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Mathematical modeling of river pollution as a result of pipeline damage

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Overview

- Objective
- Introduction
- Modeling Approach Review
- Model Validation
- Results and Discussion
- Conclusions
- Future Work
- Acknowledgements

Objective

- This makes the development of accurate **river oil pollution model** an extremely valuable research activity.
- There are **various types** of river oil pollution models: statistical, empirical, semi-empirical and physics-based.
- **The objective of this paper** is to develop and validate a fully physical Computational Fluid Dynamics (CFD) model of river oil pollution, which is advanced and pragmatic.

Modeling Approach - Geometry

- Figure 1 shows the **3D domain** containing the river flow region and a source of pollution. The specific sizes of domain, river speed and parameters of pollution source vary in various cases.

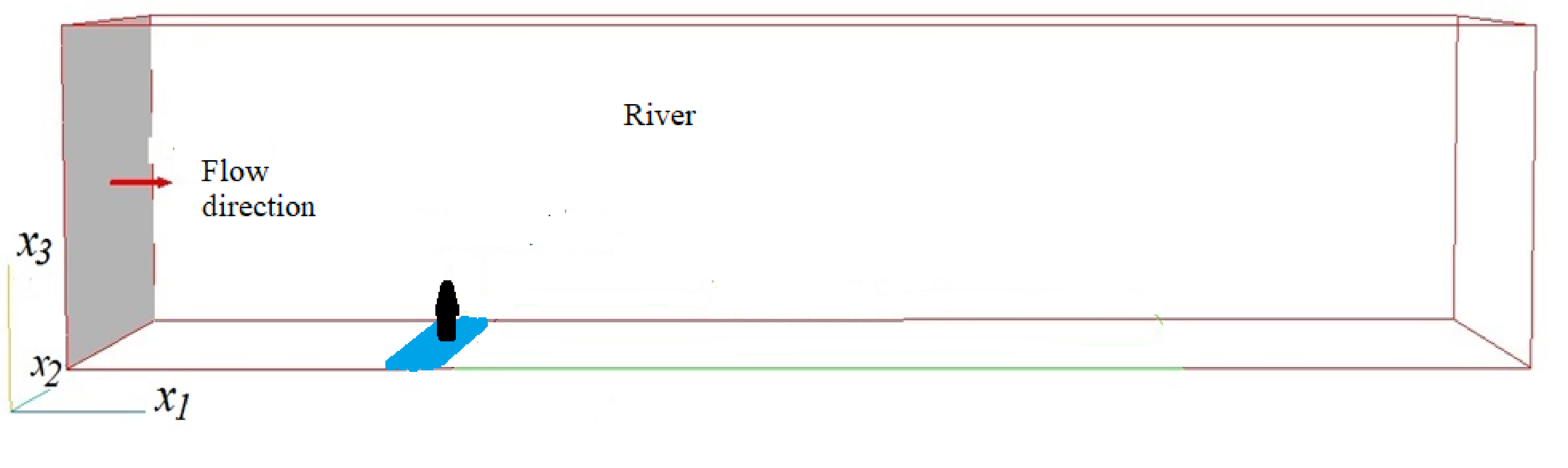

Figure 1. Computational Domain (river, flow direction, and source of pollution)

Modeling Approach - Equations

- The **fluid phase governing equations** are written in a general form:

$$\frac{\partial}{\partial t}(\rho\Phi)+\frac{\partial}{\partial x_i}\left(\rho u_i\Phi-\Gamma_\Phi\frac{\partial\Phi}{\partial x_i}\right)=S_\Phi \qquad (1)$$

- Here, t is the time; x_i is the spacial coordinate (i=1, 2, 3); ρ is the fluid mixture density; u_i is the velocity component in x_i direction and the specific expressions for dependent variable, Φ, diffusive exchange coefficient, Γ_Φ, and source term, S_Φ, are given in Table 1 below.

- The fluid density is calculated from the equation of state for mixture of fluid:

$$p=\rho RT\sum_{\alpha=1}^{2}\frac{c_\alpha}{M_\alpha} \qquad \sum_{\alpha=1}^{2}c_\alpha=1$$

where p is the pressure; T is the absolute gas temperature; R is the universal gas constant; c_α is the mass fraction of α - species of gas mixture; index α = 1,2 where 1 corresponds to oil, 2 - to all other components of fluid mixture; M_α is the molecular weight of α -component of fluid phase.

Modeling Approach Continues

Table 1. Dependent variables, effective exchange coefficients and source terms in equation (1)

Conservation of	Φ	Γ_Φ	S_Φ
Mass	1	0	$\dot{m}$
x_i – momentum	u_i	$\mu + \mu_t$	$-\frac{\partial p}{\partial x_i} + \rho g_i$
Enthalpy	h	$\frac{\mu}{Pr} + \frac{\mu_t}{Pr_t}$	
Mass of α – species	c_α	$\frac{\mu}{Sc} + \frac{\mu_t}{Sc_t}$	
Turbulent kinetic energy	k	$\mu + \frac{\mu_t}{\sigma_k}$	$\rho(P_k + W_k - \varepsilon)$
Dissipation rate of turbulent kinetic energy	ε	$\mu + \frac{\mu_t}{\sigma_\varepsilon}$	$\rho \frac{\varepsilon}{k}(C_{\varepsilon 1} P_k - C_{\varepsilon 2}\varepsilon + C_{\varepsilon 3} W_k - R_{RNG})$

Modeling Approach Continues

Here, $\boldsymbol{h}$ is the gas enthalpy; $\boldsymbol{k}$ is the turbulent kinetic energy;

$\boldsymbol{\varepsilon}$ is the dissipation rate of turbulent kinetic energy;

$\boldsymbol{\mu}$ and $\boldsymbol{\mu_t}$ are the dynamic molecular and turbulent viscosities calculated from equations:

$$\mu = \frac{1.479 \cdot 10^{-6} T^{1.5}}{(T + 116.275)} , \qquad \mu_t = C_\mu \rho k^2 / \varepsilon$$

$\boldsymbol{Pr}$, $\boldsymbol{Sc}$, $\boldsymbol{Pr_t}$ and $\boldsymbol{Sc_t}$ are the molecular and turbulent Prandtl and Schmidt numbers;

$\boldsymbol{\sigma_k}$, $\boldsymbol{\sigma_\varepsilon}$, $\boldsymbol{C_\mu}$, $\boldsymbol{C_{\varepsilon 1}}$, $\boldsymbol{C_{\varepsilon 2}}$, $\boldsymbol{C_{\varepsilon 3}}$ are the empirical constants of turbulent model;

$\boldsymbol{g_i}$ is the gravity acceleration component ($\vec{g} = (0,0,-g)$);

$\vec{u}$ - the gas velocity vector having three velocities components u_1, u_2, u_3 ;

Results and Discussion

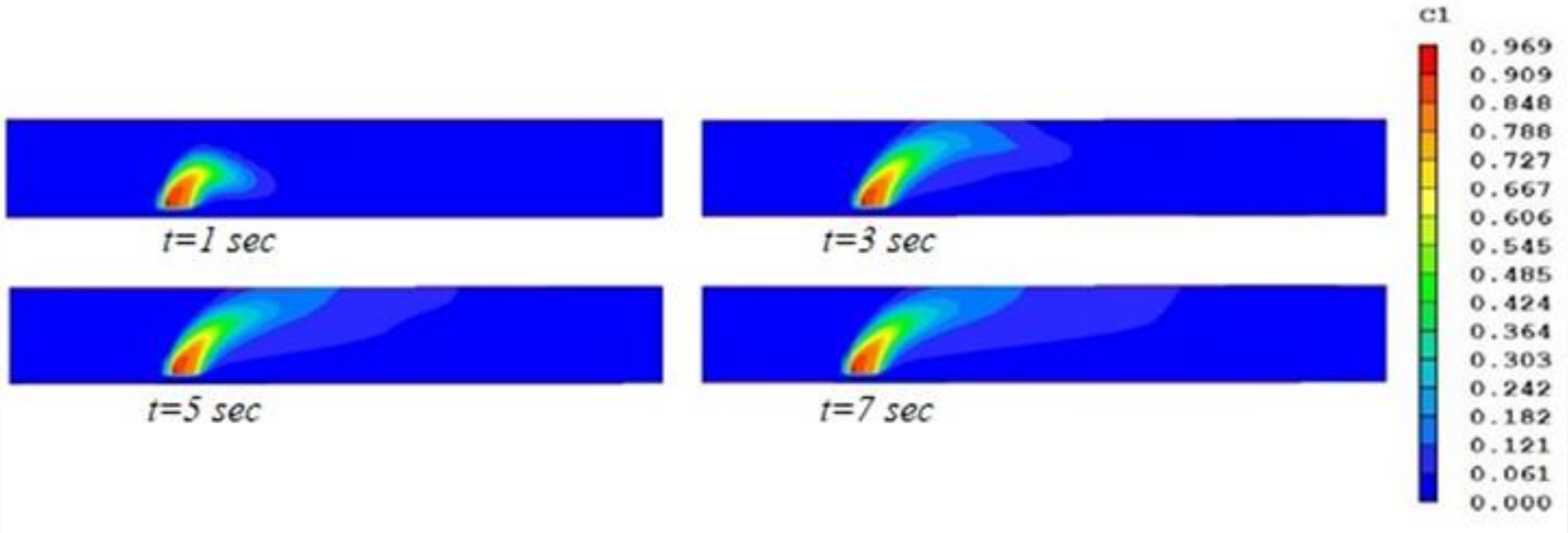

Fig. 2. C_1 distribution at different times (in the x_1x_3 plane)

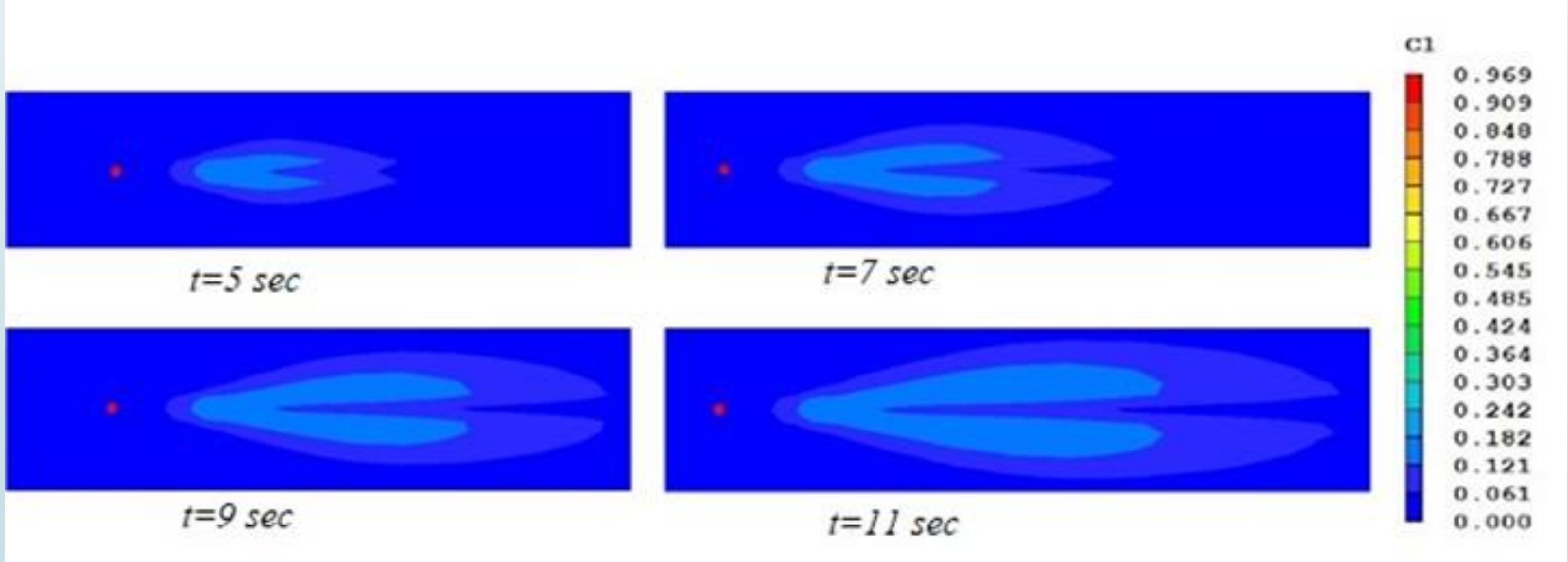

Fig. 3. The distribution of C_1 on the surface of the water at different moments of time

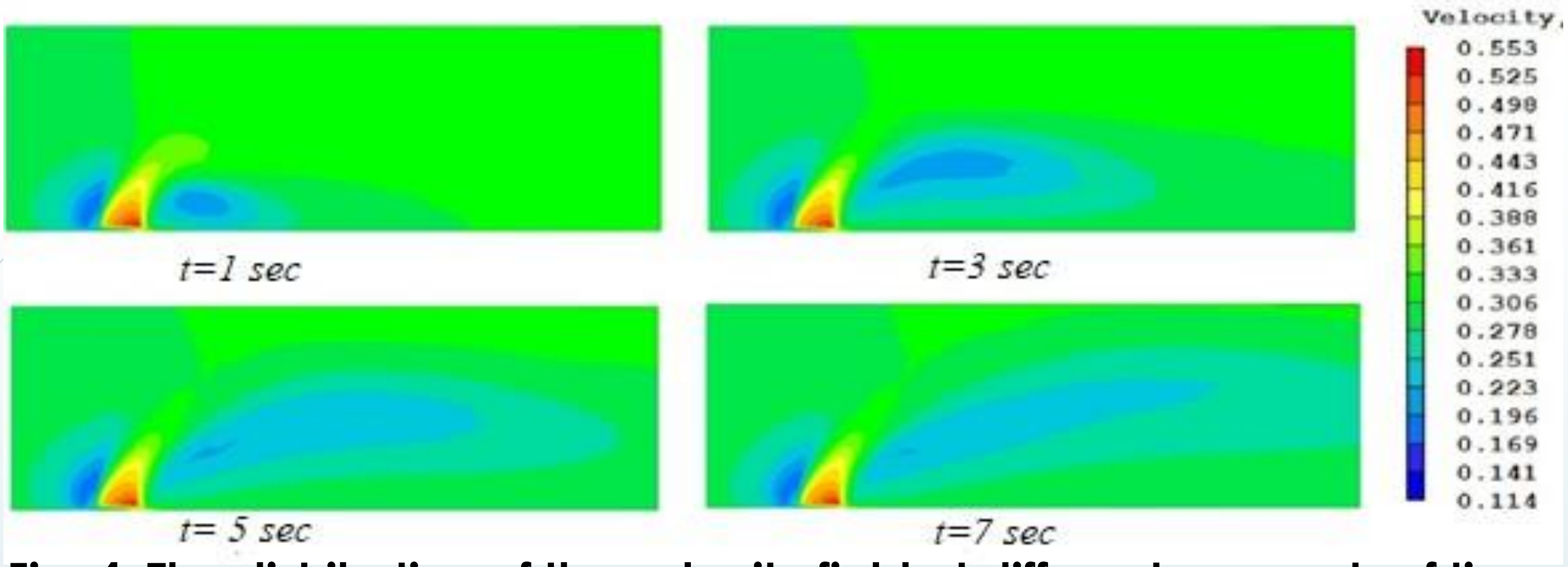

Fig. 4. The distribution of the velocity field at different moments of time

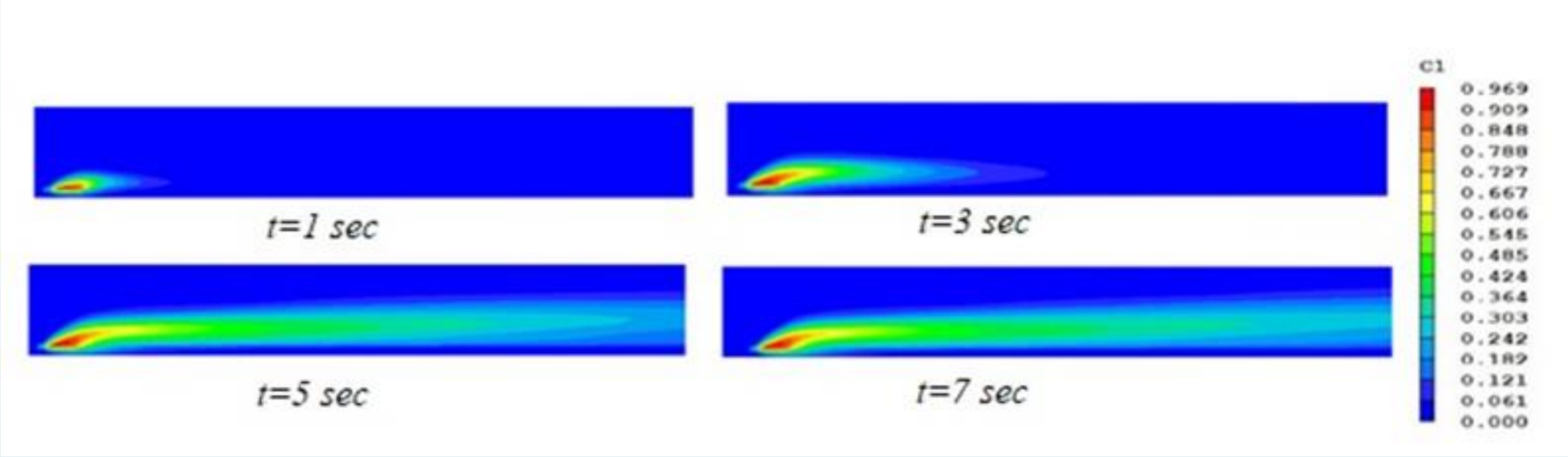

Fig. 5. The distribution of the concentration of C_1 at a flow rate of 1 m/s

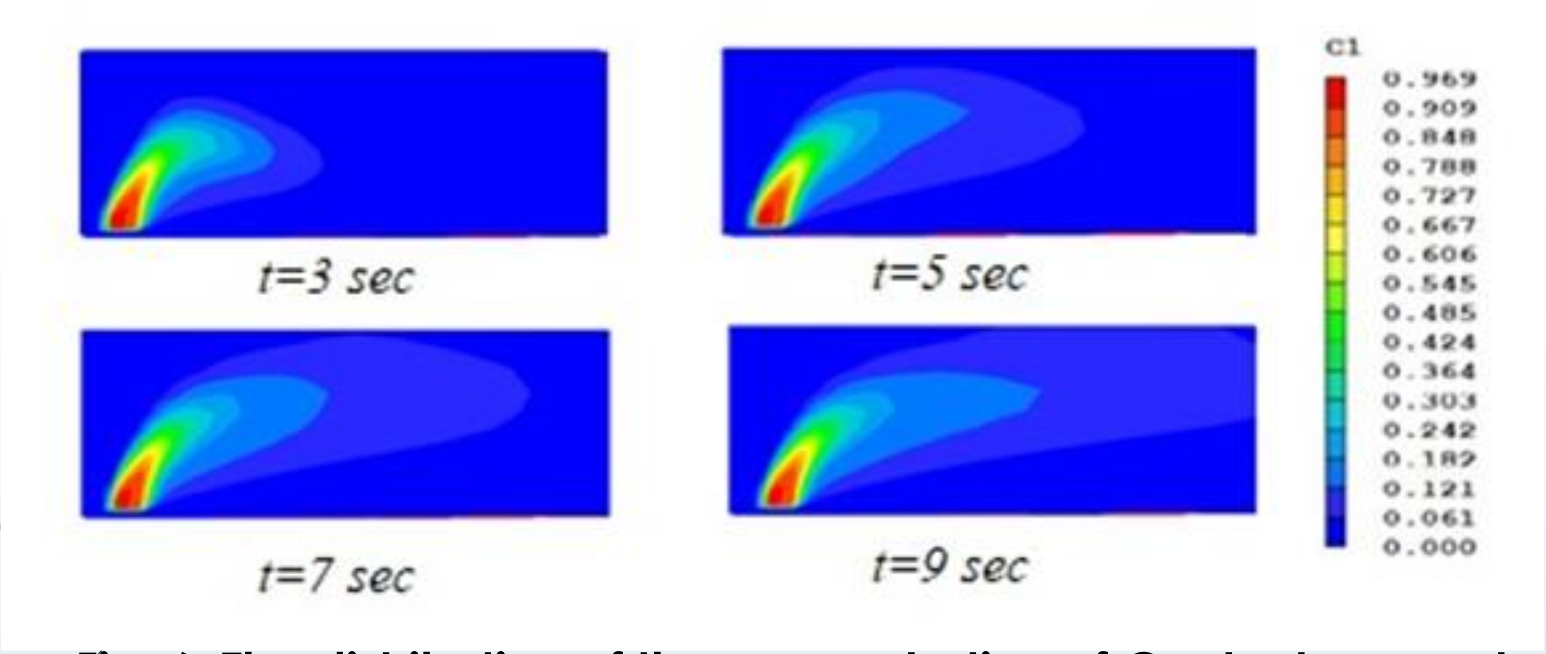

Fig. 6. The distribution of the concentration of C_1 at a temperature of oil 20^{0}C

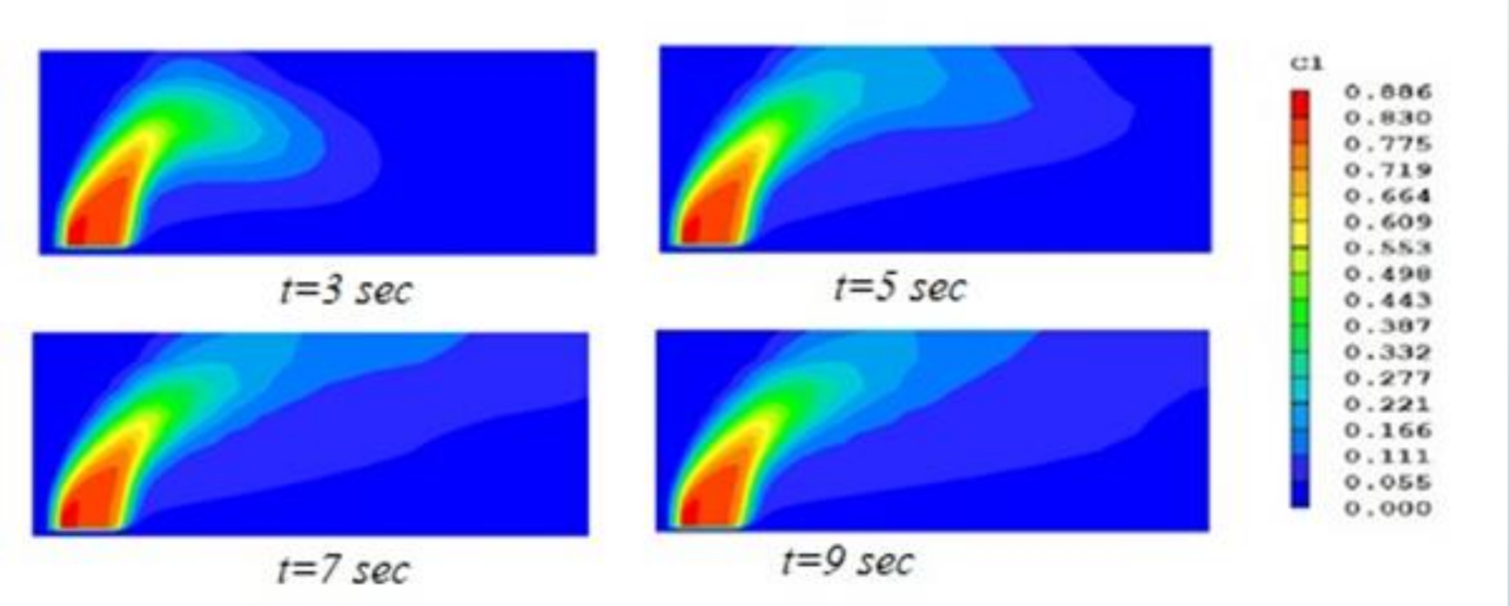

Fig. 7. The distribution of the concentration of C_1 by increasing the opening of the fistula

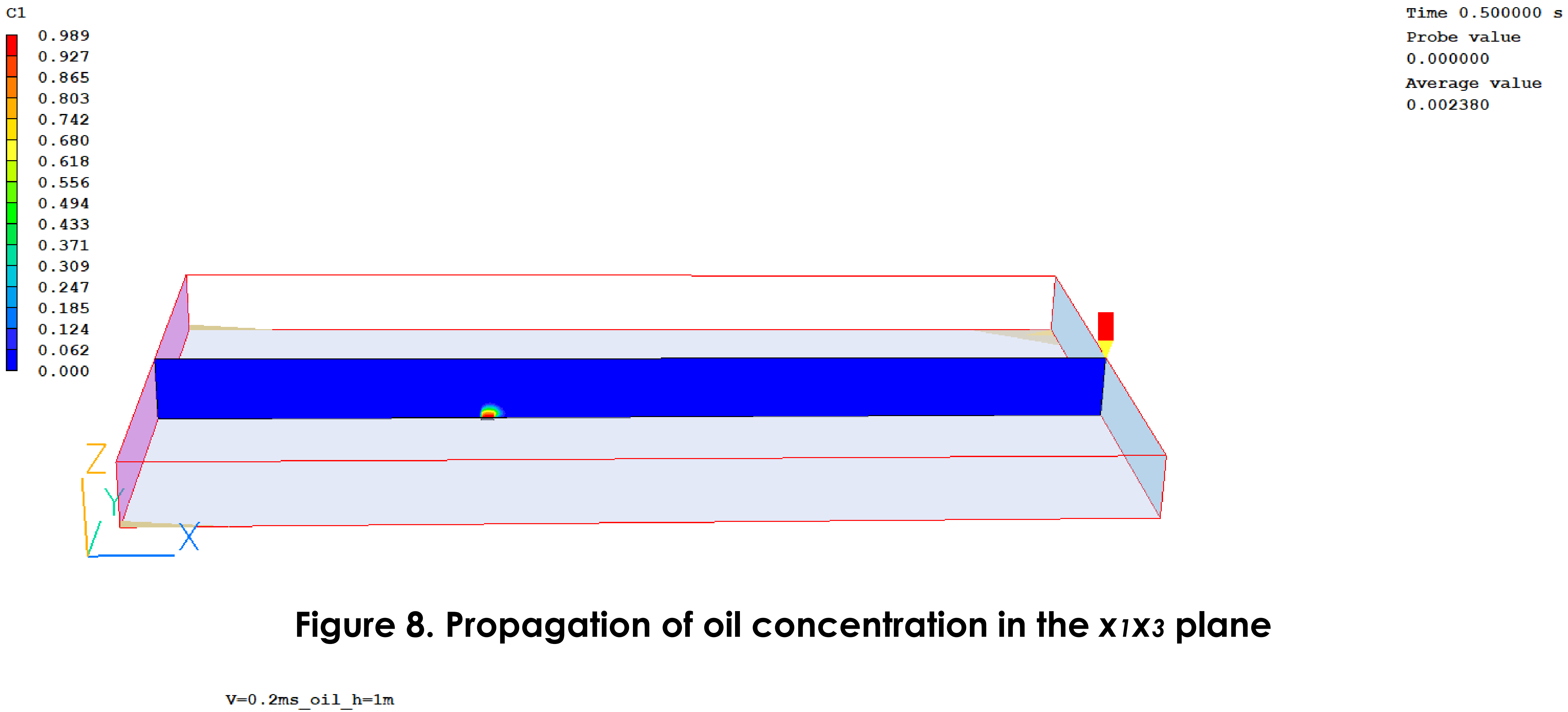

Figure 8. Propagation of oil concentration in the x_1x_3 plane

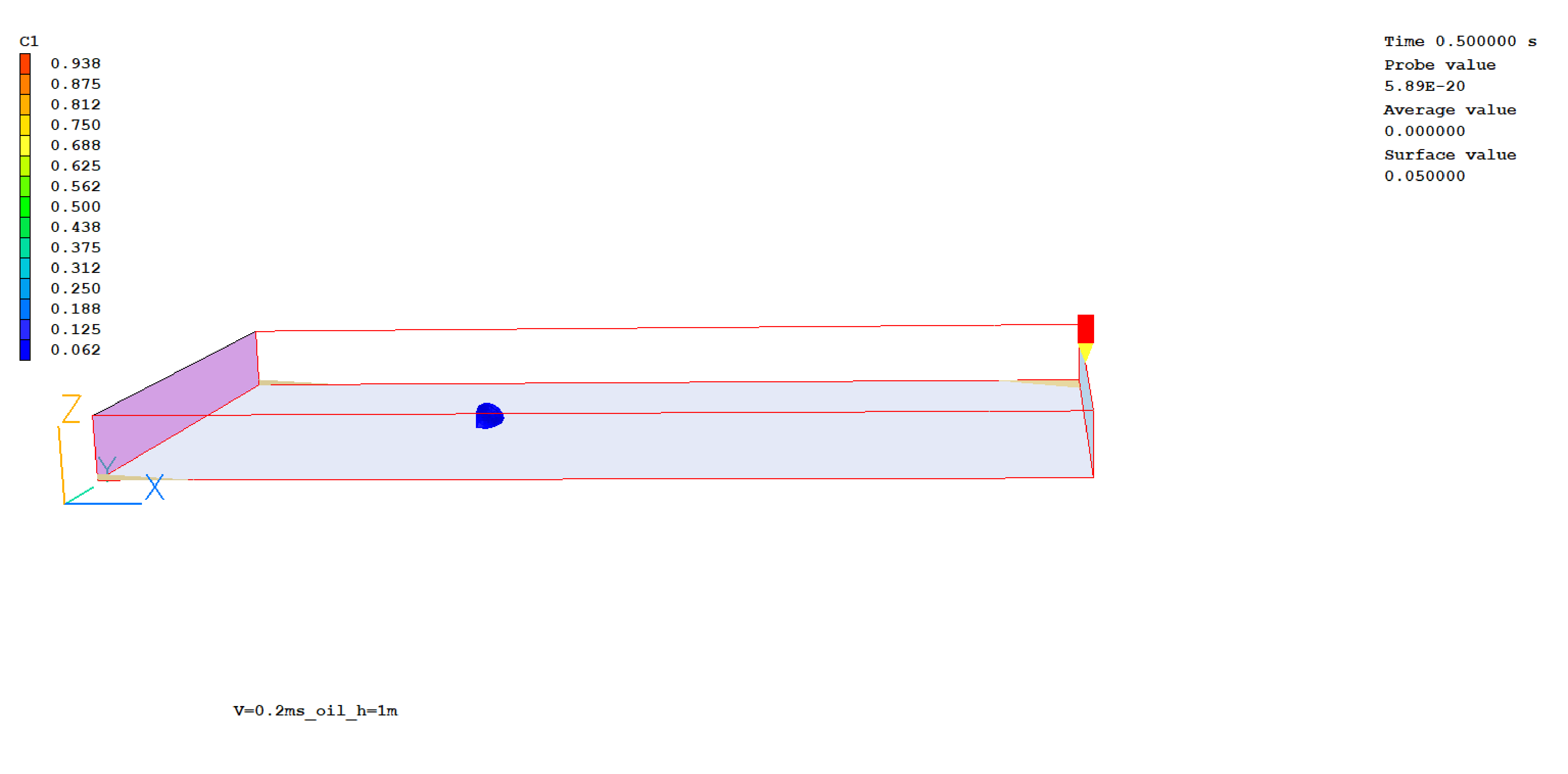

Figure 9. Isosurface of oil concentration propagation

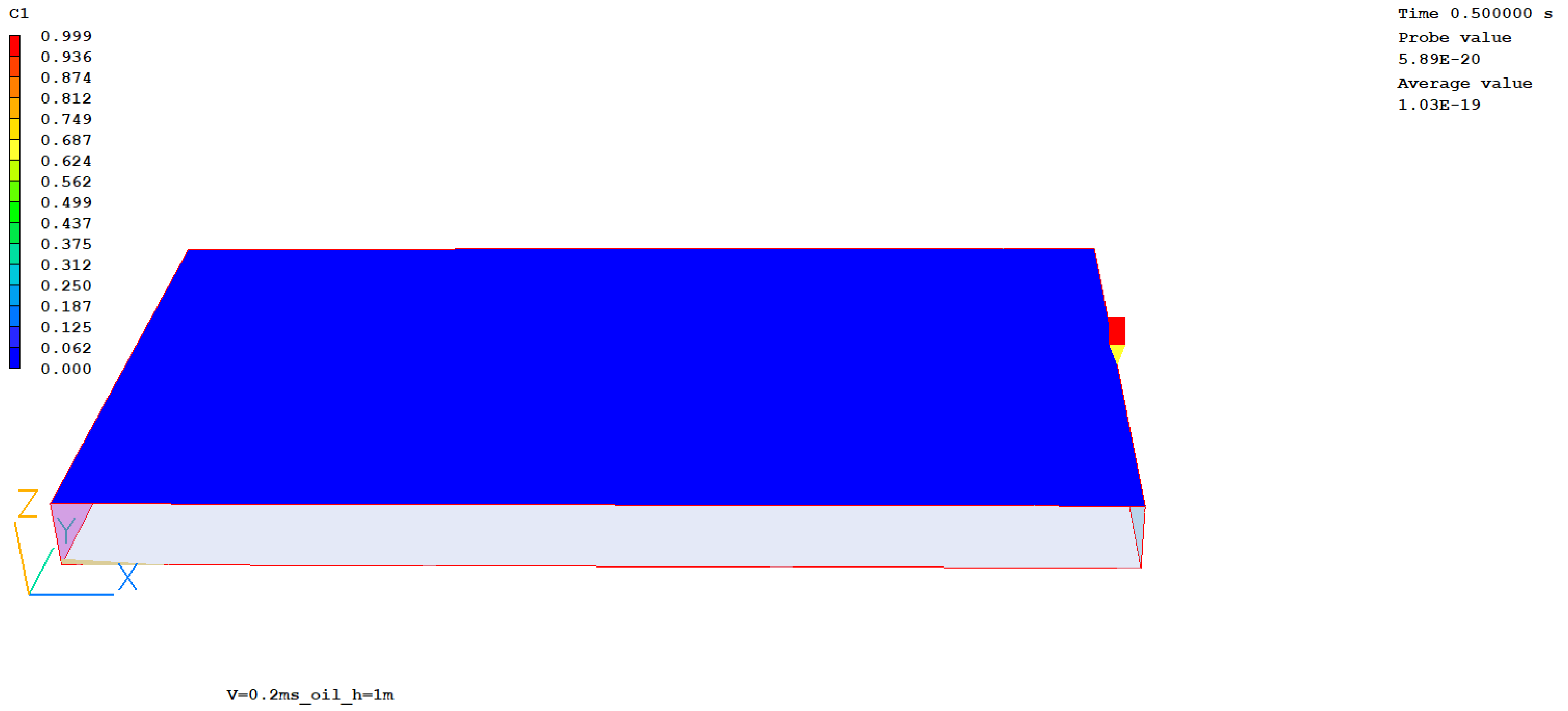

Figure 10. Propagation of oil concentration on the surface of the water

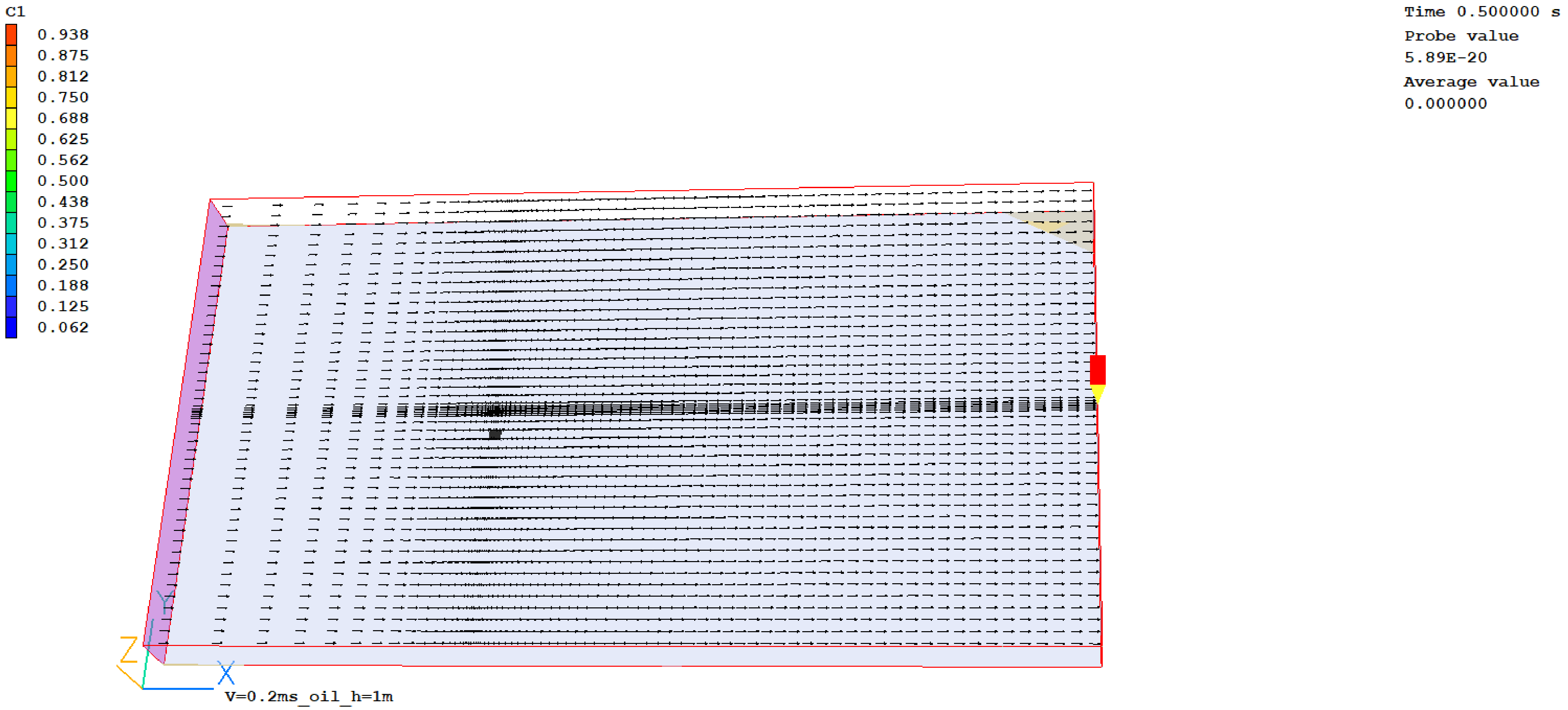

Figure 11. Velocity vector field and concentration of pollution in the x_1x_2 plane

Conclusions

- **A fully physical multiphase model of CFD for oil pollution in river has been developed.**
- **The model accounts for main the important physical processes: exchange of mass, momentum and energy between two fluids, turbulent fluid flow and convective and conductive heat transfer.**
- **The model was validated at various river speeds of flow.**
- **The calculations let to get the space distribution of oil pollution for different parameters of source of pollution and river.**

Future Work

- Further model development by improving chemical sub-model
- Sensitivity studies with various models of turbulence and chemical kinetics
- Testing the model for complex geometries
- Seeking a collaboration with universities/organizations/companies interested in developing and applying the advanced and pragmatic physical models of wildfire behavior. Inquiries are to be sent to perminov@tpu.ru .
- http://portal.tpu.ru/SHARED/p/PERMINOV/eng

Acknowledgements

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- **All the attendees of this session for their attention and patience during this presentation.**