Annual (International) Conference on Mechanical Engineering-ISME2009
Iran, Tehran, University of Tehran, April 2009

Performance of Different Turbulence Models in Modeling Two-Dimensional Density current With Hydraulic Jumps

Mani Mahdinia
M.Sc. Student
Mahdinia@mech.sharif.ir

Bahar Firoozabadi
Associate Professor
Firoozabadi@mech.sharif.ir

Hossein Afshin
PHD Student
afshin@mech.sharif.ir

Sharif University of Technology, Mechanical Engineering School, Tehran ,Iran

Abstract
In this article, $k-\varepsilon$, $k-\omega$ and Reynolds Stress turbulence models have been used for numerical simulation of hydraulic jumps in density currents. The SIMPLE algorithm for pressure-velocity coupling has been used to investigate the vertical structure of a density current encountering a hydraulic jump in its path. Distribution of quantities such as Richardson number, velocity and concentration in the height of the current and different sections have been calculated and compared with the experimental results. Validity of the Belanger semi-empirical equation for hydraulic jumps in density currents, stability of the current and the effect of the inlet concentration on the results of the simulation have also been investigated. The results show that the models used, have weaknesses and strengths in simulating different parts of the current. Such a behavior can be a consequence of the complexity of the current in the presence of the phenomena such as mass and momentum transfer and shear stress at the interface and at the bed. Also, the existence of internal hydraulic jumps is an important instability source, which has been investigated qualitatively in this article. Finally, it can be argued that the Reynolds Stress model has the ability to give results which are more accurate than those of the other models.

Keywords: Density current, 2D current, Two, three and four equation turbulence models, Hydraulic jump

Introduction
Density currents are formed when the inflow fluid has a density difference with the ambient fluid and a tangential component of gravity becomes the driving force [1,2,3]. The following figures show a schematic sketch of such a current.

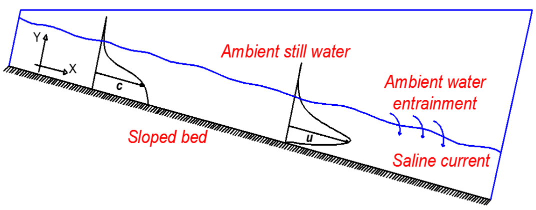

Figure 1 Schematic sketch of the density current

Until now, there has been only a limited and insufficient study of the hydraulic jumps in the density currents, either numerically or experimentally.

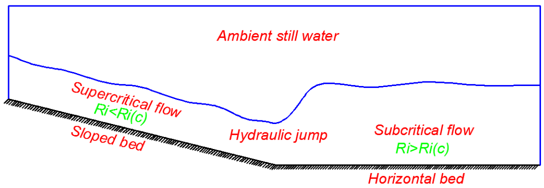

Figure 2 Hydraulic jump in density current

One such study is the experiments performed by Garcia in 1993 [4], which investigate the density currents in moving from an inclined surface to a horizontal one. The results of the present article have been validated using this empirical data.

Governing Equations and Boundary Conditions
The equations of mass conservation, momentum in the flow direction and in the direction normal to it and the concentration equation are as follows:

$$\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}=0 \tag{1}$$

$$\frac{\partial u}{\partial t}+u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}=-\frac{1}{\rho}\frac{\partial P}{\partial x}+g'\sin\theta+\frac{\partial}{\partial x}((\nu+\nu_t)\frac{\partial u}{\partial x})+\frac{\partial}{\partial y}((\nu+\nu_t)\frac{\partial u}{\partial y}) \tag{2}$$

$$\frac{\partial v}{\partial t}+u\frac{\partial v}{\partial x}+v\frac{\partial v}{\partial y}=-\frac{1}{\rho}\frac{\partial P}{\partial y}-g'\cos\theta+\frac{\partial}{\partial x}((\nu+\nu_t)\frac{\partial v}{\partial x})+\frac{\partial}{\partial y}((\nu+\nu_t)\frac{\partial v}{\partial y}) \tag{3}$$

$$\frac{\partial \delta}{\partial t}+u\frac{\partial \delta}{\partial x}+v\frac{\partial \delta}{\partial y}=\frac{\partial}{\partial x}((D+D_t)\frac{\partial \delta}{\partial x})+\frac{\partial}{\partial y}((D+D_t)\frac{\partial \delta}{\partial y}) \tag{4}$$

To close the system of equations, different turbulence models have been used. These include: $k-\varepsilon$, $k-\omega$ and Reynolds Stress models. On the inlet boundary, the concentration and velocity distribution are known. The saline current enters the channel, under the quiescent pure water, with a uniform concentration and velocity. On the surface of the bed, the velocities and normal concentration gradient are zero, because of the movement of the fluid in contact with the solid boundary. Due to the large height of the quiescent water, the upper boundary of the fluid has been given a symmetry boundary condition. At the end of the channel, the current is fully developed. But this condition can lead to a pressure feedback and invalidation of the results. So the length of the solution area has been assumed to be somewhat larger than real.

Then, the flow field has been solved using an unsteady approach, and it has been made sure that the velocity and concentration profiles do not change with time at the sections which were used for the validation.

Solution method

In this work, the finite volume method has been used to solve the equations. In order to find the velocity components and the concentration, the equations were solved in a Cartesian coordinate system in a collocated grid. This means that all the variables are stored at the center of the control volume. Velocity components on the faces of the control volume are obtained by the Rhie and Chow interpolation method and then using the SIMPLE algorithm, the pressure-velocity coupling has been modeled. Convection fluxes have been discretised, using the Hybrid method and the resulting equations have been transformed into a tri-diagonal matrix, and solved with the Tomas algorithm. Convergence criterion is defined as the ratio of the sum of the absolute errors to the entering flux which should be less than 10^{-5} for all of the variables. Fluent 6.1 software has been used for the present simulations.

Results

The results for the SALL11 and SAL29 saline currents, with the initial Δ concentrations of 0.013 and 0.012 are compared with the experimental data [4] and shown as:

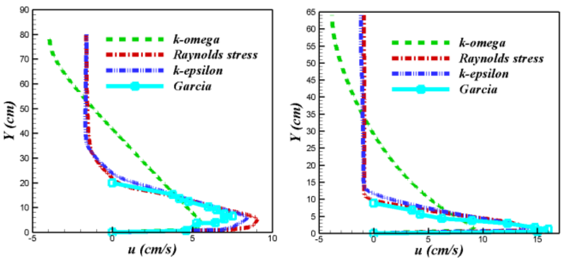

Figure 3. Velocity distribution in SALL29 exp. [4] in 3 & 8 meters from the inlet respectively

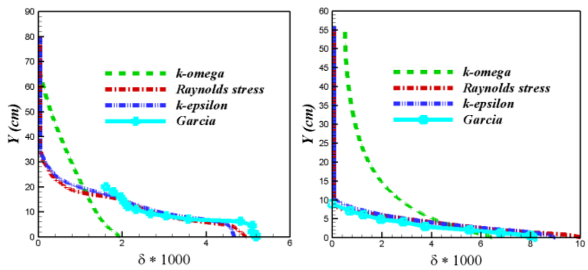

Figure 4. Concentration distribution in SALL29 exp. [4] in 2 & 9 meters from the inlet respectively

Results Discussion

The results of $k-\varepsilon$ & RSM turbulence models are close to the results of the Experiments of Garcia[4], but other parameters such as average flux and concentration and magnitude and position of the maximum velocity are calculated, which show the superiority of the Reynolds Stress model.

Conclusions

1) $k-\varepsilon$ and RSM models give the results which are

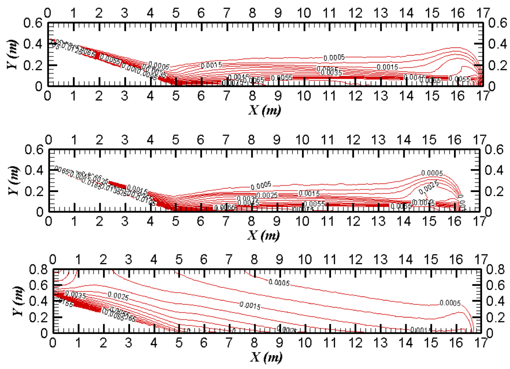

Figure 5 Concentration contours for $k-\varepsilon$, RSM & $k-\omega$ methods respectively

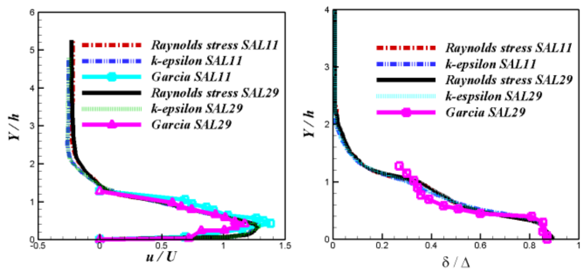

Figure 6 Normalized velocity & concentration contours in 8 and 9 meters of the entrance respectively

close to the reality. There is a difference in the position and magnitude of the maximum velocity.

2) Like all wall jets, in locations close to the inlet, the maximum velocity occurs near the bed. In farther lengths, turbulence mixing and hydraulic jump result in a more uniform current.

3) Belanger Semi-empirical equation is valid for ascertaining the increase in the current height for the hydraulic jumps in the density currents.

4) Initial concentration increase at the entrance can only be felt in the lower layers of the current.

5) Allowing sufficient time to pass, the current reaches a quasi-equilibrium condition and the velocity and concentration distributions become steady at different sections of the current.

6) Quantities such as Richardson number can be determined with a good accuracy.

7) Normalizing the diagrams, leads to a better simulation accuracy and validation of the similitude laws for the density currents.

References

[1] Akiyama, J., Stefan, H.G., (1984), “Turbidity current with erosion and deposition”, J. Hydraulic Eng., ASCE, Vol.111, No.12, pp. 1473-1496

[2] Akiyama, J., Stefan, H.G., (1988), “Turbidity current simulation in a diverging channel”, J. Water resource research, Vol.24, No.4, pp. 579-587

[3] Choi, S.C., Garcia, M.H., (2002), “$k-\varepsilon$ Turbulent modeling of density currents developing tow dimensionally on a slope”, J. Hydraulic Eng., ASCE, Vol.128, No.1, pp. 55-63

[4] Garcia, M.H., (1993), “Hydraulic jumps in sediment driven bottom currents”, J. Hydraulic Eng., ASCE, Vol.119, No.10, pp. 1094-1117.