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Application of bubble curtain system for prevention of seawater intrusion in estuary of tidal rivers

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ABSTRACT

A bubble curtain is a system that produces bubbles in a deliberate arrangement in water. This technique is based on bubbles of air (gas) under the water surface that act commonly as a barrier. When the bubbles rise they act as a barrier or a curtain. Bubble curtain is applied for breaking the propagation of waves or prevention of the spreading of particles and other contaminants. This paper paid to applications of this system for prevention of the advance of seawater in tidal estuaries and protection of environment of offshore. The multiphase flow is simulated by computational fluid dynamics method in estuary of tidal rivers. During high level of tide bubble curtain system can be used simultaneous in several parallel rows of air injection in across the river. During low level of tide air injection rate and use of the bubble curtain system is reduced. The results of the numerical models show that increasing air injection rate is caused to reduce seawater intrusion to estuary of tidal rivers.

Keywords: bubble curtain**,** multiphase flow, computational fluid dynamic method, Prevention of seawater intrusion, Fluent Software.

INTRODUCTION

Bubble curtain, in its simplest form, is a circle or square tube with holes in it that air is injected under pressure into the tube and the bubbles will create a curtain of bubbles. Components needed to create a barrier bubbles: 1 - compressed air from a compressor station, 2 - pipe with special nozzles incorporated and anchor blocks, 3 - levels produced by bubble curtains and 4- drain valve at the end of the nozzle tubes. The subjects expressed about the use of bubble curtains to protect the marine environment. Saltwater intrusion in estuaries of tidal rivers is causing environmental damage. Construction of bubble curtain must be checked in across river as a way for prevention of saltwater intrusion in estuaries of tidal rivers. In this paper is paid to two-phase flow simulation by software Fluent6.3 that freshwater input is from the left side, saltwater on the right side of the entrance and the air from vertical duct. By using of mixture model and k-ε turbulence model in software the two-phase mixture is dissolved. At first the air inlet velocity is considered 0.6 meters per second then is reduced to 0.2 meters per second. As you can see using of air (bubbles) curtain can be prevent from saltwater intrusion and also reduce density in estuaries of tidal rivers.

Figure 1: View of a bubble curtain in place of berthing the ship in Vancouver of Canada to reduce noise pollution (Swanson, 2004).

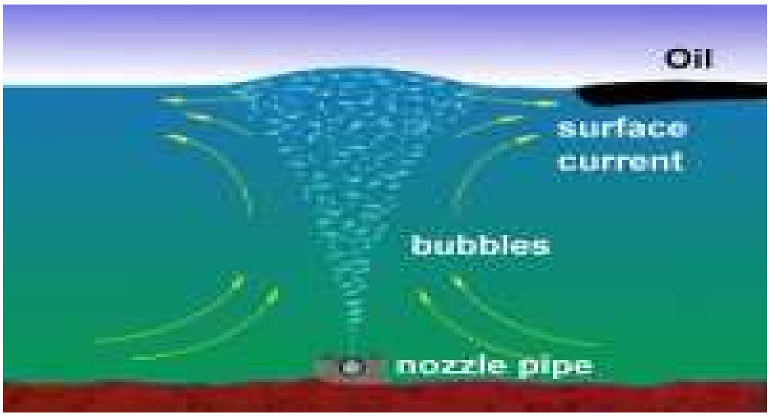

Figure 2 - Barriers (bubble) to prevent the spread of spilled oil on the water surface

Figure 3- from the right 1 - the compressor station, 2 - pipe with special nozzles incorporated and anchor blocks, 3 - level generated by bubble curtains to the surface, 4 - the discharge valves on end of the nozzle tube.

MATERIALS AND METHODS

In this study, flow is unsteady with two-dimensional turbulence form. Velocity and pressure are a function of time and space. To model of the velocity and pressure fluctuations is the integrated from the Navier Stokes equation at time. Integration of Navier Stokes equations at time is known Reynolds equations [8]. Turbulence model equations are two equation models k-ε (Standard) that have be averaged in depth [7].ε equation is as one of the main sources of the limitations of accuracy of the standard version of the k-ε model and the Reynolds stress model. It is interesting that k-ε model includes a correction term that is dependent to strain with c13 constant in the ε equation of RNG model [11]. WillCox provided turbulence equations of k-ω (standard) model [10].

$$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} + \frac{\partial w}{\partial z} = 0 \qquad (1)$$

$$\frac{\partial \rho u}{\partial t}+\frac{\partial \rho uu}{\partial x}+\frac{\partial \rho uv}{\partial y}+\frac{\partial \rho uw}{\partial z}-\rho f_c v=-\frac{\partial P}{\partial x}+\frac{\partial \tau_{xx}}{\partial x}+\frac{\partial \tau_{xy}}{\partial y}+\frac{\partial \tau_{xz}}{\partial z} \qquad (2)$$

$$\frac{\partial \rho v}{\partial t}+\frac{\partial \rho uv}{\partial x}+\frac{\partial \rho vv}{\partial y}+\frac{\partial \rho vw}{\partial z}+\rho f_c u=-\frac{\partial P}{\partial y}+\frac{\partial \tau_{yx}}{\partial x}+\frac{\partial \tau_{yy}}{\partial y}+\frac{\partial \tau_{yz}}{\partial z} \qquad (3)$$

$$\frac{\partial \rho w}{\partial t}+\frac{\partial \rho uw}{\partial x}+\frac{\partial \rho vw}{\partial y}+\frac{\partial \rho ww}{\partial z}=-\frac{\partial P}{\partial z}+\frac{\partial \tau_{zx}}{\partial x}+\frac{\partial \tau_{zy}}{\partial y}+\frac{\partial \tau_{zz}}{\partial z}-\rho g \qquad (4)$$

Turbulence model equation

Known two-equation model of k-ε (Standard) are presented for averaged form in depth as follows: [7].

$$\frac{\partial hk}{\partial t}+\frac{\partial U_j hk}{\partial x_j}=\frac{\partial}{\partial x_j}[(\nu+\frac{\nu_t}{\sigma_k})h\frac{\partial k}{\partial x}]+hP_k+hP_{kv}-h\varepsilon \qquad (5)$$

$$\frac{\partial h\varepsilon}{\partial t}+\frac{\partial U_j h\varepsilon}{\partial x_j}=\frac{\partial}{\partial x_j}[(\nu+\frac{\nu_t}{\sigma\varepsilon})h\frac{\partial \varepsilon}{\partial x}]+hc_{1\varepsilon}\frac{\varepsilon}{k}P_k+hP_{\varepsilon v}-hc_{2\varepsilon}\frac{\varepsilon^2}{k} \qquad (6)$$

$$\nu_t=c_\mu\frac{k^2}{\varepsilon},P_k=2\nu_t S_{ij}.S_{ij} \qquad (7)$$

$$P_{kv}=c_k\frac{k^2}{\varepsilon},c_k=\frac{1}{c_f^{1/2}},P_{\varepsilon v}=c_\varepsilon\frac{u_f^4}{h^2},c_\varepsilon=\frac{1}{\sqrt{e_*\sigma_t}}\frac{c_{2\varepsilon}c_\mu^{1/2}}{c_f^{3/4}},c_f=\frac{u_f^2}{u^2+v^2+w^2}=\frac{n^2g}{h^{1/3}} \qquad (8)$$

$$c_\mu=0.09,c_{\varepsilon 1}=1.44,c_{\varepsilon 2}=1.92,\sigma_k=1.0,\sigma_\varepsilon=1.31$$

P_{kv} and P_{kv} is production terms as result of non-uniform distribution velocity in depth that is stronger near-bed. P_k is production term of turbulent kinetic energy averaged in depth as result of velocity gradients in the plan. ν_t is the vortex viscosity. Turbulence model is used for calculation of lateral flow into one channel and is achieved much better results in comparison with ν_t for fixed parameters of rotational flow [6]. c_f is the bed friction coefficient. σ_t is Schmidt number that shows relationship between turbulence viscosity and turbulent diffusion coefficient according to the following equation:

$$\varepsilon_d=\frac{\nu_t}{\sigma_t} \qquad (9)$$

Amount of σ_t is considered 0.5 [5]. Although values of σ_t are 0.5 to 2 in variable references (Gibson and launder, 1978). e_* is coefficient that gives turbulence diffusion coefficient in depth by following equation [5].

$$\varepsilon_d=e_* hu_f \qquad (10)$$

Direct measurement of color broadcasting in the fixed-width channels offers 0.15 for e_*. Although Keller and Rodi achieved better solutions for the velocity and stress within the composite channels [5]. On the other hand Biglari and Sturm have been assumed e_* equaled to 0.3 to get the better answer within the composite channels [3]. MCGurik and Rodi have considered $\frac{1}{\sqrt{e_*\sigma_t}}$ equaled to 3.6 [6]. In ε equation of RNG model includes a correction term $c_{\varepsilon 1}$ that is constant strain-[11]. For k-ε (RNG), we have:

$$\frac{\partial h\varepsilon}{\partial t}+\frac{\partial U_j h\varepsilon}{\partial x_j}=\frac{\partial}{\partial x_j}[(\nu+\frac{\nu_t}{\sigma\varepsilon})h\frac{\partial \varepsilon}{\partial x}]+hc_{1\varepsilon}^*\frac{\varepsilon}{k}P_k+hP_{\varepsilon v}-hc_{2\varepsilon}\frac{\varepsilon^2}{k} \qquad (11)$$

$$c_\mu = 0.0845, c_{1\varepsilon}^* = c_{1\varepsilon} - \frac{\eta(1-\frac{\eta}{\eta_0})}{1+\beta\eta^3}, c_{1\varepsilon} = 1.68, \sigma_k = 1.39, \beta = 0.012, c_{1\varepsilon} = 1.42,$$
$$\eta = (2E_{ij}.E_{ij})^{1/2}\frac{k}{\varepsilon}, \eta_0 = 4.377 \tag{12}$$

Only constant β is adjustable, high levels of turbulent data are obtained near-wall. All other constants are calculated explicitly as part of the RNG process.

$$\frac{\partial hk}{\partial t} + \frac{\partial U_j hk}{\partial x_j} = \frac{\partial}{\partial x_j}[(\nu + \frac{\nu_t}{\sigma_k})h\frac{\partial k}{\partial x}] + P_k + P_b - h\varepsilon \tag{13}$$

$$\frac{\partial h\varepsilon}{\partial t} + \frac{\partial U_j h\varepsilon}{\partial x_j} = \frac{\partial}{\partial x_j}[(\nu + \frac{\nu_t}{\sigma\varepsilon})h\frac{\partial \varepsilon}{\partial x}] + hc_{1\varepsilon}\frac{\varepsilon}{k}P_k + hc_1 S_\varepsilon - hc_2\frac{\varepsilon^2}{k+\sqrt{\nu\varepsilon}} + S_\varepsilon \tag{14}$$

$$c_1 = Max[0.43, \frac{\eta}{\eta + s}], \eta = s\frac{k}{\varepsilon}, s = \sqrt{2s_{ij}s_{ij}}, \mu_t = hc_\mu\frac{k^2}{\varepsilon}, P_k = -\rho\overline{u_i' u_j'}\frac{\partial u_j}{\partial x_i'},$$
$$P_k = \mu_t s^2, P_b = \beta g_i\frac{\mu_t}{\Pr_t}\frac{\partial T}{\partial x_i}, \mu_t = \rho c_\mu\frac{k^2}{\varepsilon}, c_\mu = \frac{1}{A_0 + A_s\frac{KU^*}{\varepsilon}}, U^* = \sqrt{s_{ij}s_{ij} + \overline{\Omega_{ij}}\,\overline{\Omega_{ij}}},$$
$$\overline{\Omega_{ij}} = \Omega_{ij} - \varepsilon_{ijk}\omega_k, A_0 = 4.04, A_s = \sqrt{6}\cos\Phi, \Phi = \frac{1}{3}\cos^{-1}(\sqrt{6}\omega), \omega = \frac{s_{ij}s_{jk}s_{ki}}{\tilde{s}^3}, \tilde{s} = \sqrt{s_{ij}s_{ij}},$$
$$s_{ij} = \frac{1}{2}(\frac{\partial u_j}{\partial x_i} + \frac{\partial u_i}{\partial x_j}), c_{1\varepsilon} = 1.44, c_2 = 1.9, \sigma_k = 1, \sigma_\varepsilon = 1.2, \beta = -\frac{1}{\rho}(\frac{\partial P}{\partial T})p, \Pr_t = 0.85 \tag{15}$$

WillCox, turbulence model k-ω (standard) equation to be provided as follows: [10]:

$$\frac{\partial k}{\partial t} + U_j\frac{\partial k}{\partial x_j} = \tau_{ij}\frac{\partial U_i}{\partial x_j} - \beta^* k\omega + \frac{\partial}{\partial x_j}[(\nu + \sigma^*\nu_T)\frac{\partial k}{\partial x_j}] \tag{16}$$

$$\frac{\partial \omega}{\partial t} + U_j\frac{\partial \omega}{\partial x_j} = \alpha\frac{\omega}{k}\tau_{ij}\frac{\partial U_i}{\partial x_j} - \beta\omega^2 k\omega + \frac{\partial}{\partial x_j}[(\nu + \sigma\nu_T)\frac{\partial \omega}{\partial x_j}] \tag{17}$$
$$\nu_t = \frac{k}{\omega}, \alpha = \frac{5}{9}, \beta = \frac{3}{40}, \beta^* = \frac{9}{100}, \sigma = \frac{1}{2}, \varepsilon = \beta^*\omega k$$

RESULTS AND DISCUSSION

Numerical Model

The values of the physical properties of water are considered 998.2, 0.001003, 4182 and 0.6, respectively, for density, viscosity, heat capacity and thermal conductivity. Solutions of all governing equations are subject to assignment of variables correctly in the boundary nodes. In steady state problems required only boundary condition but in unsteady state problems is required the initial conditions for all nodes in the network. Common boundary conditions in hydraulic issues include [1].

A- Inlet boundary condition: numerical models can fit the model by means of the various boundary conditions such as velocity, mass flow, etc. For example, in modeling of flow inside a closed or open channel can be used velocity inlet as input boundary condition. B- The outlet boundary condition is considered pressure outlet equals the atmospheric pressure. If the output is chosen at a far distance from geometric constraints, and no change in direction of flow then the flow state is developed full. Using this model is caused the output surface is perpendicular to the flow and gradient is zero in the perpendicular direction on the output surface [1]. C - Wall boundary condition: the wall boundary condition is used to limit the area of between fluid and solid. The model is ready for simulation by Solutions set and defining the model. The following steps show the simulation process [9]: selection methods of discretization equation: In this paper first order upstream difference method is used for discretization of momentum, k, ε and ω equations and the standard method is used to find the pressure. Selection methods of the relation velocity - Pressure: this step is only be studied segregated. In this paper is used from SIMPLE method for velocity - pressure coupling. Determine the discount factors: the discount factor values are used for control of calculated variables in the each iteration. In this paper, the default values 0.3, 1, 0.7, 0.8, 0.8 and 1 is used respectively for the pressure, density, momentum, k, ε and turbulent viscosity. In this paper, the initial values of the relative pressure is considered zero And the initial values of velocity components close to the average values presented in the input stream. By completing the steps in the numerical model, we can start the introduced process of problem by defining of repeat process. The frequency of reporting of results can be introduced before computing the numerical model. During solution process can be seen convergence of solution by the control of residues, integral of surface, statistics and values of the force. After finishing solution the computation of the unknown quantities and the results can be calculated at any point of the field and can be displayed by vector in the form, contour and profile views [9]. In this paper for solution of flow is usually introduced initial number repeat 1000 with report of every step of the calculation that conditions for convergence of the unknown parameters were satisfied after 300 to 350 iterations. The results of the numerical models show that increasing air injection rate is caused to reduce seawater intrusion to estuary of tidal rivers as figure 4 to 8.

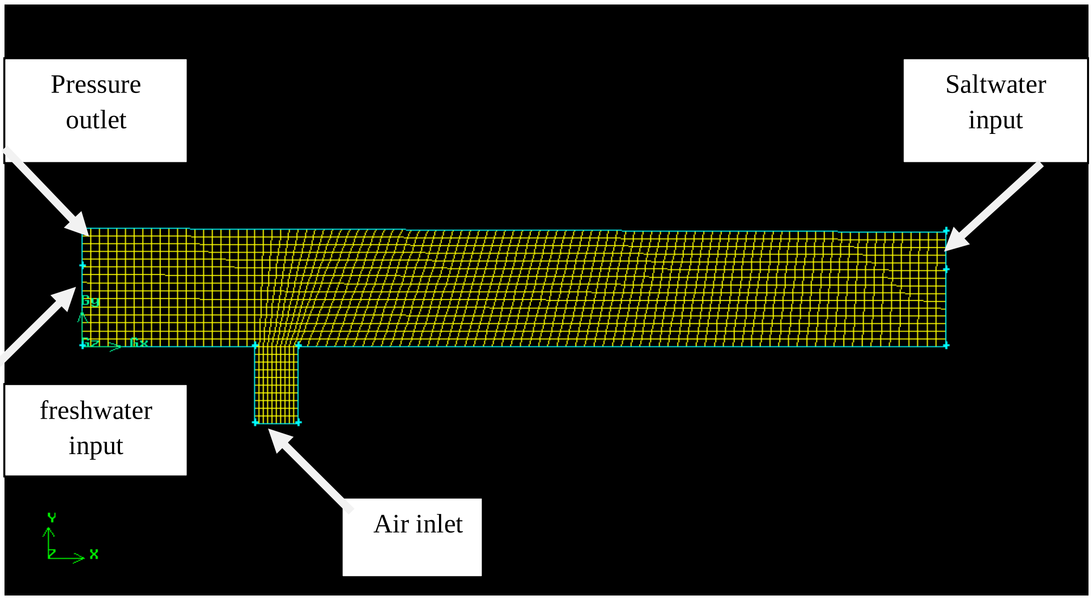

Figure 4- meshing of model and boundary conditions.

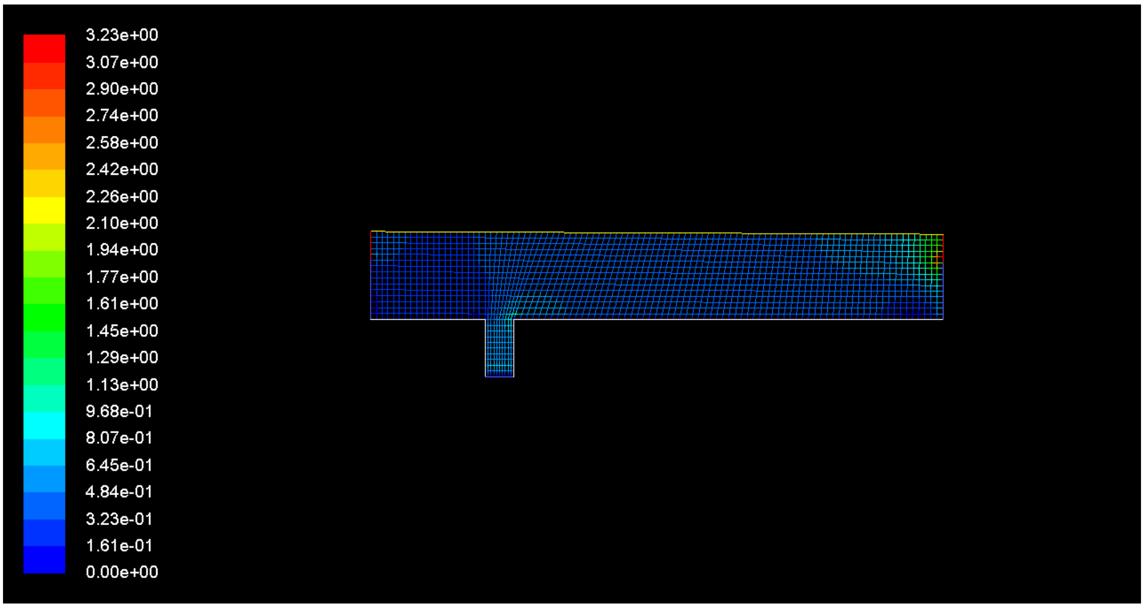

Figure 5- a- Velocity magnitude contours for the two phase flow for seawater intrusion from right input, bubble curtain channel and freshwater from left input (air velocity is 0.6 m/s).

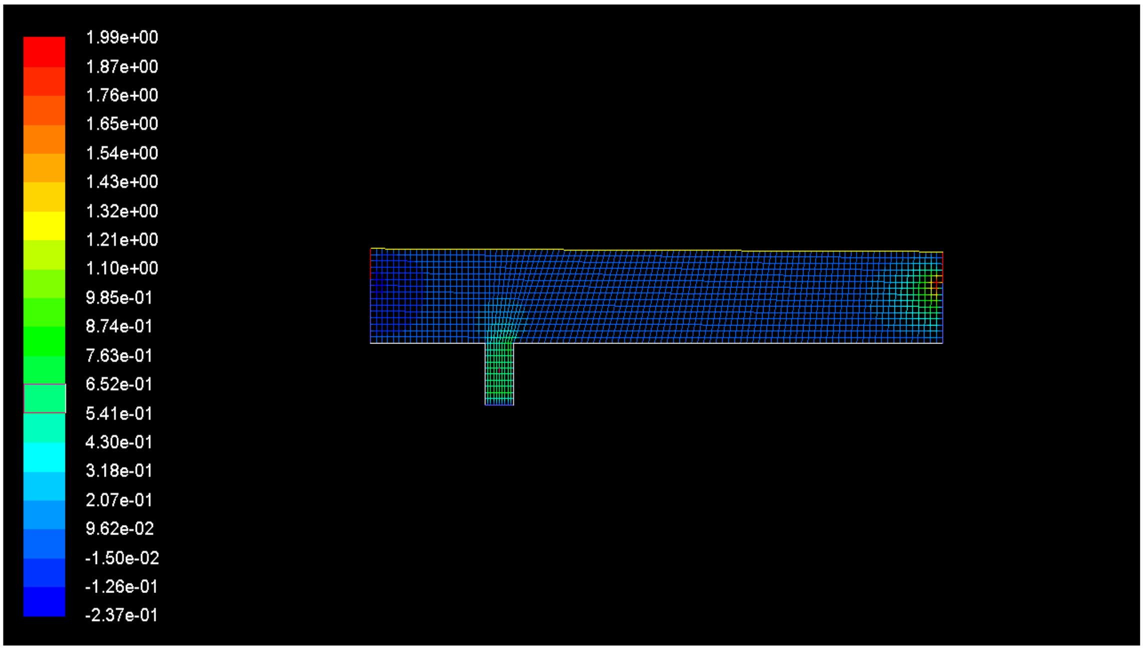

Figure 5- b- the y velocity contours for the two-phase flow in the y direction, (air velocity is 0.6 m/s).

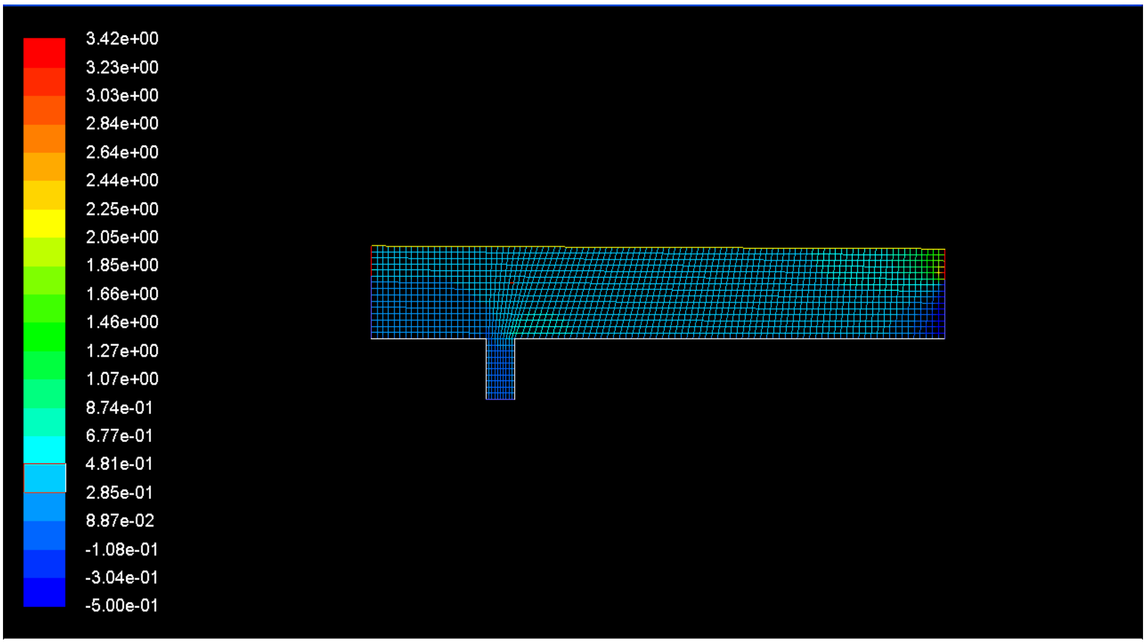

Figure 5- c- the x velocity contours for the two-phase flow in the x direction (air velocity is 0.6 m/s).

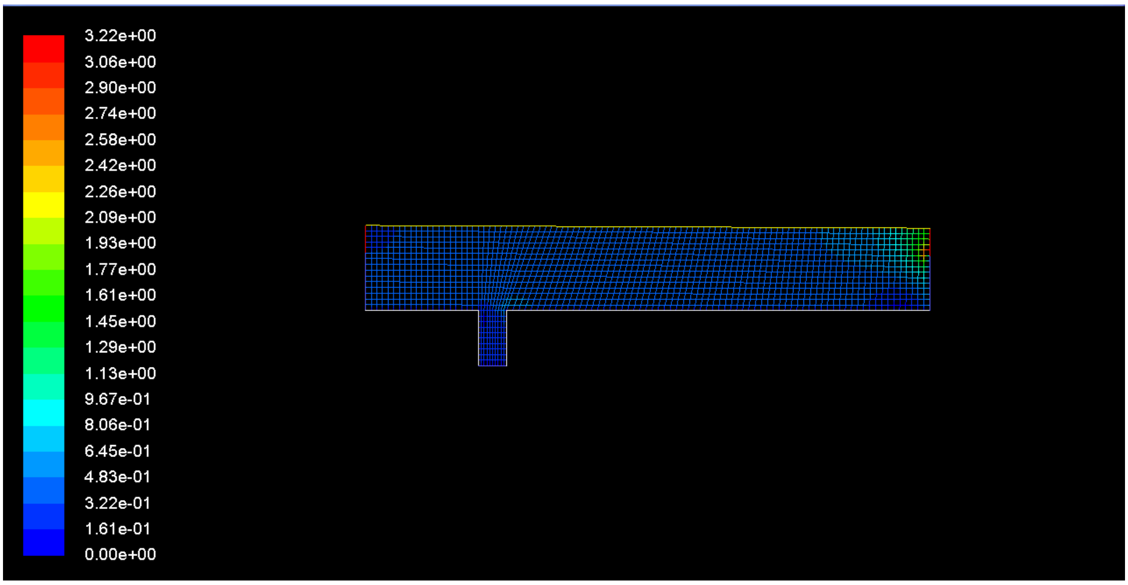

Figure 6-a- the velocity magnitude contours for the two-phase flow (air velocity is 0.2 m/s).

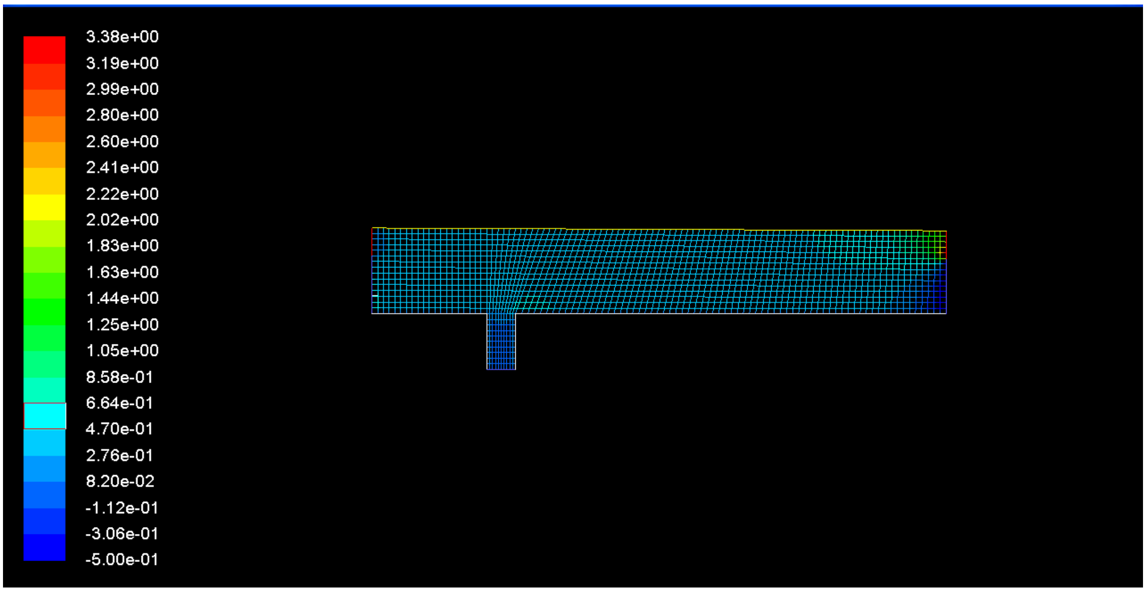

Figure 6- b- the x velocity contours for the two-phase flow in the x direction (air velocity is 0.2 m/s).

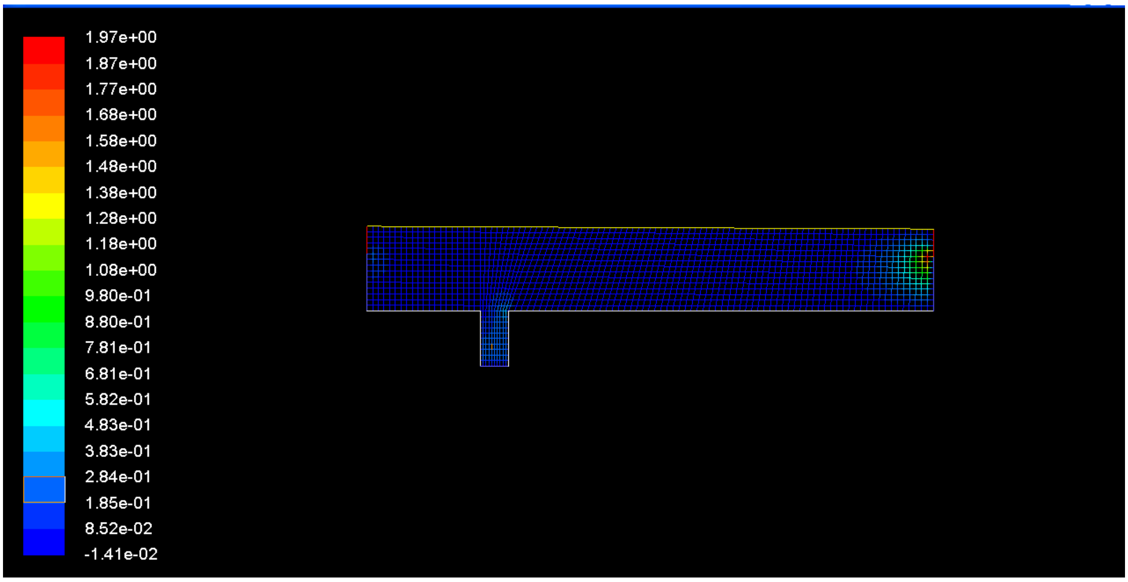

Figure 6- c- the velocity contours for the two-phase flow in the y direction, (air velocity is 0.2 m/s).

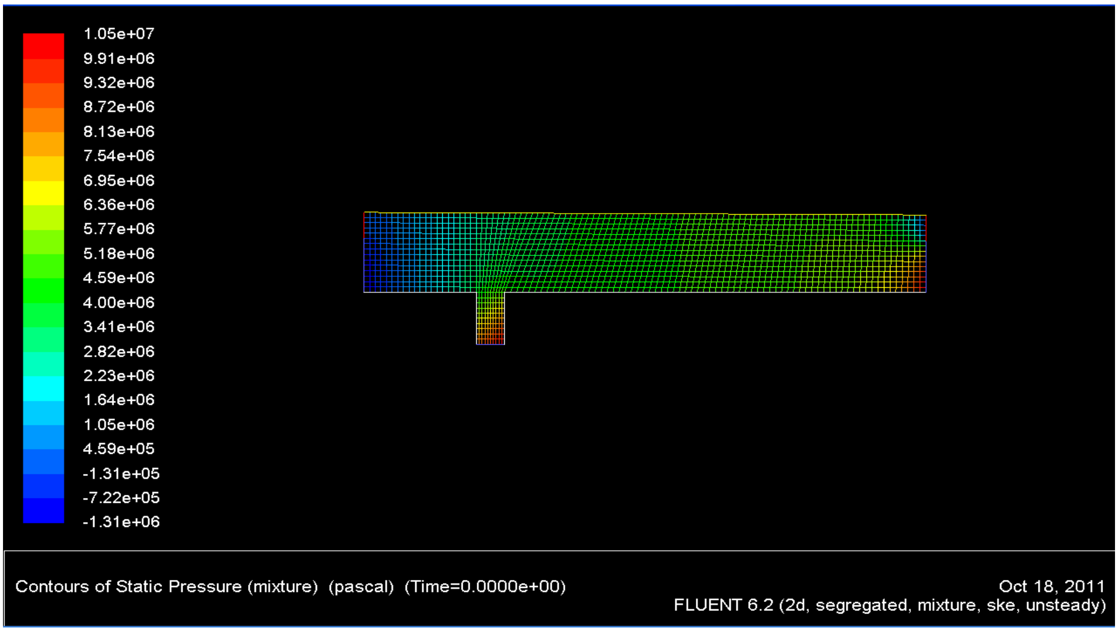

Figure 7-a- the pressure contours for the two-phase flow (air velocity is 0.2 m/s).

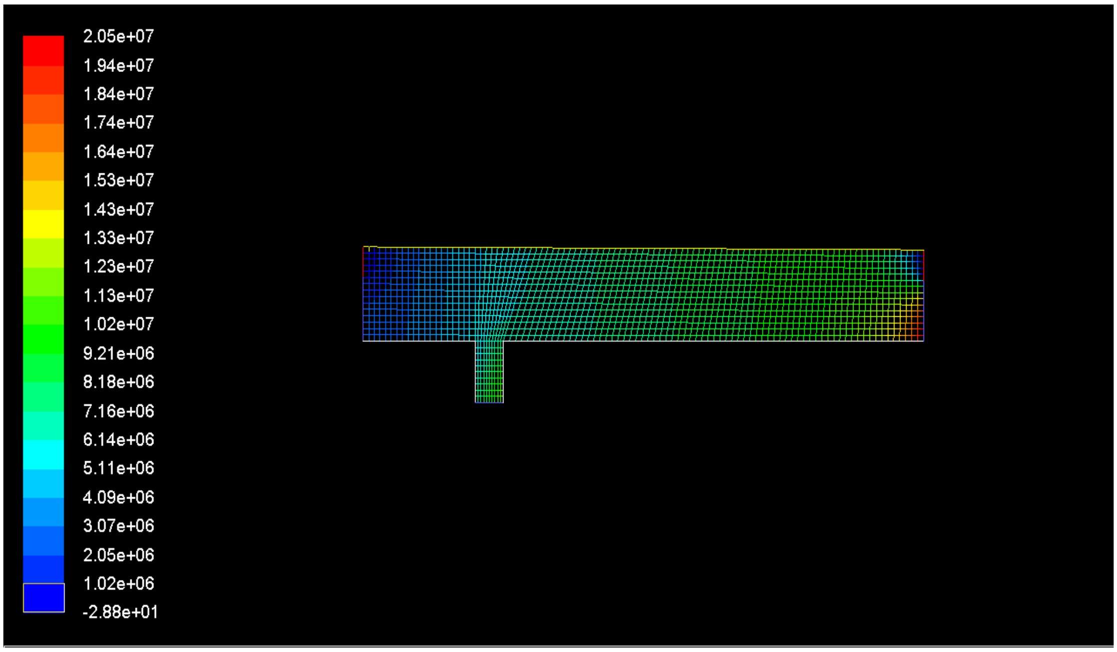

Figure 7-b- the pressure contours for the two-phase flow (air velocity is 0.6 m/s).

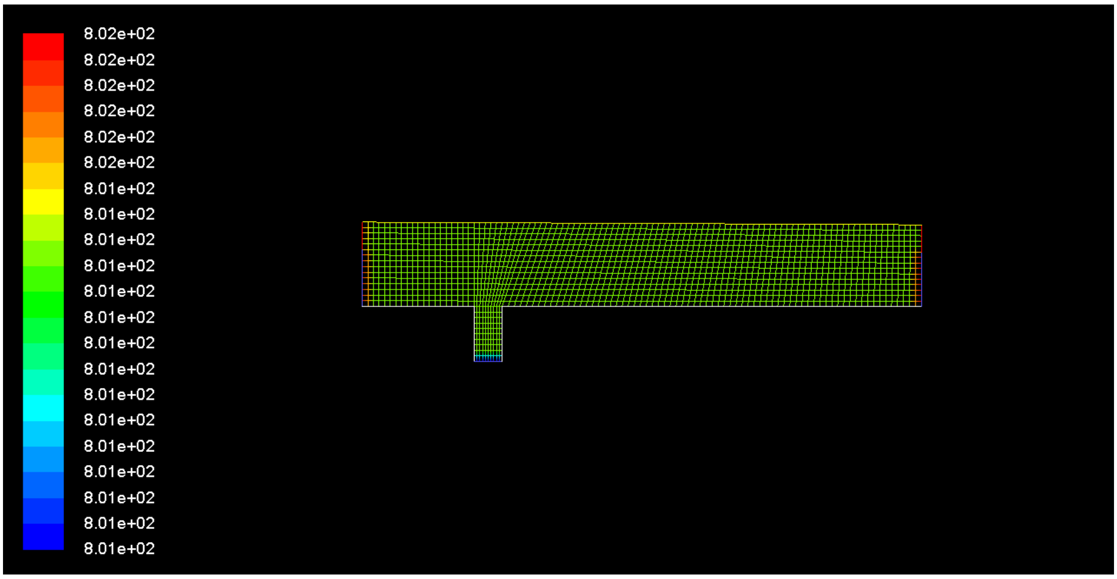

Figure 8-a- the density contours for the two-phase (air velocity is 0.2 m/s).

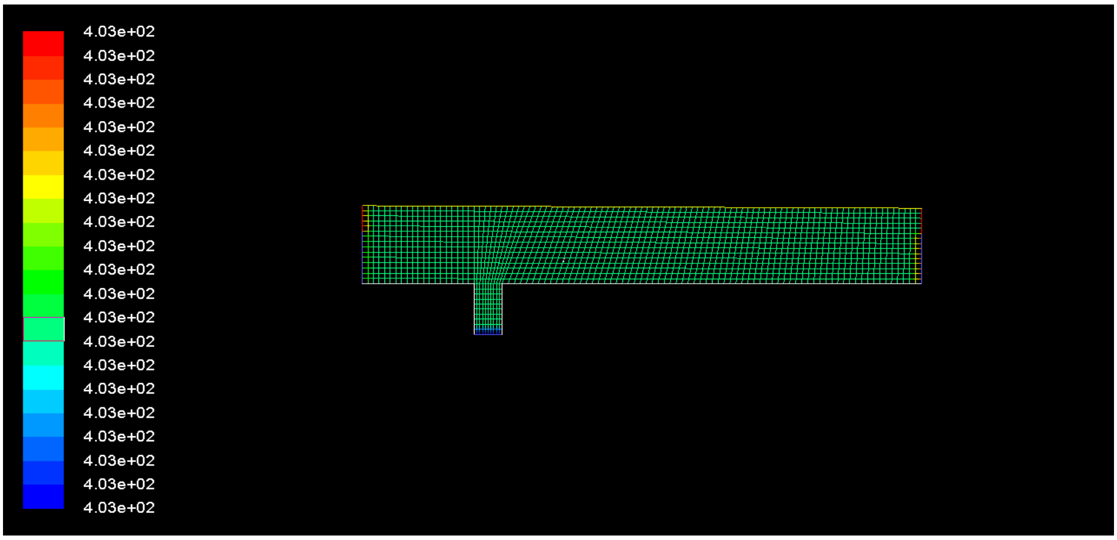

Figure 8- b- the density contours for the two-phase flow (air velocity is 0.6 m/s).

Meshing model

Gambit software version 2.3.16 is used to generate the channel geometry and meshing. Model of the network is used Quad element and the types of Map and Pave for pages and Hex elements and types of Map of Cooper for volumes. Inlet and outlet and wall boundary conditions and symmetry were introduced in the software.

CONCLUSION

A bubble curtain is a system that produces bubbles in a deliberate arrangement in water. Bubble curtain is applied for breaking the propagation of waves or prevention of the spreading of particles and other contaminants. This paper paid to applications of this system for prevention of the advance of seawater in tidal estuaries and protection of environment of offshore. The multiphase flow is simulated by computational fluid dynamics method in estuary of tidal rivers. In this paper is paid to two-phase flow simulation by software Fluent6.3 that freshwater input is from the left side, saltwater on the right side of the entrance and the air from vertical duct. By using of mixture model and k-ε turbulence model in software the two-phase mixture is dissolved. At first the air inlet velocity is considered 0.6 meters per second then is reduced to 0.2 meters per second. The results of the numerical models show that increasing air injection rate is caused to reduce seawater intrusion to estuary of tidal rivers. As you can see using of air (bubbles) curtain can be prevent from saltwater intrusion and also reduce density in estuaries of tidal rivers.

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