REAL TIME FOLLOWUP OF LEAKS AND DISPERSION ACCIDENTS

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Fluidyn

Most of the hazards occurring on a petrochemical onshore platform have their origin in a very localised accidental leak of toxic or flammable gases. The extent of human and material losses depends on speed of the detection and subsequent intervention.

A fast detection requires prediction of impact zone on the inhabited area around the site, which will be valuable information to be used for evacuation planning.

In this context, a numerical tool has been developed to predict the drift of the cloud and the expected concentrations on a region covering the industrial site and the area around it. While in operation, the simulation should run faster than the evolution of accident.

Two simulation methods are traditionally used:

- Empirical or Gaussian formulations: They can estimate maximum extent of the hazard consequences but cannot take into account local variations both in time (weather conditions) and in space (topography, obstacles). These limitations do not allow them to be used for real-time simulations on an actual site.
- Deterministic 3D CFD software: If there effect is properly evaluated, it is possible to take into account all the configurations of ground and meteorology and give answers with far greater precision with CFD software. However high number crunching and long computational times are usual deterrents. This drawback hampers any real time usage unless a very fast and expensive computer is available to respond to the exigencies of a real life emergency.

The methodology presented here is a mix between these two methods. A set of windfield conditions are computed in advance with a 3D CFD model and stored in a database. In case of an alarm on site, the actual data from the monitoring stations and from the weather station is fed in the software. A probable location and likely quantity of release will then be estimated (this methodology is not presented in the scope of this paper). Then the numerical tool will rebuild the correct wind-field by interpolation between existing windfields in the database. Finally the software will perform the consequences simulation. In various test cases, the timeline for this entire process was found faster than the unfolding accident allowing for some hindsight on the possible course of action. This methodology has been implemented on actual sites and some results will be presented here.

INTRODUCTION

On industrial installations devoted to oil and gas extraction, processing, refining or petrochemical production, accidental emissions of toxic compounds represent a significant part of the risks related to these activities. When such an accident occurs, the knowledge in real time of the concentration of toxic gas resulting from the release of the hazardous substance would be extremely valuable information to initiate any emergency actions and evaluation of impact on the industrial site and its vicinity. For that purpose, the modelling tool being developed will be applied for real-time simulation of atmospheric dispersion of hazardous substances.

Significant technical difficulties have been solved for this project:

- the calculation of the dispersion must take into account the detailed 3D industrial lay out to correctly simulate their effect on gas concentration on the industrial site,
- Computational time must be low enough to enable real time usage of simulated results.

The overall project is divided in two phases: a first phase devoted to the development of the modelling platform and its implementation on an industrial site and a second phase devoted to in situ validation of the platform developed.

In this paper, it is intended to present the results and conclusions obtained during phase 1 of this work. The different options and advantages of this development will be developed and compared to other approaches. The industrial implementation of the real time modelling platform will be described. While the second phase of this work will deal with an experimental campaign designed to simulate an accidental release, a first on-site validation could be obtained by applying the same methodology to regular releases of the site. The numerical results of real time simulation pertaining to this validation will be presented here.

AVAILABLE MODELLING TECHNIQUES

The framework of the intended use of the software, as described in the introduction, calls for the following points:

- Simulation of atmospheric flows and dispersion of toxic species (especially in close field) compatible with the complexity of the industrial site terrain:
  - topography and obstacles, however complex they might be,

  - variable meteorology during the emission and dispersion of gas cloud
- Fast and robust simulation required for real time management.

The transportation and dispersion of substances in the atmosphere are primarily driven by two main vectors: wind and turbulence. The concentration variation in the plume is quantified by the solution of a mass transport equation where the local variation, both temporal and spatial, of concentration is a function of the flow due to the wind (convection) and turbulence (diffusion and turbulent mixing). It is thus necessary to know 3D wind-field and turbulence field at all points of the domain.

There are three families of models for simulation of dispersions of gaseous pollutants:

- Gaussian models,
- Integral models,
- 3D CFD (Computational Fluid Dynamics) models.

Gaussian (2D) models are the fastest and therefore might look appropriate for real-time dispersion. However passive formulations suppose that the dispersion of the pollutant is done according to a Gaussian law (probabilistic approach: mathematical correlation and statistics of experimental tests) whose standard deviations depend on the distance to the source (Pasquill, Turner) or on past time (Doury) as well as characteristics of the atmosphere. Gaussian models assume that the wind is neither modified by the presence of the pollutant nor by the features of the terrain (topography and obstacles). They also use average stable wind conditions. As the formulations assume dispersion in horizontal plane mostly, Gaussian models fail at low/moderate wind velocities where vertical component due to natural convection or due to terrain features is significant. It is found that for a usual site with obstacles and a hilly terrain, the distance reached by the cloud for a set concentration could be 3 or 4 times shorter than the distance obtained by Gaussian simulations.

Integral models also make a large number of assumptions which are usually not valid on complex terrain or moderate wind conditions. They are used only for dense gas dispersion on flat terrain but with a surface roughness. The model assumes that the emission temperature should be less than ambient temperature and the source is positioned on the ground. Obstacles are not taken into account and only a global roughness is assumed on the entire domain. In the same way as for Gaussian simulations, passive formulations are used.

For real time response, the credibility of the prediction is very important for the fire fighters and far-reaching assumptions have to be avoided. Moreover, the close range can strongly affect the extent to the harmful concentrations, by widening their reach or slowing down the cloud formation. In that respect, the deterministic CFD models are to be used. The wind and turbulence variations over the terrain and the dispersion are computed based on the fully turbulent fluid dynamics (Navier-Stokes) resolving conservation equations of mass, energy and momentum. The equations are discretized on a finite number of spatial points, the mesh. The finer the mesh and higher numerical scheme order, the closer the solution is to real wind and dispersion conditions but higher is also the CPU time.

DEVELOPMENT OF A NEW METHODOLOGY

The purpose of this development is to fill the technological gap between the two methods described in the previous section. On the basis of already existing tool (*fluidyn*-PANEPR), the methodology seeks to gather the precision provided by 3D simulations of wind-fields along with the speed of calculations associated with Gaussian models.

Fluidyn-PANEPR is a 3D CFD model used for emergency planning and response, designed to analyse the consequences of industrial accidental leaks.

The methodology suggested is thus the following one:

- Creation of a numerical model of terrain including the site and its surroundings
- Creation of a 3D database of wind-field beforehand
- Integration of the network of monitoring points in the numerical model of terrain
- Following an alert, simulation of dispersion in real time starting from the identified source with the Lagrangian puff model
- Confrontation in real time between simulation and on-site observations
- Feedback for operator as a part of decision-making process.

The evaluation of the fields of wind and turbulence in the domain is based on a resolution of Navier-Stokes equations by using as boundary conditions the weather conditions representative of the area. Thus, the air flow (velocity and direction of the wind) are recomputed locally to take account the specificities of the ground: topography, obstacles, land usage.

According to the stability class of the atmosphere and the ground roughness, a vertical profile of wind is estimated initially. Profiles in power law or logarithmic law based on the theory of Monin-Obukhov and other similar theories can be forced on the basis of weather microparameters to evaluate the local development of the atmospheric boundary layer. The fields of local winds are recomputed in 3D over the domain on an unstructured or curvilinear mesh. They are validated by comparison with on-site recordings of weather episodes (for a known weather condition, it will be checked that the data recorded on local weather measurements at the site are in conformity with those predicted by the simulation).

For real-time numerical response, a significant number of wind-fields are selected, based on those most frequently seen on site, and computed beforehand. The continuous measurements recorded by the local weather measurements make it possible to identify the wind condition at the time of the event and the closest wind condition in the database will be retrieved for simulation purposes. If, during the dispersion calculations, weather measurements show that the wind has changed sharply, the software will retrieve a new wind field from the database. The dispersion, performed with Lagrangian puffs, could thus be adjusted on a new wind-field, if necessary, during simulation.

The Lagrangian description consists in discretizing the fluid and following the modifications of the properties of the moving fluid. Two main techniques are available:

- **Lagrangian particles**
  Dispersion is evaluated by the calculation of several thousands of trajectories of discrete particles from the same source. The concentrations are then given by summation of the number of particles present in a given volume. This method makes it possible to represent accurately the physical phenomena but is computationally quite expensive since it requires simulation of a huge number of particles to correctly represent the turbulent dispersion of the particles and to obtain a precise concentration.
- **Lagrangian puffs**
  The pollutant emission process is discretized by a succession of puffs. A puff can be regarded as a Lagrangian element with a local spatial distribution of the concentration as a Gaussian curve. The centre of each puff is transported by the field of the mean wind and the extent of Gaussian dispersion increases with the diffusion, including turbulence. This local dispersion makes it possible to quickly obtain the field of concentration with a relatively small number of puffs. Taking into account the constraints known on the site, the Lagrangian technique by puffs is retained here. The performances of the method of dispersion by Lagrangian puffs are in particular exposed by Cheng, Y.-H. and Al. The consequences of an accidental emission on a nuclear site have been evaluated by the authors with a puff model simulating 100 minutes of emission in 22 minutes (CPU time) on a PC Pentium RD 3.2 GHz/2GB RAM.

EXAMPLE ON AN INDUSTRIAL SITE

The methodology outlined above has been used for demonstration purposes on an industrial site. Before the experimental campaign to design to assess the fiability of the software in a mock-up accidental scenario, a first application in regular site operation has been performed. In this application, the software was made to follow in real-time the usual emissions of the site.

The site is located next to a river in a very hilly region, illustrated in Figure 1.

The 3D site map is shown in Figure 2 with the landscape objects taken into account: forests in green, water bodies in blue, urban areas in pink and the buildings of the industrial site itself modelled as 3D obstacles. Possible emission sources are modelled as points. Another close view of the model of the industrial site is presented in Figure 3. The pink points are showing monitoring points location, while the red points are representing possible emission sources location.

In order to be as precise as possible without penalizing too much the computational time, the mesh has been refined next to the significant obstacles of the site and then

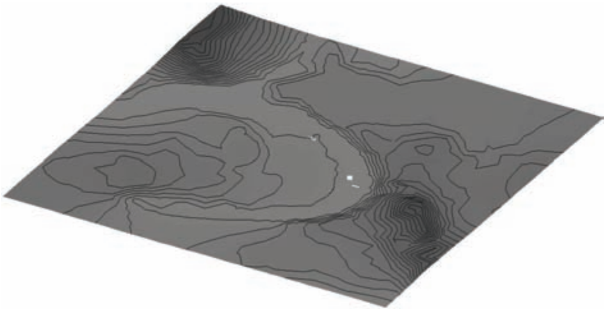

Figure 1. Altitude contours around the industrial site location

Figure 2. Example of the numerical model of terrain of an industrial site used for demonstration

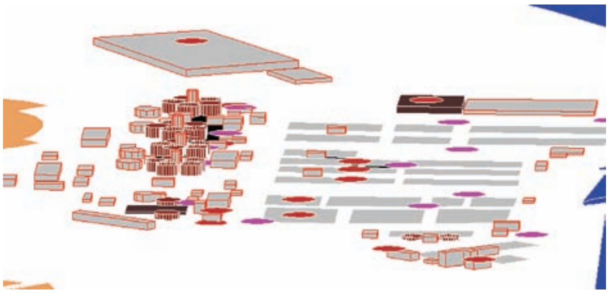

Figure 3. Close-up on the modelled industrial site

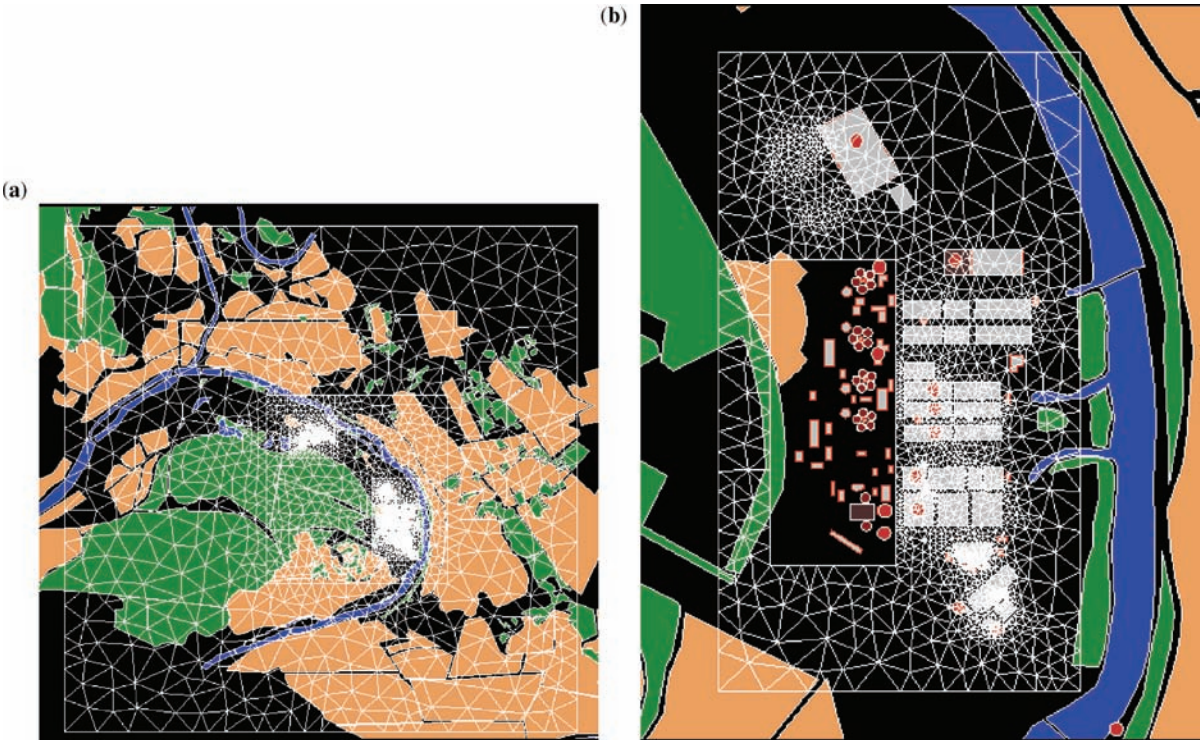

Figure 4. Unstructured multi-block refined mesh

has been coarsened using the unstructured and multi-blocks techniques (Figure 4).

A database of 60 wind conditions has been pre-established. The database is meant to increase: the more windfields are available, the better the precision will be.

An example of a windfield represented next to the ground and in the vicinity of obstacles on the industrial sites has been included in Figure 5. The vectors colours are based on the wind intensity and the vectors give the local direction of the wind. The effect of the buildings on the local air flows can easily be seen as well as local perturbations and recirculations.

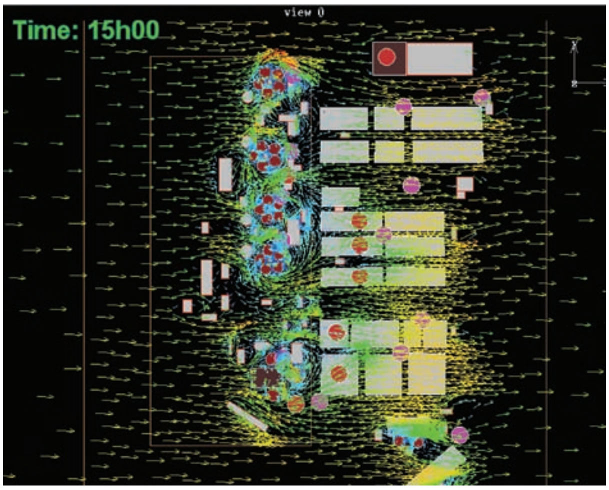

Figure 5. Wind vectors next to the ground on a close-up of the industrial site

For the demonstration purpose, all the identified potential sources have been set to emit pollutants at the same time. In the simulation process, the link between monitoring points and the software triggers the database search of the closest weather condition to the one really experienced and the emission of Lagrangian puffs from all the sources on that windfield. This is being updated every half-hour as new wind measurements are made on site.

An example for 4 consecutive half-hours is being presented in Figure 6. The concentration levels have been set at random. The number and frequency of Lagrangian puffs emission have been fine-tuned so that the simulation runs twice as fast as the real-time. These adjustments can be changed depending on the computer used as well as on the time to be achieved.

CONCLUSION

Within the framework of emergency response by simulation in real time of the evolution of an accidental emission, the added options in the 3D code Fluidyn-PANEPR must make it possible to carry out dispersion on the site and in its environment on scales of time lower than those of real dispersion. Of course, time to integrate the data (monitoring points, meteorology, source location and estimation) should be taken into account in the overall estimation.

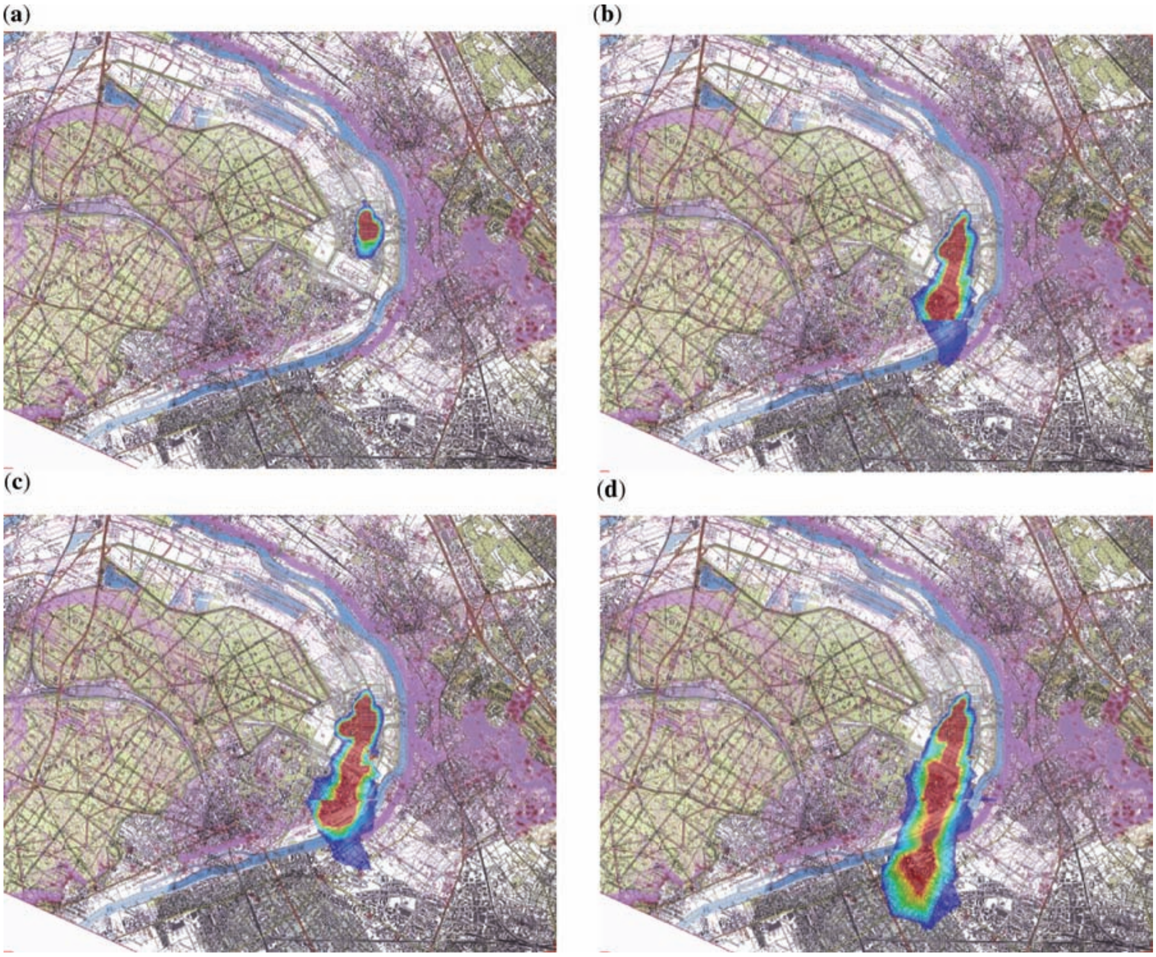

Figure 6. Concentration contours of pollutants from 0 to 2 hours by steps of 30 minutes for emission from all sources

This innovative methodology answers the objectives and expectations of real-time emergency management, supported by a strong know-how in 3D modelling and benefiting from advantages of all available techniques. The work in progress will deal with on-site validation of the simulations and includes now the emission source and strength determination by inverse modelling based on monitoring points measurements.

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