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Numerical simulation of prevention of saltwater intrusion in panama channel by using of bubble curtain system

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ABSTRACT

A bubble curtain is a system that produces bubbles in a deliberate arrangement in water. The technique is based on bubbles of air (gas) being let out under the water surface, commonly on the bottom. When the bubbles rise they act as a barrier, a curtain for prevention of the spreading of particles and other contaminants. In this paper is paid to applications of bubble curtain in protection of environment of offshore. Due to the salt water intrusion in Panama navigable channel is causing environmental damage. Construction of bubble curtains along the channel can be studied as a playbook. In this study, two-phase flow is simulated with simulation software Fluent6.3 for freshwater input from the left, saltwater input from the right, air from several vertical bubbles and water injection. The model is solved by using of two-phase Mixture pattern. For problem solving is used the k-ε turbulence model. The air inlet velocity is considered 0.6 meters per second and again 0.2 meters per second. By using air curtains (bubbles) can be prevented salt water intrusion and the density also be reduced. In this paper the multiphase flow is simulated by computational fluid dynamics method in Panama channel.

1. Introduction

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. This paper paid to applications of this system for prevention of the advance of seawater and protection of environment of offshore. The multiphase flow is simulated by computational fluid dynamics method. During high level of tide bubble curtain system can be used simultaneous in several parallel rows of air injection in across the offshore. 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. 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 are 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.

Two researchers named Ghyben and Herzberg separately studied fresh underground water flow to the oceans along the coasts of Europe. They found that anywhere from a coastal aquifer, If depth of interface between fresh and saltwater is measured from sea level, (h_sh$_s$), then level of fresh ground water from sea level, (h_fh$_f$), will be 1/40 (h_sh$_s$) in that point (Ghyben 1889; Herzberg 1901). Since these studies were started by two scientists this phenomenon is mentioned with regard to "Ghyben - Herzberg" that will be explained. Many reviews on the types of groundwater management models and their applications are made by Gorelick (1983), and Yeh (1986). The management models applications in saltwater intrusion, are relatively recent, (Cheng et al. 1999; Fatemi and Ataie-Ashtiani 2008; Bear and Cheng 1999; Cheng and Ouazar 1999; Cummings 1971; Cummings and McFarland 1974; Dagan and Bear 1968; Das Gupta et al. 1996; Naji et al. 1999; Bear and Verruijt 1987; Shahmoradi and Qavami 2008; Siddiqui et al. 2011; Reddy and et al. 2009; Mertzanides et al. 2010; David et al. 2008; Salamasi and Azamathulla; 2013; Kouzana et al. 2009; Jorreto et al. 2014; Van Camp et al. 2013; Zghibi et al. 2010; Werner et al. 2013; Sanz and Voss 2006; Rajabi and Ataie-Ashtiani 2014). In this study, flow is unsteady with two-dimensional turbulence form. Velocity and pressure are a function of time and space. For 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 (Reynolds 1984).

Turbulence model equations are two equation models k-ε (Standard) that have been averaged in depth (Rastogi and Reddy 1978). 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 (Yakhot et al. 1992). WillCox provided turbulence equations of k-ω (standard) model (WillCox 1988).

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

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

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

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

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

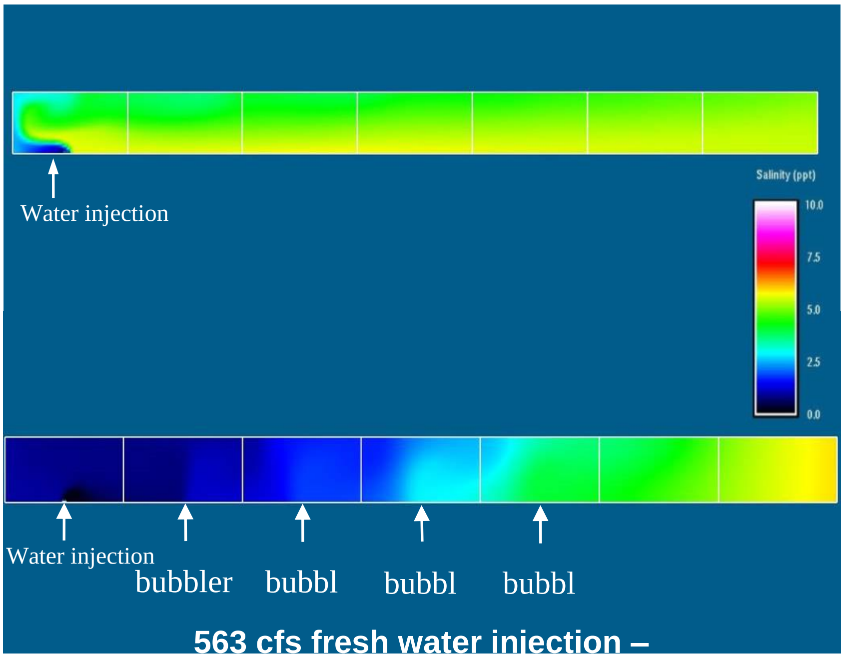

Fig. 2. Simulation of a salinity intrusion barrier, Panama Canal study with one water injection at started of canal and four bubblers in canal (Luong and et al. 2007).

2. Turbulence model equation

Known two-equation model of k-ε (Standard) are presented for averaged form in depth as follows (Rastogi and Reddy 1978):

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

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

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

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

where c_μ=0.09, $c_{\varepsilon 1}$=1.44, σ_k=1 and σ_ε=1.31. P_{kv} and $P_{\varepsilon v}$ are 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 (MCGurik and Rodi 1978). 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:

$$\varepsilon_d=\frac{\nu_t}{\sigma_t} \tag{9}$$

Amount of σ_t is considered 0.5 (Keller and Rodi 1988). 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 (Keller and Rodi 1988).

$$\varepsilon_d=e_* hu_f \tag{10}$$

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 (Keller and Rodi 1988). On the other hand, Biglari and Sturm have been assumed e_* equaled to 0.3 to get the better answer within the composite channels (Biglari and Sturm 1998). MCGurik and Rodi have considered $1/\sqrt{(e_*\sigma_t)}$ equaled to 3.6 (MCGurik and Rodi 1978). In ε equation of RNG model includes a correction term $c_{\varepsilon q}$ that is constant strain-dependent (Yakhot et al. 1992). For k-ε (RNG), we have:

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

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

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.

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

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

$$c_1 = Max[0.43, \frac{\eta}{\eta + s}], \eta = s\frac{k}{\varepsilon}, s = \sqrt{2s_{ij}s_{ij}},$$
$$\mu_t = hc_\mu\frac{k^2}{\varepsilon}, P_k = -\rho\overline{u'_i u'_j}\frac{\partial u_j}{\partial x'_i}, \quad (15)$$

$$P_k = \mu_t s^2, P_b = \beta g_i\frac{\mu_t}{\Pr_t}\frac{\partial T}{\partial x_i}, \mu_t = \rho c_\mu\frac{k^2}{\varepsilon}, c_\mu = \frac{1}{A_0 + A_s\frac{KU^*}{\varepsilon}}, U^* = \sqrt{s_{ij}s_{ij} + \overline{\Omega_{ij}}\,\overline{\Omega_{ij}}}, \quad (16)$$

$$\overline{\Omega_{ij}} = \Omega_{ij} - \varepsilon_{ijk}\omega_k, A_0 = 4.04, A_s = \sqrt{6}\cos\Phi, \Phi = \frac{1}{3}\cos^{-1}(\sqrt{6}\omega), \omega = \frac{s_{ij}s_{jk}s_{ki}}{\tilde{s}^3}, \tilde{s} = \sqrt{s_{ij}s_{ij}}, \quad (17)$$

$$s_{ij} = \frac{1}{2}(\frac{\partial u_j}{\partial x_i} + \frac{\partial u_i}{\partial x_j}), c_{1\varepsilon} = 1.44, c_2 = 1.9, \sigma_k = 1, \sigma_\varepsilon = 1.2, \beta = -\frac{1}{\rho}(\frac{\partial P}{\partial T})p, \Pr_t = 0.85 \quad (18)$$

WillCox, turbulence model k-ω (standard) equation to be provided as follows (WillCox 1988):

$$\frac{\partial k}{\partial t} + U_j\frac{\partial k}{\partial x_j} = \tau_{ij}\frac{\partial U_i}{\partial x_j} - \beta^* k\omega + \frac{\partial}{\partial x_j}[(\nu + \sigma^*\nu_T)\frac{\partial k}{\partial x_j}] \quad (19)$$

$$\frac{\partial \omega}{\partial t} + U_j\frac{\partial \omega}{\partial x_j} = \alpha\frac{\omega}{k}\tau_{ij}\frac{\partial U_i}{\partial x_j} - \beta\omega^2 k\omega + \frac{\partial}{\partial x_j}[(\nu + \sigma\nu_T)\frac{\partial \omega}{\partial x_j}] \quad (20)$$

where $v_t=k/\omega$, α=5/9, β=3/40, β^*=9/100, σ=1/2, ε= β^* ωk.

3. Numerical model

The values of the physical properties of water are considered as a default 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 (Soltani and Rahimi Asl 2003):

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 (Soltani and Rahimi Asl 2003).

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 (Versteeg and Malalasekera 2007): 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 being 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 each iteration. In this paper, the default values are 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 (Versteeg and Malalasekera 2007). 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 saltwater hydraulic gradient and times of tidal flow are caused to seawater intrusion from over underground dam to coast as figure 2-a to 2-e.

4. 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.

5. Bubble curtain system for prevention of seawater intrusion in coastal aquifers

In this paper is paid to three-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 three-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.

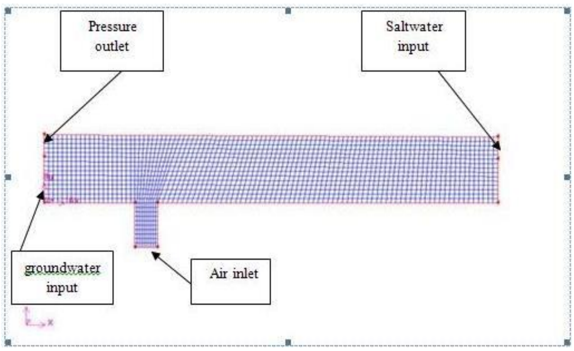

Fig. 3. Meshing of model and boundary conditions.

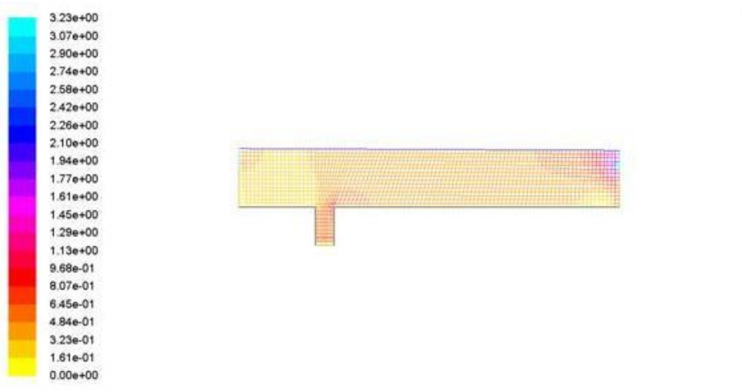

Fig. 4. Velocity magnitude contours for the three phase flow for seawater intrusion from right input, bubble curtain channel and freshwater from left input (air velocity is 0.6 m/s).

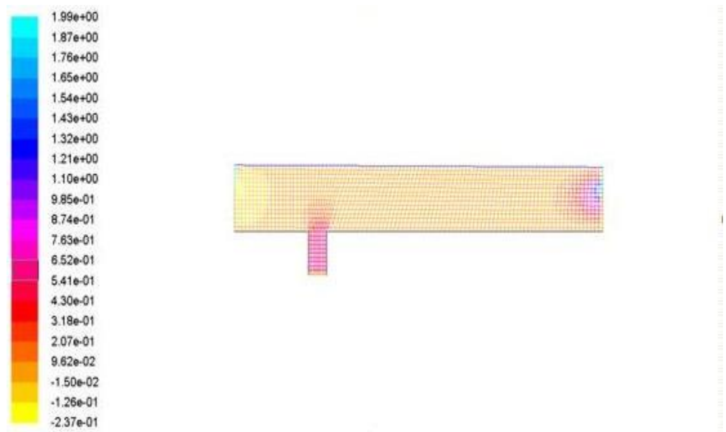

Fig. 5. the y velocity contours for the three-phase flow in the y direction (Air velocity is 0.6 m/s).

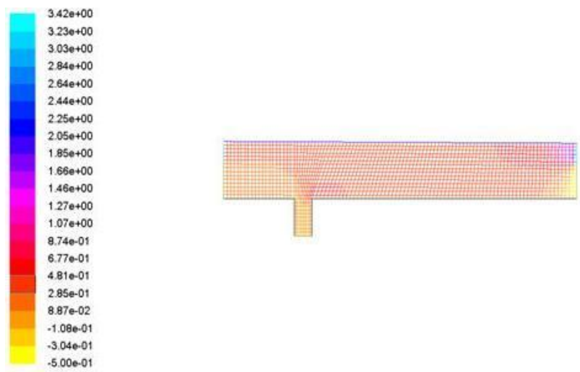

Fig. 6. the x velocity contours for the three-phase flow in the x direction (air velocity is 0.6 m/s).

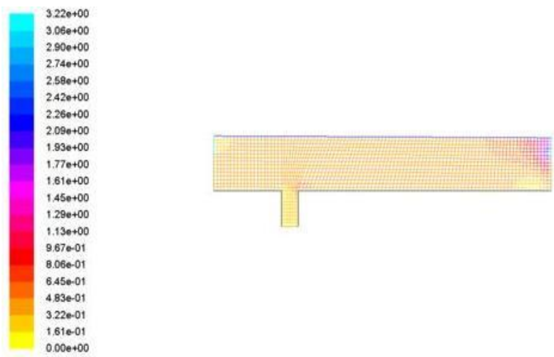

Fig. 7a. The velocity magnitude contours for the three-phase flow (air velocity is 0.2 m/s).

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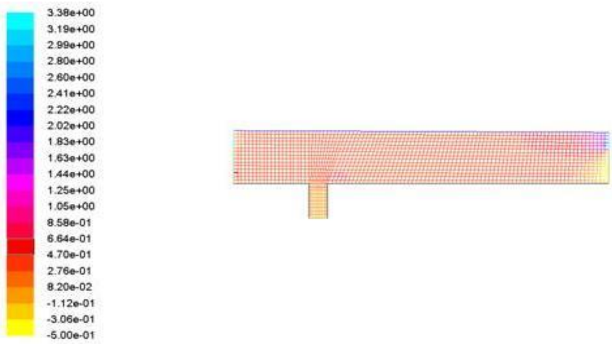

Fig. 7b. the x velocity contours for the three-phase flow in the x direction (air velocity is 0.2 m/s).

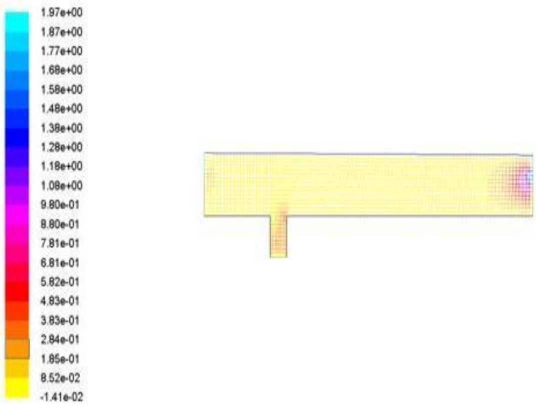

Fig. 7c. The velocity contours for the three-phase flow in the y direction, (air velocity is 0.2 m/s).

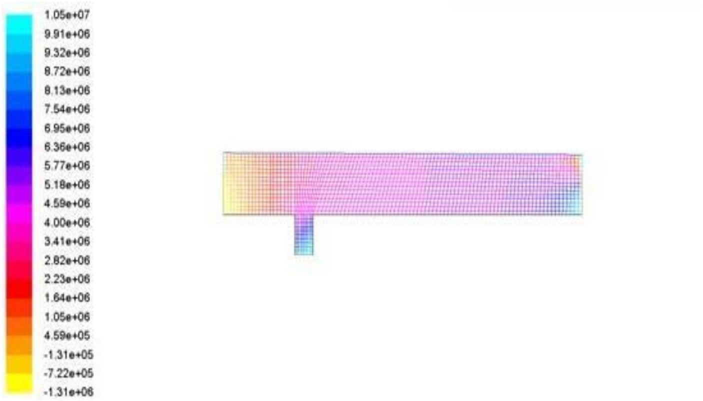

Fig. 8a. the pressure contours for the three-phase flow (air velocity is 0.2 m/s).

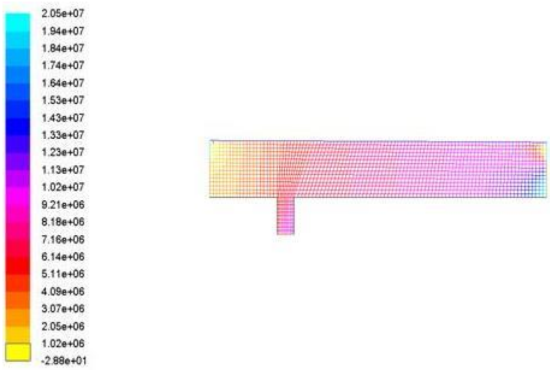

Fig. 8b. the pressure contours for the three-phase flow (air velocity is 0.6 m/s).

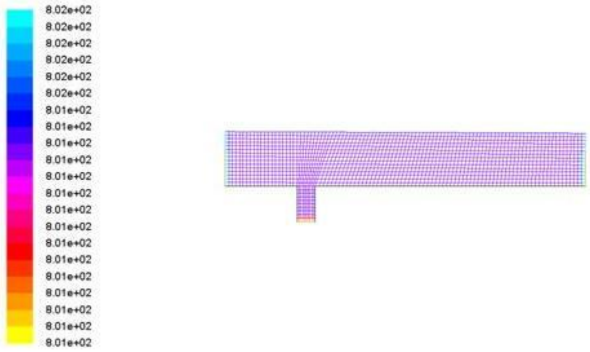

Fig. 9a. The density contours for the three-phase (air velocity is 0.2 m/s).

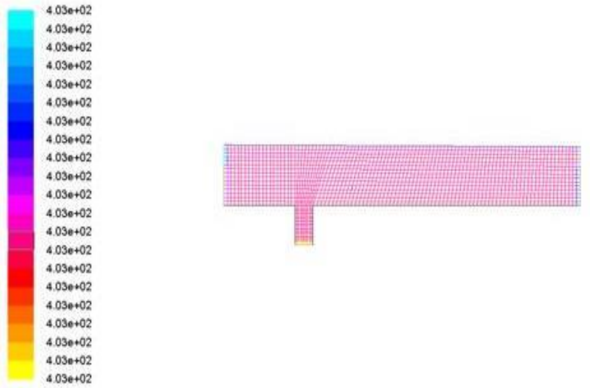

Fig. 9b. the density contours for the three-phase flow (air velocity is 0.6 m/s).

6. Conclusions

A bubble curtain is a system that produces bubbles in a deliberate arrangement in water. In this paper is paid to three-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 three-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. As you can see using of air (bubbles) curtain can be prevent from saltwater intrusion and also reduce density.

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