}) \quad (5)$$

In this paper, the following relationships have been used to obtain the Stokes constant settling velocity, particle variable settling velocity and sediment profile [4-7]:

$$v_s = gd_P^2\frac{\rho_P - \rho_w}{18\mu} \quad (6)$$

$$v_s = V_0[e^{-k_1(c-c_{\min})} - e^{-k_2(c-c_{\min})}] \quad (7)$$

$$Q_s(x) = \int_0^\infty C_w(x,t)v_s dt \quad (8)$$

Where μ is fluid dynamic viscosity, d_p particle diameter, $C_{min}=0.002C_{in}$, $k_1=0.00565$, $k_2=0.02$, V_0=Stokes constant settling velocity and is density current concentration on the channel surface.

4- Numerical Results

In stratified environments, the Kelvin–Helmholtz instability appears and develops when the density current is formed. For density currents in a uniform environment, instabilities due to the more speed are larger. As a result, the structure of turbulence is rapidly formed and there is no Eddy in its large size. In the compared to density currents in a uniform environment, the turbulence mixing of density currents in stratified environments generally decreases.

In addition, the results showed that with increasing channel slope, the vertical component of the inertial force ($F\sin\theta$) has been strengthened therefore, the amount of sedimentation increases. This case is correct when the channel slope is less than 45 degrees and the vertical component of inertia is the dominant force of the current. In the previous range of current separation, The 12 degree slope increases the sedimentation rate by 15 and 40 percent compared to the 9 and 6 degrees slopes.

By investigating the results, it was observed that increasing the particle diameter reduced the momentum current. The larger particle falls more rapidly due to more weight. The amount of sediment in the turbidity current in separation start range, which contains particle with 30 microns diameter, is 0.75 and 3.7 times more than the particle of 20 and 10 microns, respectively. Due to the sediment amount increase with increasing particle diameter, the driving force of the current induced by the density difference due to the presence of suspended particle decreases. Therefore, the current containing larger particle is depreciated faster than the current containing smaller particle. Consequently, the current is containing 30 microns diameter particle is separated earlier than the other cases from the channel surface, and the amount of particle deposition reaches zero.

In the next section of the paper, the particle velocity is considered to be variable with concentration for more accurate representation of the particle interaction. In variable speed mode, the current separation location increases by 22% (As shown in Fig. 1). The driving force of the density current is increased in this case. The driving force has caused the particles to be deposited much less in the canal (About 90% decrease in sedimentation) and the current is going to propagate more distant.

Investigations in the research showed that the current head velocity of the density current with a discontinuous entrance is inversely related to any factor that causes the density difference to be reduced or eliminated. Among these factors is the sedimentation of suspended particle.

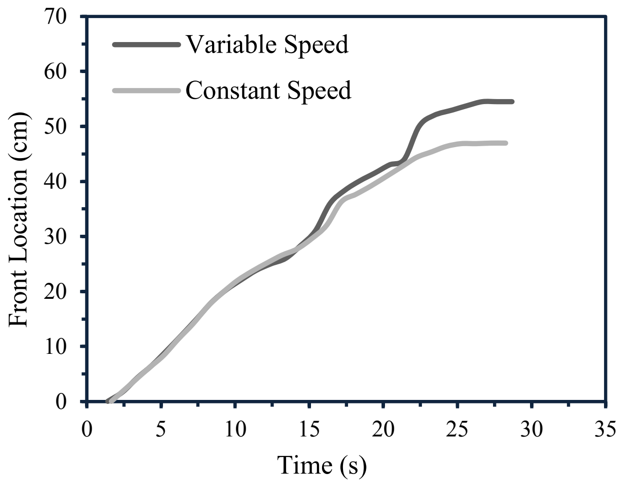

Fig. 1. The density current front location diagram containing the particle of 20 microns in the case of constant and particle variable falling velocity with a concentration in a density stratified environment

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