Estimation of pollution by fire extinguishing water

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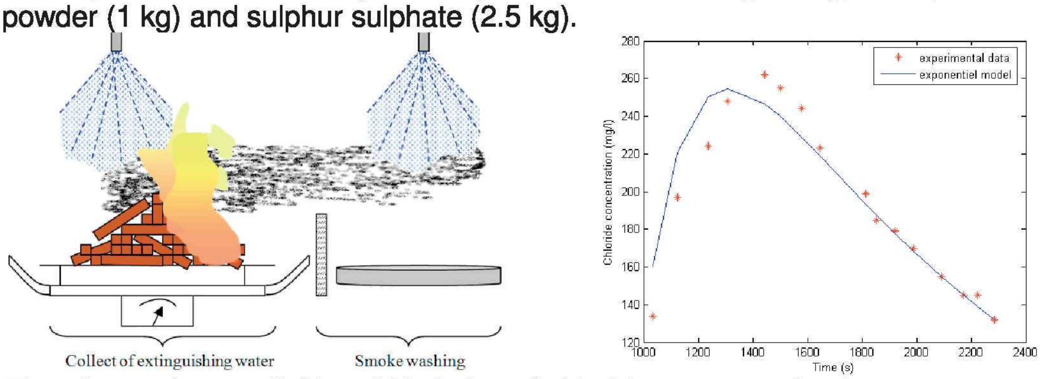
1. Introduction

Industrial fires may be violent and significant and involve the combustion of large quantities of substances which could be hazardous. Therefore the environmental impact could be significant.
Water is mainly used to extinguish industrial fires. Water is deployed to capture the energy released by combustion and consequently the water will be loaded with pollutants such as HCl and HCN.
The project O2FEU is interested in analysing the life cycle of water in industrial fire fighting. This water presents a source of pollution for soil and subsoil. The project consists in studying the fate of run-off waters in environment using mathematical models.
The aim of this work is the development of a mathematical model. This model will be used to determine the infiltration of the contaminated water in soil.

2. Statement of the problem

Industrial fire fighting is usually based on the use of water. This water, in contact with smokes and toxic products of combustion, is loaded with toxic substances before seeping through the soil.
The knowledge of impact of extinguishing waters on environment is necessary considering the important number of industrial fires.
In this work the infiltration of run-off waters in soil is considered. So mathematical modelling of infiltration in porous media is introduced. The soil is represented by the unsaturated zone and the saturated zone.
Experiments were conducted to determine the concentration of pollutants in the extinguishing waters. This data is necessary for the numerical simulation.
Various charge and discharge curves of pollutant concentration are obtained from the collect of extinguishing water. These initial concentrations will be used as reference source terms for the input of infiltration model.
The experiments consist in producing wood fire containing two types of pollutants: PVC in powder (1 kg) and sulphur sulphate (2.5 kg).



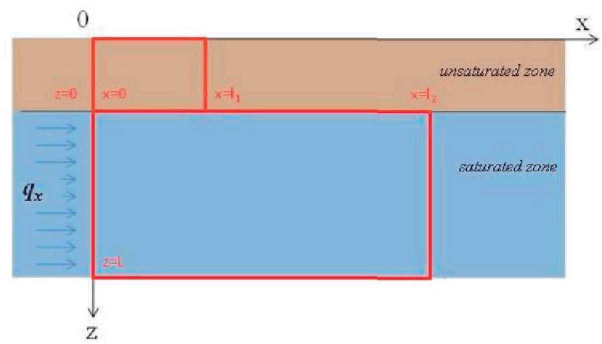
Experimental setup (left) and Variation of chloride concentration in water versus time (right)

The gaseous effluents are analyzed and the extinguishing waters are collected to determine their composition.

The concentrations of chloride and sulphur were around 250 mg/l and 200 mg/l in extinguishing waters, respectively. Due to the significant concentration of pollutants the development of the mathematical model proves to be necessary.

3. Infiltration problem

The model is based on the transport equations in porous media. The model takes into account the retention and biodegradation of the pollutants in soil. The model uses specific numerical resolution adapted for the transport equations. A simplified model of soil is used representing the unsaturated and saturated zone of the soil.



Computation domain

The equations used to simulate the infiltration of extinguishing waters in soil are the following:

- Unsaturated Zone:

The Van-Genutchten model was used as it takes into account the variation of water content in soil [1]. According to the Van-Genutchen model, water content $\theta(h)$ is given by:

$$\theta(h) = \theta_R + (\theta_S - \theta_R)(1 + |\alpha h|^n)^{-m} \tag{2.1}$$

Where θ_R = the residual moisture content

θ_S = the moisture content at saturation

α , n = empirical parameters

The transport equations are summarized by the following system [2, 3]:

$$R\frac{\partial(\theta C)}{\partial t} = D_L \frac{\partial}{\partial z}\left(\theta \frac{\partial C}{\partial z}\right) - \frac{\partial(q_z C)}{\partial z} - \alpha C \tag{2.2}$$

$$q_z = -K_{zz}\frac{\partial H}{\partial z} \tag{2.3}$$

$$\frac{\partial \theta}{\partial t} = \frac{\partial}{\partial z}\left(K_{zz}\frac{\partial H}{\partial z}\right) \tag{2.4}$$

This model is composed by the solute transport equation (2.2), the Darcy equation (2.3) and the Richards equation (2.4).

In equations (2.3) and (2.4), the Mualem-Van Genutchen model used for the hydraulic conductivity $K(\theta)$ is given by the following relation:

$$K(\theta) = K_S\, Se(\theta)^l \left[1 - (1 - Se^{1/m})^m\right]^2 \tag{2.5}$$

Where K_S = the conductivity at saturation

Se = the effective saturation

m = a retention parameter

l = a coefficient of pore connectivity

In equation (2.2) the addition of the coefficient *R* allows to take into consideration the delay due to the absorption phenomena in soil. So this equation computes the concentration of pollutant and takes into account the dispersion, convection and biodegradation of the pollutant in porous media.

- Saturated Zone:

The solute transport equation is given by:

$$R\frac{\partial C}{\partial t} = D_L \frac{\partial^2 C}{\partial x^2} + D_T \frac{\partial^2 C}{\partial z^2} - \frac{q_x}{\theta_S}\frac{\partial C}{\partial x} - \frac{\alpha}{\theta_S} C \qquad (2.6)$$

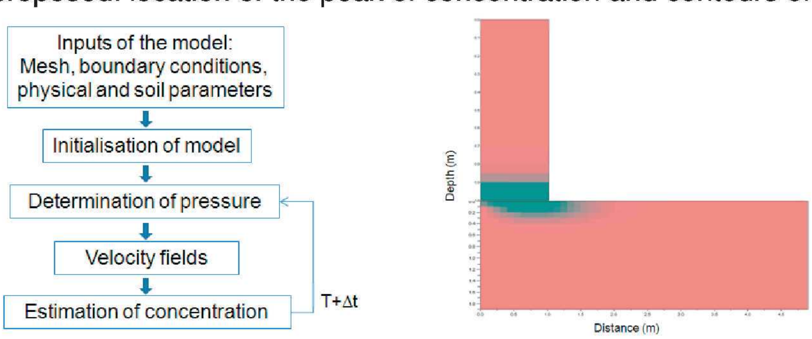
where D_L and D_T are the longitudinal and transversal diffusion coefficients.

Regarding boundary conditions, the relation $C(x;z=0;t) = C_0(x;t)$ is adopted at $z=0$.

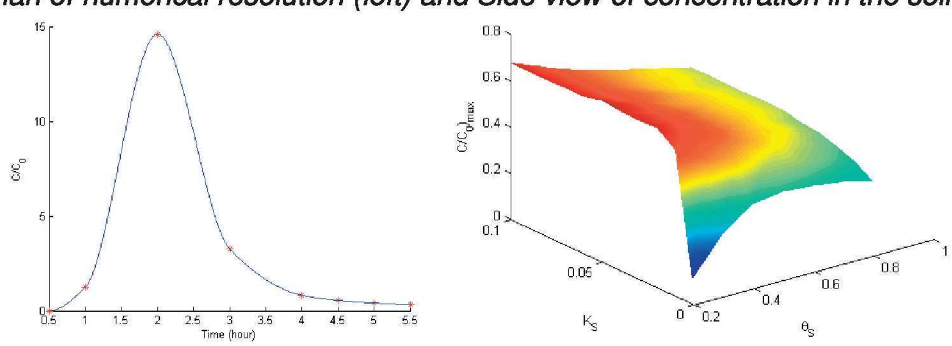
Considering the sprinkling of fire zone by firefighters, boundary conditions at the surface of the soil is modelled by echelon-type solicitations. Three stages are considered. The first corresponds to situation where extinguishing waters contained pollutants. The second corresponds to situation where fire watering continues, but water does not contain pollutant anymore and the third corresponds to situation where sprinkling is ended.
The numerical method used a non-oscillatory scheme for the discretization of equations [4].

4. Results

The software introduces user's interfaces for the model parameters. Various outputs are proposed: location of the peak of concentration and contours of concentration in 2D.



Plan of numerical resolution (left) and Side view of concentration in the soil (right)



Local variation of concentration versus time (left) and Variation of $(C/Co)_{max}$ versus parameters Ks and θ_s(right)

Performed simulation allows good estimation of flow and pollutant transport in soil. First sensibility analysis has been performed for the model regarding conductivity and moisture content at saturation.

5. Perspectives

The developed model represents a practical, simple and quick tool for the estimation of pollution generated by fire extinguishing water.
In case this tool predicts a high pollutant concentration, the use of 3D model proves to be necessary to refine calculation but it requires more calculation time.
Improvements are necessary to reduce calculation time; the implementation of implicit numerical scheme is under way of implementation.
The modelling of transport of pollutants in the soil is an over-defined problem. Moreover, some parameters are hardly measurable. To compensate for this problem, modelling with uncertain parameters could be a solution. Based on Mikhailov works [5], the introduction of parameters known a priori in form of distribution could be used to determine probable concentration as a result of the model.

6. Conclusion

To estimate the impact of fire extinguishing waters a model was developed. It is composed of two sub models. The first one, based in experimental results, is dedicated to the calculation of pollutant concentration in run-off water. The second is dedicated to the modelling of water and pollutant infiltration in the ground.
The infiltration model is based on a combination of classical equations for infiltration and transport in the unsaturated and saturated medium. It was implemented using a non oscillatory scheme.
The first results are in good agreement with the literature data.
The global model should be used for consequence assessment in risk estimation of a variety of industrial sites as well as in emergency situations.
Therefore, it requires to be usable without thorough data search. The next step is the development of a database of model parameters to be used in most typical situations.
Future developments also concern the management of uncertainly with the capacity to estimate probabilistic distributions of concentration at various stages of the simulation.

Reference

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