Study Velocities Distribution of Unsteady Turbulent Flows in an Open Channel

Fourar Ali, Merrouchi Farida, Abdessemed Fouzi, Boudjellal Samia

***Abstract*—The malfunctioning sewage systems, particularly in wet weather are common in some cities, pollution of receiving waters, sometimes direct consequences of uncontrolled spills, are poorly supported by the natural environment and population. And improving the quality of natural receptors urban pollution through control of finer flows and pollution loads of wastewater systems and especially sewerage. The main objective of this study is three-dimensional modeling of the velocity field with free surface in an overdraft remediation using a three-dimensional isotropic turbulence model unsteady. Detailed understanding of three-dimensional velocity profiles in a pipeline is a precondition to consideration of the transfer of elements of different nature (pollution, solid materials etc ...) in wastewater systems; the model used is based on the model of the system of Navier-Stokes averaged (Reynolds) given the isotropic turbulence model k-ε. A special study was performed after fixing the boundary conditions at the walls and the free surface of the field and a calculation program was developed by our own care.**

***Index Terms*—Free surface flow; closed channel; vertical turbulent fluctuations; model k- ε.**

I. INTRODUCTION

Historically, the velocities fluctuations of turbulent flows with free surface in open channels are smooth transverse sensing obstacles have been the subject of numerous investigations. Indeed the study of these phenomena related to turbulence can help to identify all aspects of this problem. The technical solutions proposed for such study will build expertise in the design of hydraulic related and contribute to cost optimization.

In this study done by the difficulties to converge the model of turbulence is very sensitive to boundary a condition, our purpose was to varying conditions of the free surface. Because the effects of turbulence on the latter are particularly important in modeling of free surface flows.

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II. EFFECTS OF FREE SURFACE ON THE TURBULENCE

When compared to the plane of symmetry of a load flow there are two main effects of the free surface on turbulence:

- Reducing the length scale vortex energy carriers
- The redistribution of turbulent energy coenobitic the spherical components of the tensor of Reynolds. We dealt with two cases;

A. Case1

The effect of the free surface is similar to that of a solid[1] wall, in this case it appears that the surface free damped motion in fluctuating turbulent stresses amplify the longitudinal and transverse to the benefit of vertical stress. We take:

1-normal derivative of tangential velocity null, no shear stress
2-average velocity field is not null.

*- The interaction of vortex energy carriers with the free surface results in a reduction in the length scale of these vortices resulting in a distortion of the free surface along with a local increase in hydrostatic pressure, this mechanism leads to a decrease in the eddy viscosity of the free surface. Hunt offers a decay law near the free surface.

$$\frac{w}{u^*} = 1{,}34 \quad \left(\frac{\varepsilon h}{u^{*3}}\right)^{\frac{1}{3}} (1-\xi)^{\frac{1}{3}} \qquad (1)$$

u^* : Friction velocity, ξ : External variable, h : Draught

The free surface reduces the vertical displacement. To assess the values of velocity fluctuations near the free surface is fixed first K and ε with the formula of CELIK and RODI.

$$\varepsilon_s = \frac{k_s^{\frac{3}{2}}}{\alpha h} \qquad (2)$$

α : is a coefficient determined empirically (α ≌ 0,18) ,

h : Water depth in the channel.

B. Case2

The free surface is the interface of two volumes (volume of water and air volume)[2], i.e. the system is no longer a set of "particles" of water but water volume and a volume of air bunk which is subjected to atmospheric pressure in each grid computing, it is calculated at each iteration, the respective volume fraction of air and water.

The principle of this method is to define a characteristic function $c(x,y,z,t)$ convected by the flow:

$c(x,y,z,t) = 0$ If the cell is filled with air

$c(x,y,z,t) = 1$ If the cell is filled with water.

$$\rho = c(x,y,z,t)\,\rho_{eau} + (1 - c(x,y,z,t))\,\rho_{air} \tag{3}$$

We solve the equation system:

$$\overline{NVS} + k + \varepsilon \tag{4}$$

Then we convects volume fraction

$$\frac{\partial c}{\partial t} + \vec{u}\nabla c = 0 \tag{5}$$

This condition leads to satisfactory results.

III. LAWS OF WALLS

. The flow near the walls is complex.

It requires a good understanding of the phenomenon of boundary layer. However the thickness of the boundary layer is too thin compared to the scale of our problem[3].

The laws of walls reflect the properties of similarity of the velocity components and Reynolds stresses of turbulent shear flows near the wall, in a region where the flow is controlled by parameters characteristic of the wall:

(The friction velocity, viscosity, and / or a characteristic scale of roughness)

- The formulation of law of the wall has a double interest:

• They need to determine the wall friction and possibly an equivalent scale roughness from the velocities measured over the wall.

• It has the advantage of simplifying the choice of boundary conditions in models of developed turbulence on the statistical approach

$u_{moy\,p} = u_\tau \,.\, u^+$ with:

$$u_t = \sqrt{\frac{\tau_p}{\rho}} \tag{6}$$

with $\tau_p = \mu \dfrac{\partial \gamma_p}{\partial t} = \mu \dfrac{4Q}{\pi R^3}$ (7)

Where : R : Hydraulic radius.

$u^+ = 5 \ln y^+ - 3{,}05$ Semi-empirical formula Reichert, on the border of the boundary layer with a turbulent core : $y^+ = 30$.

$$V_{moy\,p} = W_{moy\,p} = 0 \;,\; \varepsilon_p = \frac{c_u^{\frac{3}{4}} k_p^{\frac{3}{2}}}{k y_p} \tag{8}$$

IV. EQUATIONS FOR A TURBULENT FLOW

Equation of Reynolds ($\overline{NVS}$) on three axes:

$$\frac{\partial \rho \bar{u}}{\partial t} + \frac{\partial}{\partial x}\rho \bar{u}^2 + \frac{\partial}{\partial y}\rho \bar{u}\,\bar{v} + \frac{\partial}{\partial z}\rho \bar{u}\,\bar{w} = -\frac{\partial \bar{p}}{\partial x} + \mu \nabla^2 \bar{u} - \frac{\partial}{\partial x}\rho \overline{\grave{u}\grave{u}} - \frac{\partial}{\partial y}\rho \overline{\grave{u}\grave{v}} - \frac{\partial}{\partial z}\rho \overline{\grave{u}\grave{w}} + \rho g_x \tag{9}$$

$$\frac{\partial \rho \bar{v}}{\partial t} + \frac{\partial}{\partial x}\rho \bar{u}\,\bar{v} + \frac{\partial}{\partial y}\rho \bar{v}^2 + \frac{\partial}{\partial z}\rho \bar{v}\,\bar{w} = -\frac{\partial \bar{p}}{\partial y} + \mu \nabla^2 \bar{v} - \frac{\partial}{\partial x}\rho \overline{\grave{u}\grave{v}} - \frac{\partial}{\partial y}\rho \overline{\grave{v}\grave{v}} - \frac{\partial}{\partial z}\rho \overline{\grave{v}\grave{w}} + \rho g_y \tag{10}$$

$$\frac{\partial \rho \bar{w}}{\partial t} + \frac{\partial}{\partial x}\rho \bar{u}\,\bar{w} + \frac{\partial}{\partial y}\rho \bar{v}\,\bar{w} + \frac{\partial}{\partial z}\rho \bar{w}^2 = -\frac{\partial \bar{p}}{\partial z} + \mu \nabla^2 \bar{w} - \frac{\partial}{\partial x}\rho \overline{\grave{u}\grave{w}} - \frac{\partial}{\partial y}\rho \overline{\grave{v}\grave{w}} - \frac{\partial}{\partial z}\rho \overline{\grave{w}\grave{w}} + \rho g_z \tag{11}$$

These equations are coupled with equation of mass conservation

$$\frac{\partial \bar{u}}{\partial x} + \frac{\partial \bar{v}}{\partial y} + \frac{\partial \bar{w}}{\partial z} = 0 \tag{12}$$

Equation of model $k - \varepsilon$:

$$\mu_t = c_\mu \rho \frac{k^2}{\varepsilon} \tag{13}$$

$$\frac{\partial k}{\partial t} + \bar{v}_i . grad\, k = div.(grad\, k) + P - \varepsilon \tag{14}$$

From which [4]: $p = \overline{\grave{u}_i \grave{u}_j} \dfrac{\partial \bar{u}_i}{\partial x_j}$

$$\frac{\partial \varepsilon}{\partial t}\, \bar{v}. grad\, \varepsilon = div \left(\frac{v_t}{\sigma_\varepsilon} grad\, \varepsilon\right) + \frac{\varepsilon}{k}\left(c_{\varepsilon_1} p - c_{\varepsilon_2} p\right) \tag{15}$$

$c_u = 0{,}09$, $c_{\varepsilon_1} = 1{,}44$, $c_{\varepsilon_2} = 1{,}92$, $\sigma_k = 1$, $\sigma_\varepsilon = 1{,}3$ [5]

All equations can be used as a general equation of convection

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-Diffusion for variable $\emptyset$ [6]:

$$\underbrace{\frac{\partial(\rho\emptyset)}{\partial t}+\frac{\partial}{\partial x_j}(\rho\emptyset u_j)}_{1}=\underbrace{\partial(\tau_\emptyset\frac{\partial\emptyset}{\partial x_j})}_{2}+\underbrace{s_\emptyset}_{3} \qquad (16)$$

1 - Terms of convection, 2 - Terms of diffusion,
3 - Terms of source.

They will be resolved through initial and boundary conditions by the finite volume method used by a program.

Equation of pressure

The main difficulty in solving the Navier-Stokes equations is to check the continuity equation at each time step. Indeed, based on equations discretized momentum, the latter being fully explicit, may be sufficient at each iteration of the velocity field inferred from the pressure field digital The trick that we are going to works to overcome this difficulty is based on a method developed by (see R. Peyret & Taylor TD 1983), is based on splitting the time step

$$\left(\frac{\partial^2 p}{\partial x^2}+\frac{\partial^2 p}{\partial y^2}+\frac{\partial^2 p}{\partial z^2}\right)-\frac{1}{\Delta t}\left(\frac{\partial u^*}{\partial x}+\frac{\partial v^*}{\partial y}+\frac{\partial w^*}{\partial z}\right)=0 \quad (17)$$

Boundary conditions: Condition type New Mann at the borders :

$$\frac{\partial p}{\partial \eta}=0 \quad \text{(Case 1)}$$

- A dynamic system sensitive.
- Use of ampirical laws.
- Boundary layer unmodelled.

V. RESULTS

Results of case 1

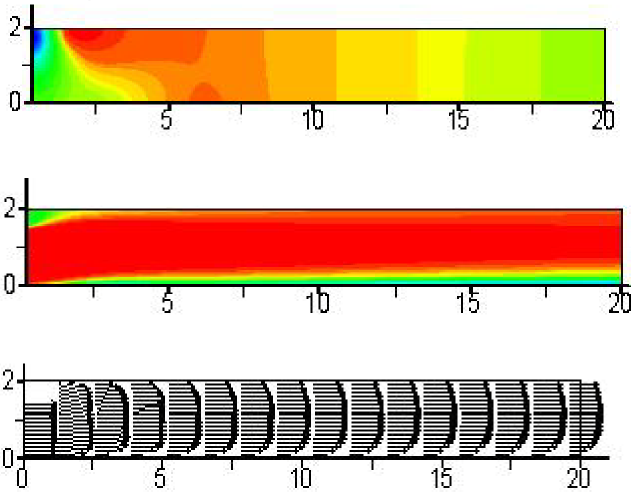

Fig. 1. Temporal variation of the pressure , Energie cinétique and champs de vitesses in the pipe (without obstacle).

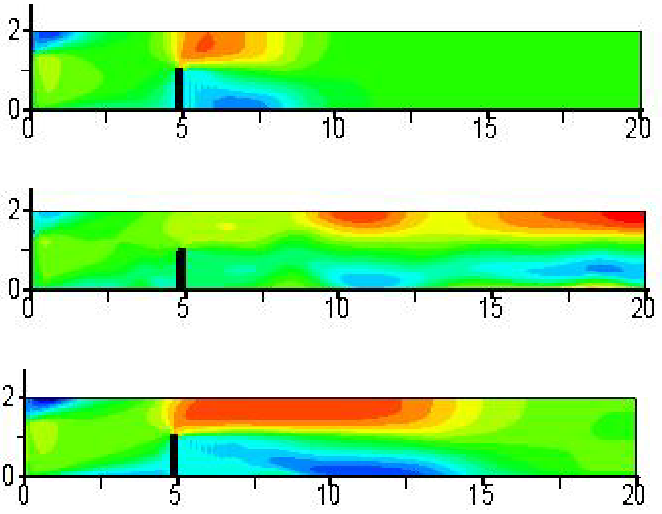

Fig. 2. Temporal variation of the velocity field (T = 5s ,50s, 65s) in the pipe (with obstacle).

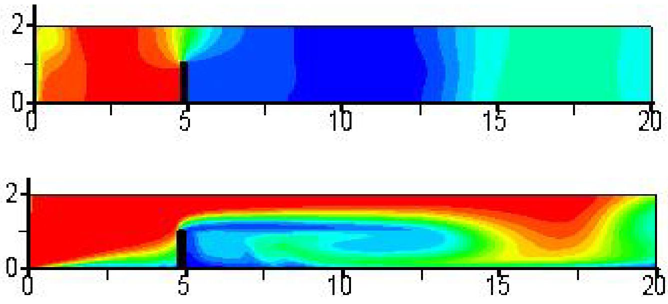

Fig. 3. Temporal variation of the pressure and energie cinetique in the pipe (with obstacle).

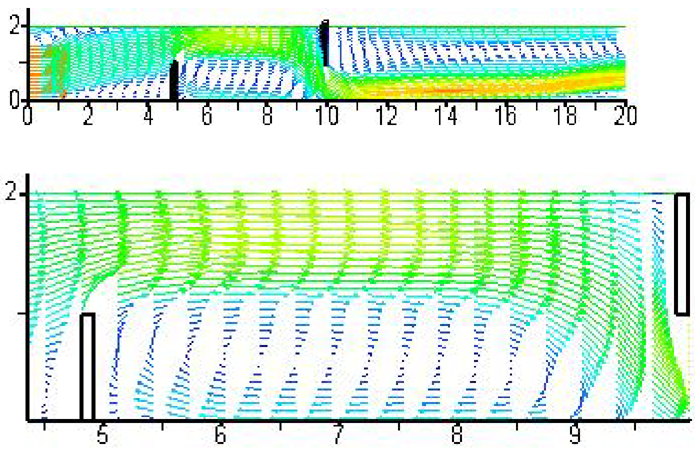

Fig. 4. Distribution of velocities in the pipe (between two obstacle).

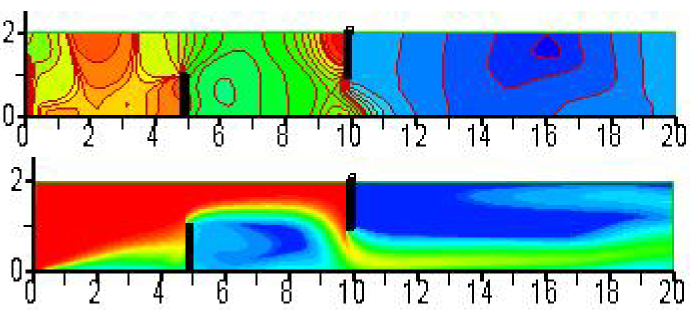

Fig. 5. Temporal variation of the pressure and energie cinetique in the pipe (with two obstacles).

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Results of case 2

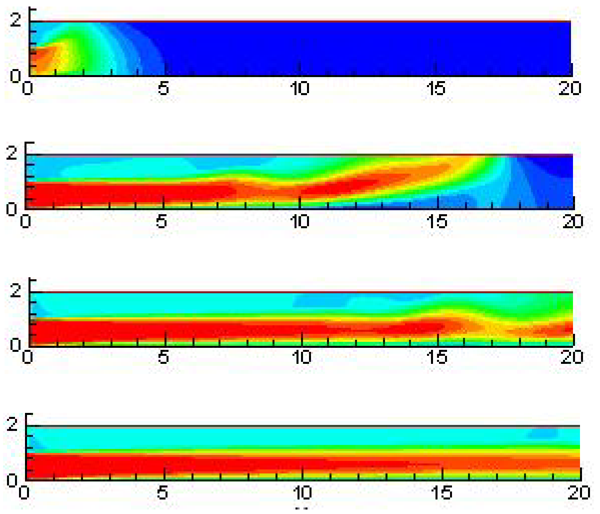

Fig. 6. Temporal variation of the velocity field (T = 2.5s, 15s, 30s, 40s) in the pipe (without obstacle).

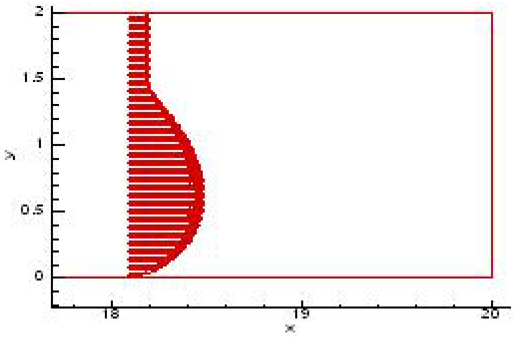

Fig. 7. Distribution of velocities in the pipe (without obstacle).

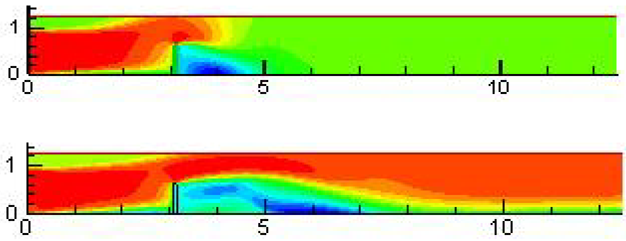

Fig. 8. Temporal variation of the velocity field (T = 2,5-40s)in the pipe (with obstacle).

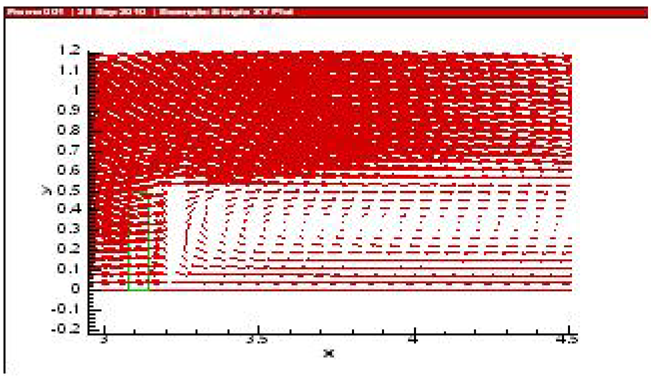

Fig. 9. Distribution of velocities in the pipe (with obstacle).

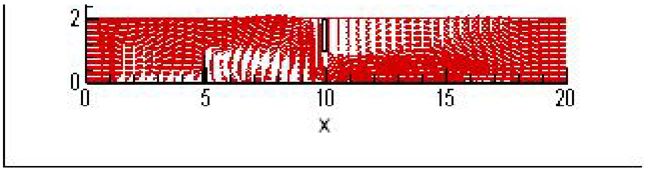

Fig. 10. Distribution of velocities in the pipe (with two obstacles).

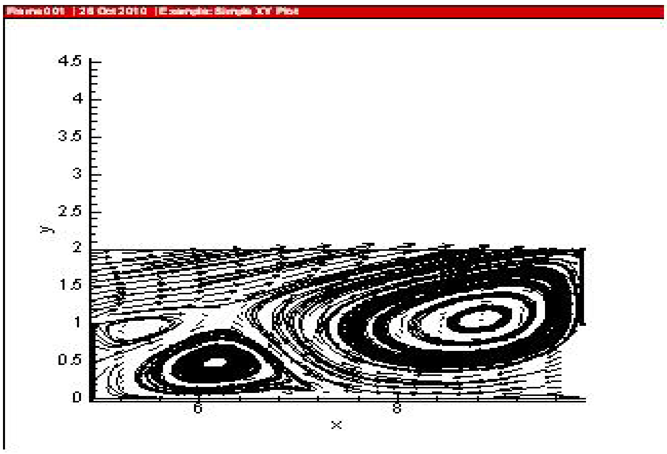

Fig. 11. Distribution of velocities in the pipe (between two obstacles).

VI. CONCLUSION

In many cases, hydraulic and fluid mechanics, there is transport a mixture of several fluids (Newtonian or non-Newtonian) in widely varying proportions. This study focused rightly on the problem of coupling between turbulence and free surface, as it focused on the numerical solution of turbulent free surface parietal first without distribution or transfer or interplay between two volumes (air, water), then with the transfer.

The three-dimensional flow is considered. The mathematical formulation of these flows is derived from writing the laws of conservation of mass and conservation of momentum since the problem concerns the free-surface flows, the model can handle this case must be appropriate or selected so this case we fit for the k-ε model developed by Jones and Lander.Because it can reflect the transport of turbulent quantities in their equations involving differential transport.

The results obtained using the computer code in Fortran made by us are satisfactory given the conditions of this study apart from the case of the free surface effect likened to a solid wall.

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