Prevention of explosion occurrence in a compressor room using numerical simulation of methane leakage and deflagration.

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Abstract

In the set-up of a new industrial process, careful thought is being given to safety aspects. Often, these aspects can control the design of the process itself or more generally the environment in which the process will be implemented. Such safety aspects include prevention of toxic gas dispersion, fires or explosions. As an example, the explosion of a gas leakage from a compressor and its consequences on the design of the compressor room is presented here. Explosion simulations are often performed under standardized, penalizing conditions for the gas, and rarely take into account the dispersion of gas in a room. This dispersion depends a lot on leakage parameter (size, pressure, temperature, etc…) and room size. In some conditions, gas can be considered as well mixed in the room or space of study. In most of real cases, the dispersion of gas leads to non-homogenous cloud concentrations in time, and sometimes to high mean velocities and high turbulence intensities. The study proposed here deals with a credible leakage at compressor 2nd stage pipe in a confined room. The leakage flow rate is defined using *fluidyn*-ASSESS RISK, the dispersion of natural gas and explosion are solved successively in 3D with *fluidyn*-VENTCLIM and *fluidyn*-VENTEX. The risk of explosion is eliminated by using the simulation to design a natural ventilation coupled with well-located sensors.

I. Introduction

In the set-up of a new industrial process, careful thought is being given to safety aspects. Often, these aspects can control the design of the process itself or more generally the environment in which the process will be implemented. Such safety aspects include prevention of toxic gas dispersion, fires or explosions. As an example, the explosion of a gas leakage from a compressor and its consequences on the design of the compressor room is presented here. Explosion simulations are often performed under standardized, penalizing conditions for the gas, and rarely take into account the dispersion of gas in a room. This dispersion depends a lot on leakage parameter (size, pressure, temperature, etc…) and room size. In some conditions, gas can be considered as well mixed in the room or space of study. In most of real cases, the dispersion of gas leads to non-homogenous cloud concentrations in time, and sometimes to high mean velocities and high turbulence intensities. The study proposed here deals with a credible leakage at compressor 2nd stage pipe in a confined room. The leakage flow rate is defined using *fluidyn*-ASSESS RISK, the dispersion of natural gas and explosion are solved successively in 3D with *fluidyn*-VENTCLIM and *fluidyn*-VENTEX. The risk of explosion is eliminated by using the simulation to design a natural ventilation coupled with well-located sensors.

II. Case description

In the frame of a security analysis for explosion risks in some re-compression room of natural gas, a computational study was performed in a closed room of dimension : L66m*H14m*W16m (see figure 1). It comprises of compressors of different capacities which are disposed longitudinally in the room. Each compressor comprises of different pipes which are connected to the external piping devices. In this study, only the potentially damaged pipes are modeled, and the room is considered as completely closed (see Figure 1).

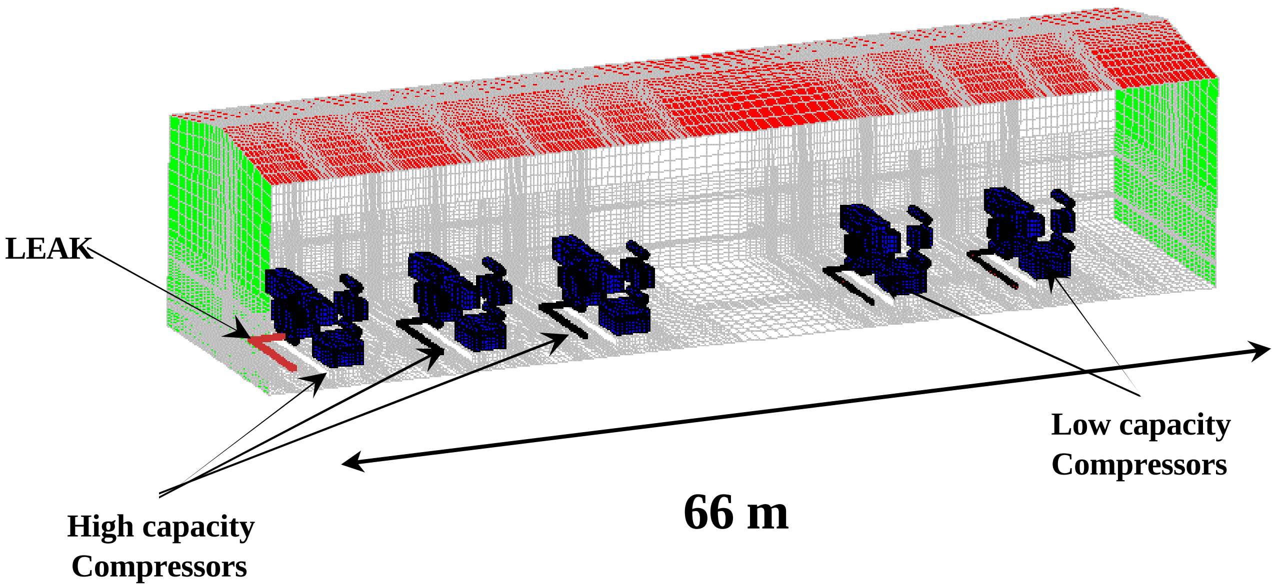


Figure 1 : Mesh geometry

The leak characteristics are taken from a specific scenario, which is to consider a round rupture in a pipe. The dimensions of the hole and the flow rate of methane are specified in the table n°1 below.

Table 1 : Parameters for leak computation

Composition du gaz (fraction molaire %)	Méthane	76,77%
	Azote	23,22%
	Ethane	0,01%
Masse molaire du gaz (g/mol)	18,82	
Pression opératoire de la canalisation (bar)	10,5	
Débit dans la canalisation (kg/h)	11566	
Longueur de canalisation		
Type de brèche		
Coefficient de débit	0,9	
Diamètre de la canalisation	DN250	
Température du gaz (°C)	79	

The leak itself is calculated with specific code ASSESS RISK, which computes the flow regime of the gas at the outlet of the leak. In this case, it is assumed that the leak flow rate is constant. The mass flow rate computed with this values is : $Q = 2.66\ kg.s^{-1}$. Sonic regime is occurring in this case.

The leak characteristics are introduced into the CFD-3D computation of dispersion into the room containing the compressors. Natural gas composition is introduced into the domain, which is composed essentially of N_2, 0_2 with reference pressure being atmospheric pressure P_{atm}.

III. Dispersion results

The dispersion of natural gas from the previous defined leak is depicted in the following pictures, which show the time evolution of gaz fraction (methane into the room domain). Note: Dispersion was performed also on multi-bloc mesh (simplified) to allow explosion modeling in the room using Fluidyn-VENTEX.

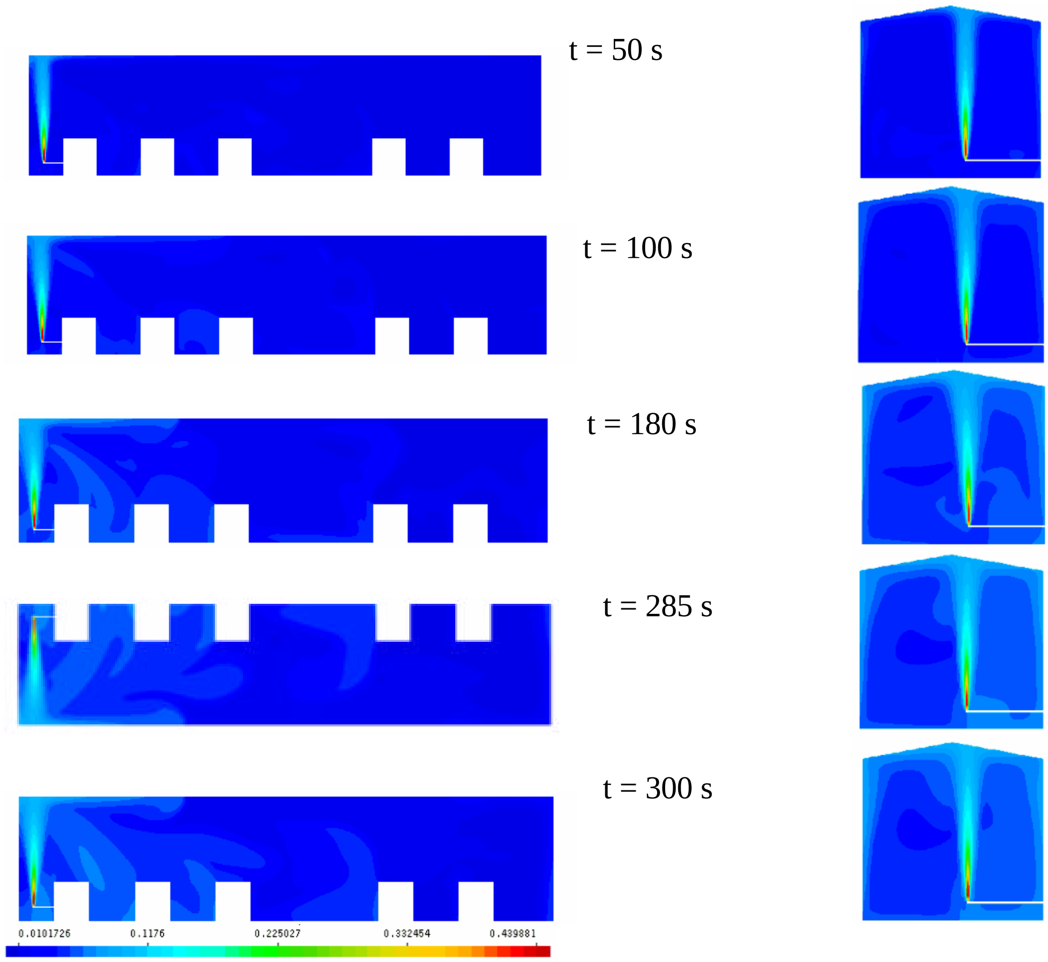


Figure 2 : Volumic fraction of Methane in the room at different times. Column a. Longitudinal section. Column b. Cross section.

The leak duration is about 5 minutes. After the leak stops, gas is still diffusing into the room, but it is assumed that the maximum flammable cloud is obtained after these five minutes of leak. The explosion case is perform using Fluidyn-VENTEX which allows to compute the whole fast transient problem including the combustion model.

Since the typical length of turbulence in the flow issuing from the leak are relatively high, and the mesh relatively coarse compared to combustion typical length scales, the BML model was chosen for that particular case.

III. Explosion results

Ignition points of the combustion (hot source) were placed in the computational domain at different locations.

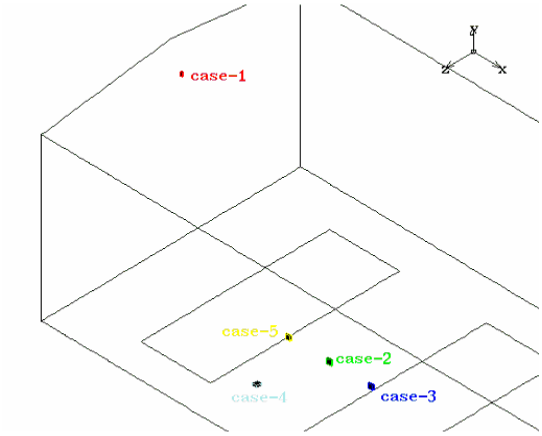


Figure 3 : Ignition points.

The flammable limits of the methane in air are given below in terms of mass fraction or volumetric fraction.

Table 2 : Limites de concentration

	Mass fraction (%)	Volume Fraction (%)
LFL	2.6	4.6
UFL	9.7	15

The cloud of flammable gas in the room was found to be relatively big after a five minutes leakage (see figure 4). The region of

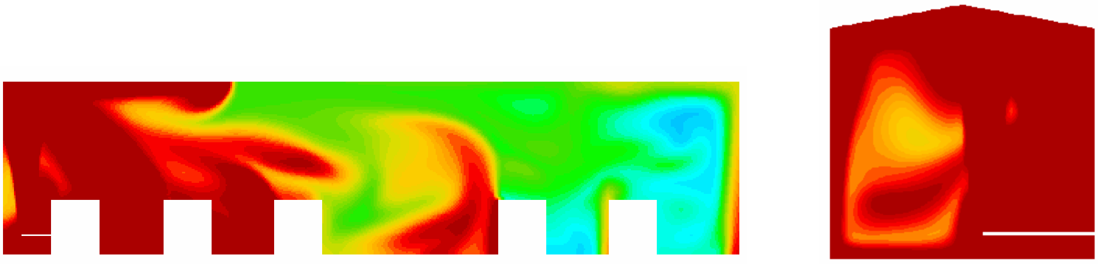


Figure 4 : Flammable cloud (dark red) after 5 minutes leak.

The results of explosion from different ignition points give approximatively the same results. For the purpose of simplification, the general trend is given here as a description of the combustion phenomena which occurs in the room. For simplicity and comprehension, the temperature and the methane fraction are plotted (Figure 5).

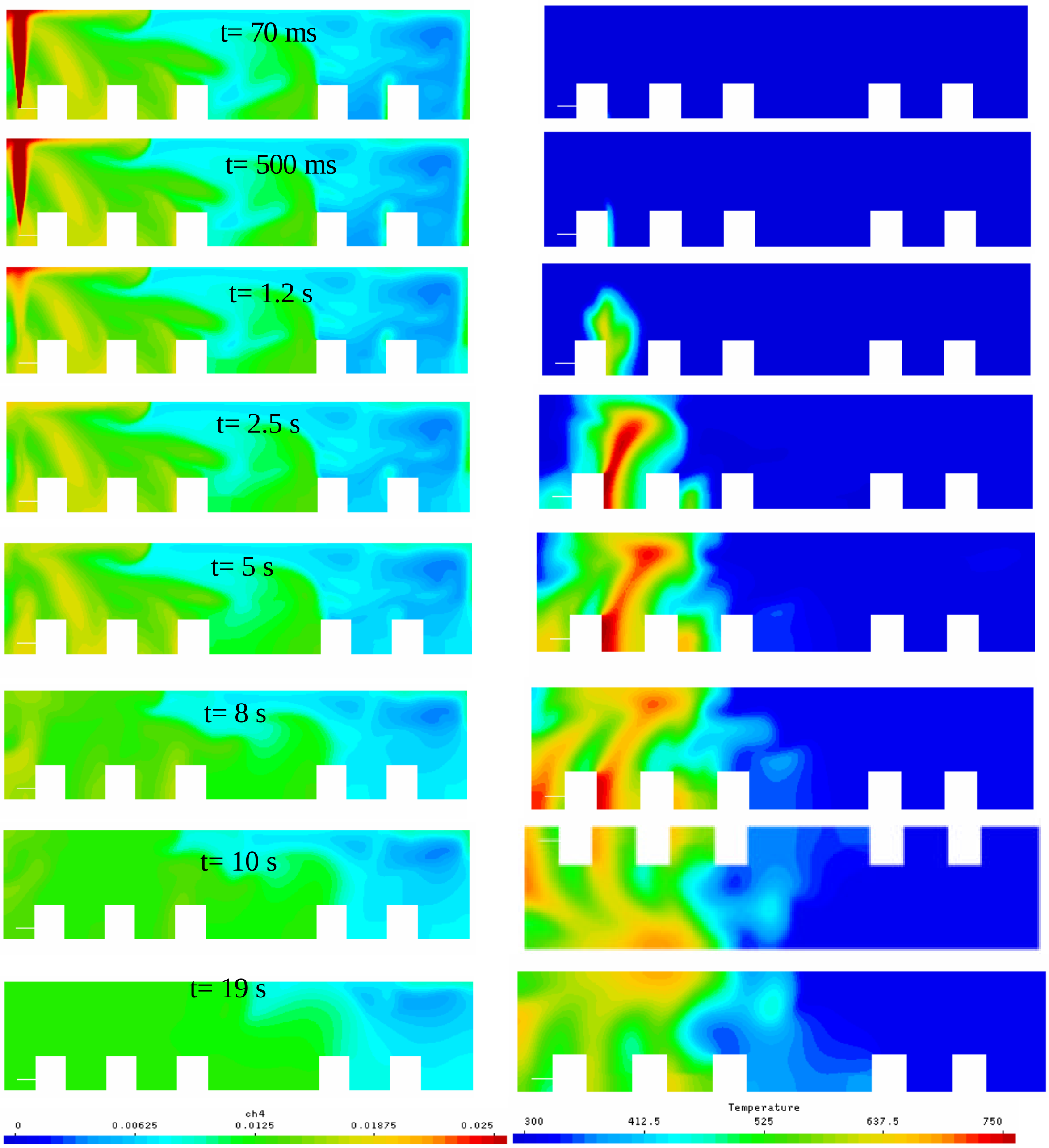


Figure 5 : Mass fraction of Methane and temperature in the longitudinal section during the combustion (case 5).

One of the interesting feature of the combustion which is occurring in this case is that the combustion characteristic time is very large. Combustion is slow because of the high rate of turbulence in the room and the local competition of combustion vs. dispersion. As a consequence of this phenomena, it is interesting to see that there is actually no pressure front in the room. The pressure is growing up regularly in the hole room up to the maximum value of approx. 0.5 bar overpressure (see fig. 6 and 7).

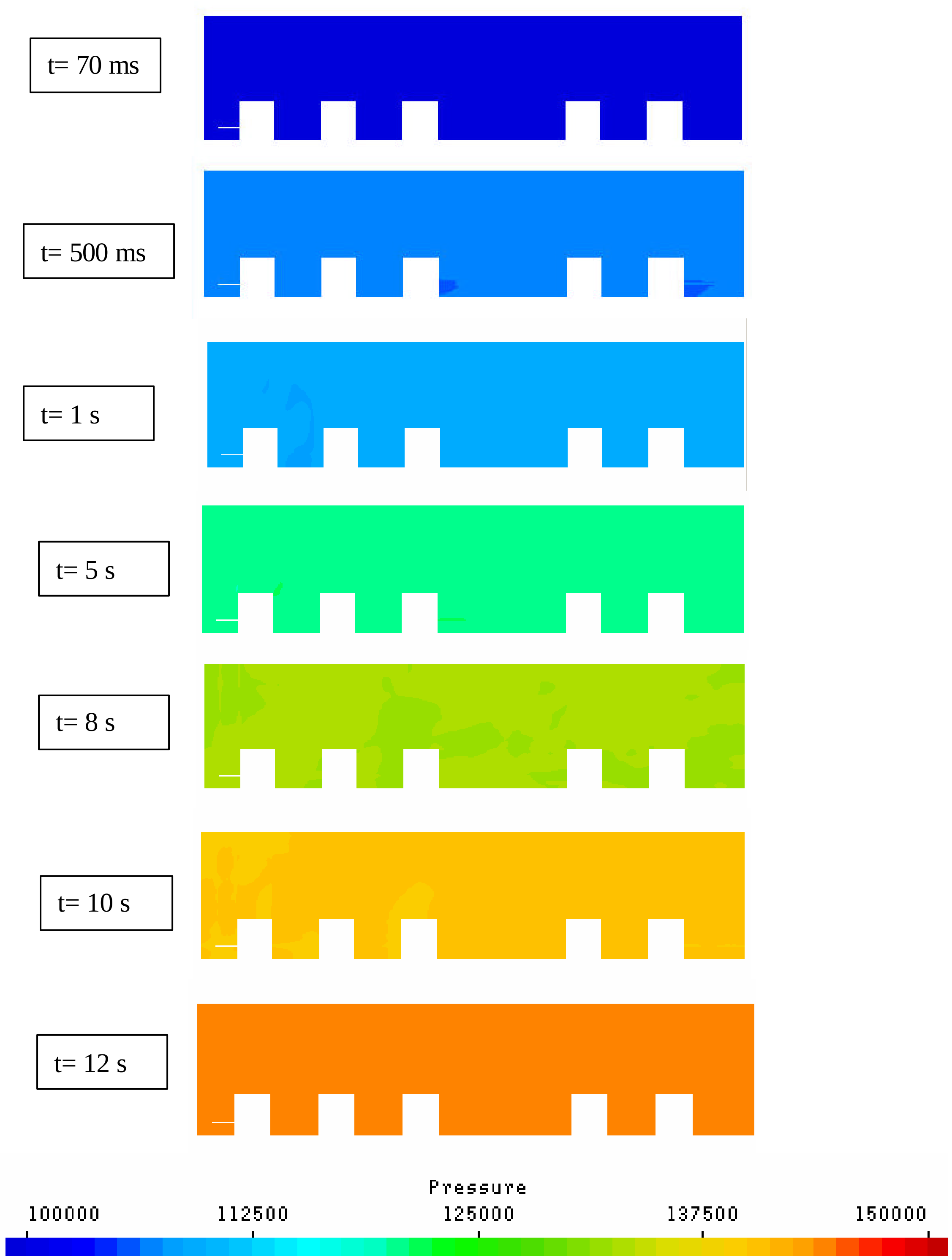


Figure 6 : Pressure evolution in the room (Pa)

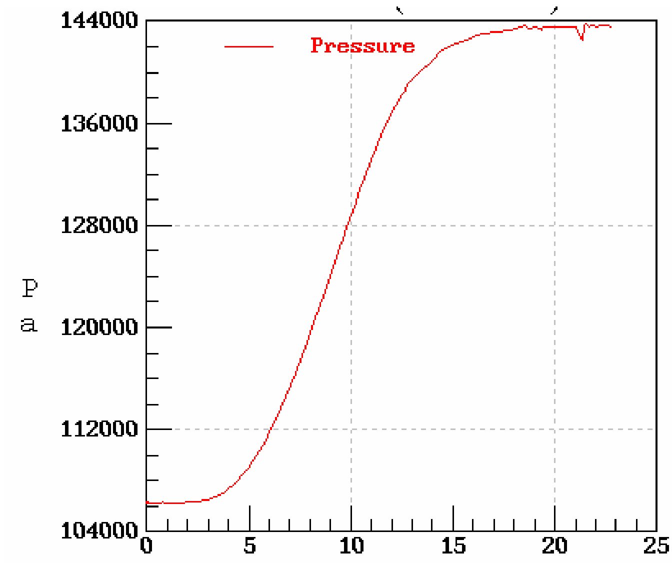


Figure 7 : Pressure profile in the room vs. time (s)

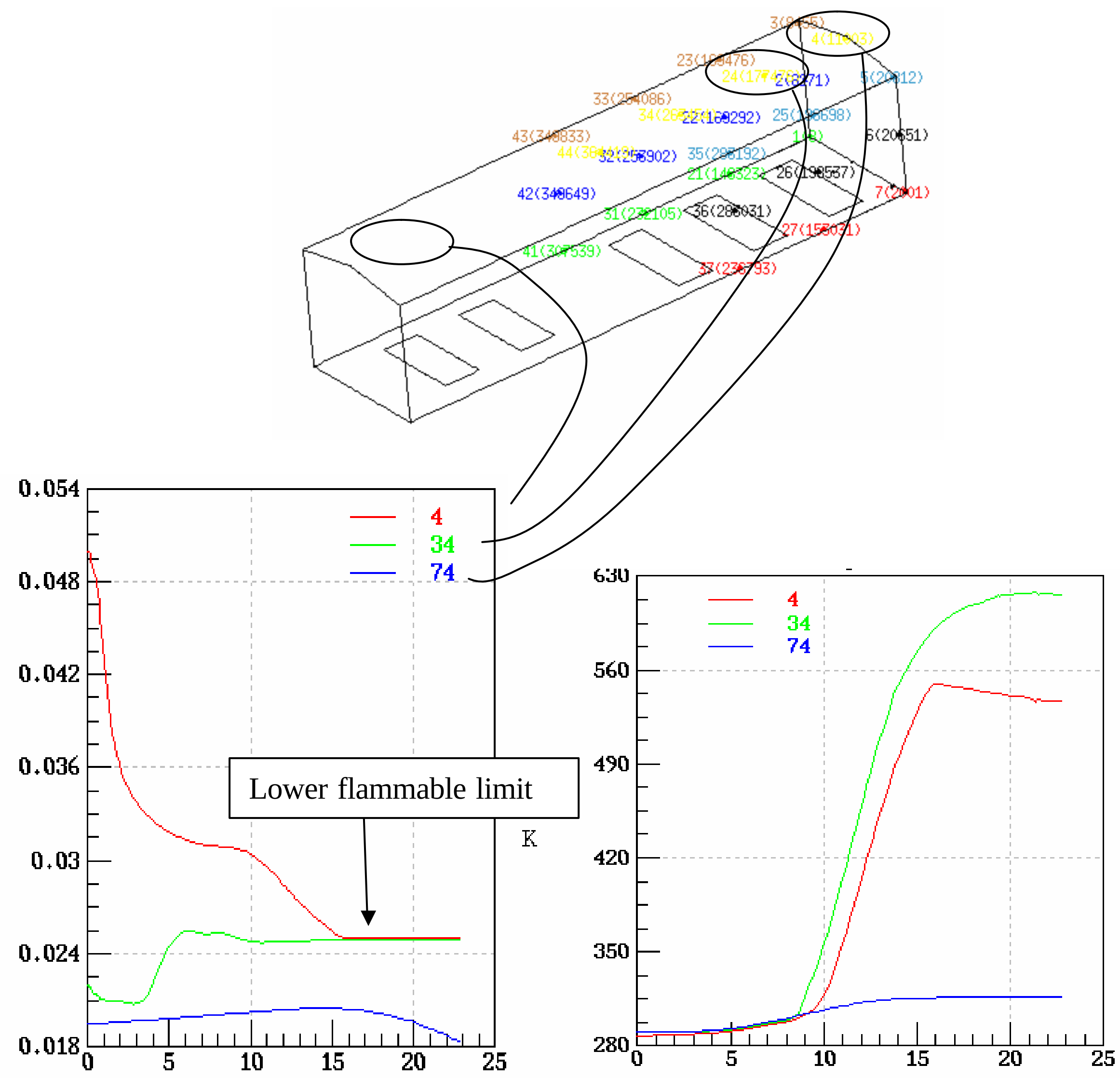


Figure 8 : Profile of methane and temperature at different roof captors (s)

IV. Optimisation of roof design

Hence, due to this low combustion velocity, the classical laws applied for openings in potential explosive rooms can not be applied here, and a small study on roof openings was done to design the room and avoid overpressure. The best way found to reduce overpressure was to reduce the flammable cloud by introducing some openings in the roof.
The three scenarios held for this design optimization are depicted on the following picture (picture 9).

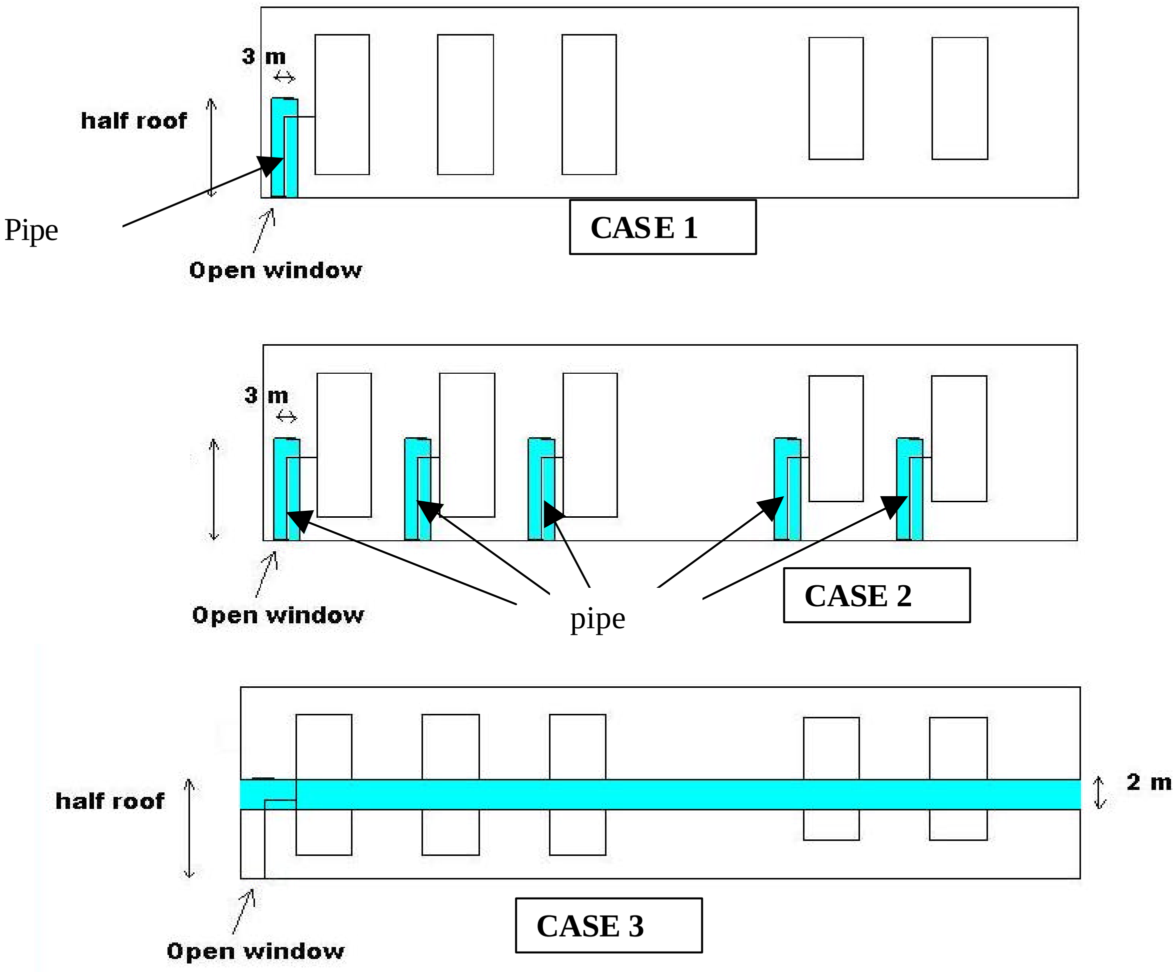
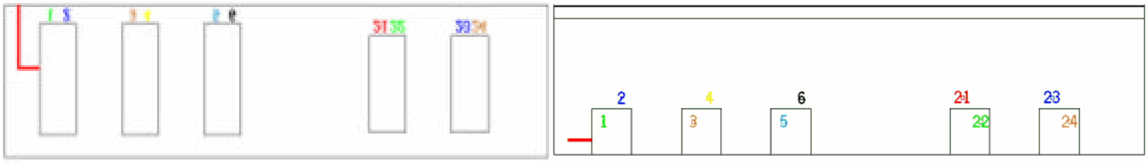


Figure 9 : Different openings in roof.

Again, as a result, the general trend found for different roof openings were similar from one to another, and only one case is described here : CASE 3.

IV. 1 Dispersion

In this case, an automatic opening system is built in, which allows a detection of methane fraction, and a progressive opening of the windows. The captors location is described on figure 10. Captors are supposed to react immediately and detect a percentage 20% of LFL of methane which is approximatively 1% volume of methane in air. After detecting, a delay of 10 seconds for opening is implemented in the run scenario synopsis, and then windows are considered to be completely open.



Top view *Side view*

Figure 10 : Methane detection captors (1% methane).

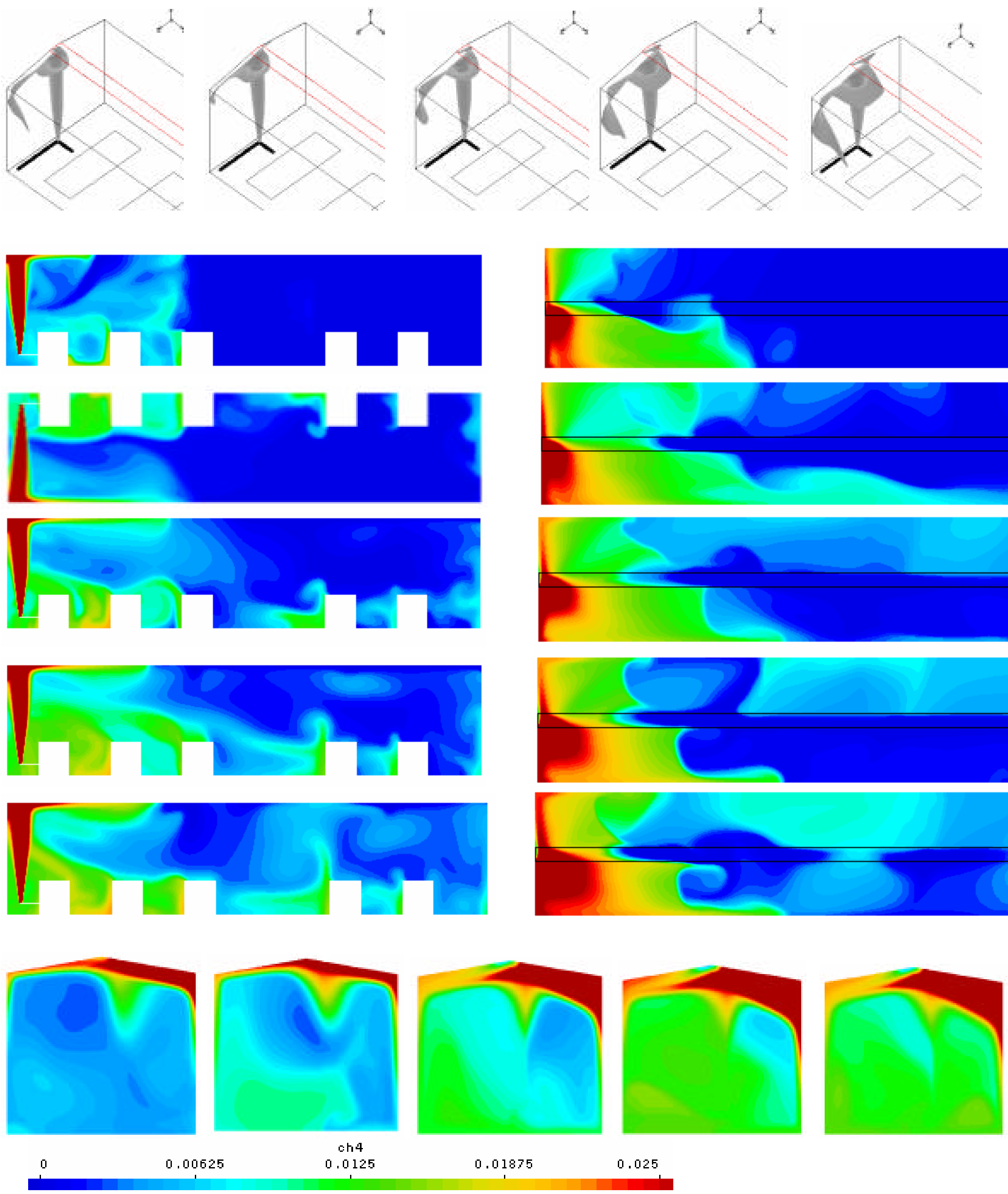


Figure 11 : Visualisation of the flammable cloud in case of an opening window. Dark red cloud = Flammable cloud.

It can be seen on the dispersion visualizations, that the flammable cloud in this case remains low, because of the efficiency of the evacuation. This evacuation is mainly due to the pressure difference between the inside room and the outside of the building. This can be seen on figure 12 on speed contours.

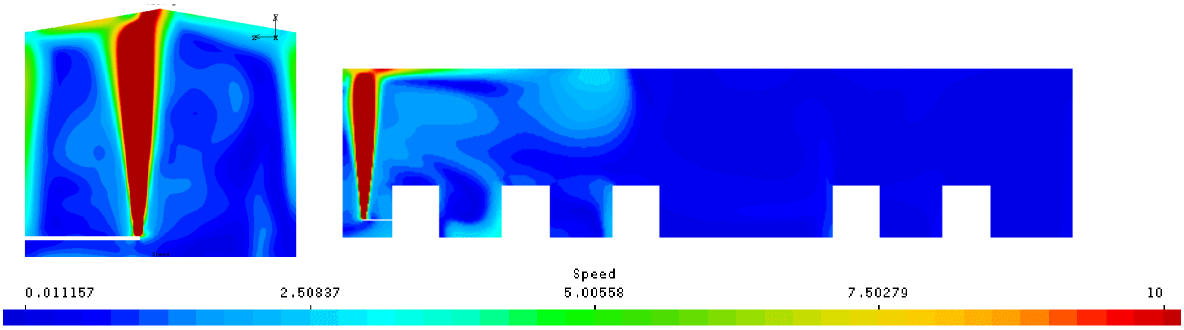


Figure 12 : Speed contours in longitudinal section for case 3.

After 5 minutes of leak, there is no real flammable cloud in the room except near the initial leak jet. Due to diffusion of this jet, a small cloud is formed as can be seen in different views of figure 11. Additionnaly, the concentration of methane is relatively poor in the cloud.

IV. 2 Explosion.

From this state of dispersion, an explosion scenario was considered, by igniting combustion in this small diffused formed cloud. The objective there is to find an order of magnitude of the explosion in these regions.
The cloud was ignited at two specific locations as shown in Figure 13.

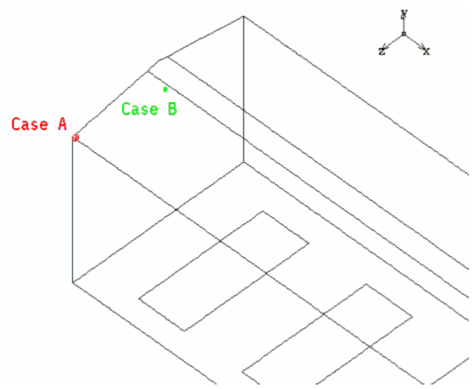


Figure 13 : Location of ignition points.

The result of deflagration run is given in figure 14, where it is seen that the presence of the open window lead to an oscillating pressure wave on the roof. The overall overpressure is then very small and kept within the structure damage limits. Typically, 3 millibars are found for maximum overpressure, together with a temperature of 420 °K maximum.

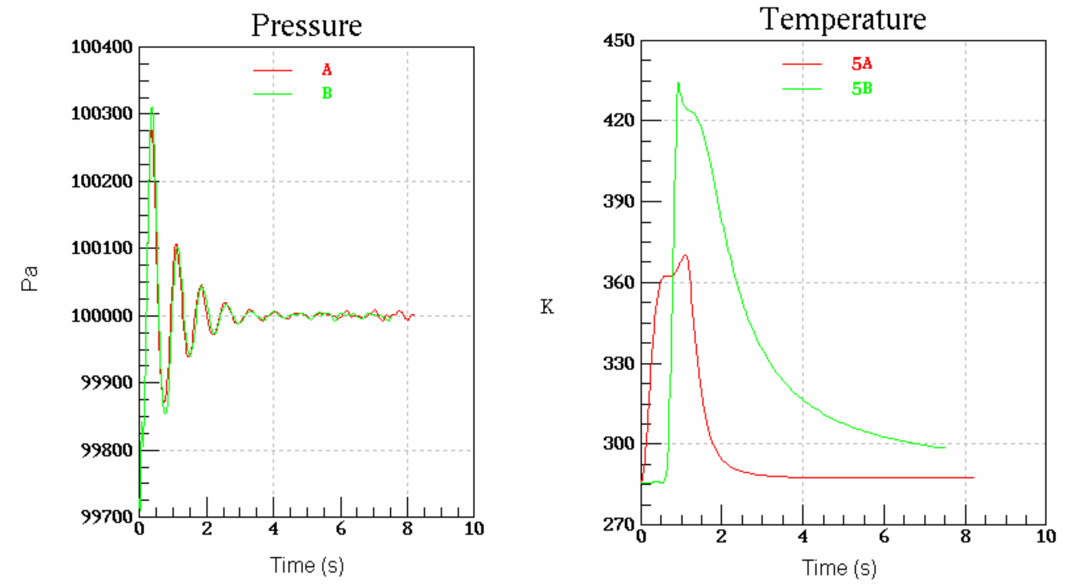


Figure 14: Pressure evolution and temperature vs time for explosion scenario of CASE 3.

V. Conclusion

A security study in a large compressor room was performed, considering a 5 minutes leakage of a small circle rupture of 50 mm diameter. The dispersion is done using 3D CFD code FLUIDYN-VENTEX, and led to a relatively large flammable cloud in the room. The combustion which was initiated at five ignition point locations, gives a specific general trend. Combustion is slow, and the pressure is growing quasi-homogenously in the room. The overpressures found were about 0.5 bars.
Considering the dispersion in the closed room, some openings in the roof were implemented, with a commanded opening. The windows open 10 seconds after detection of 1% methane at one of the methane detectors in the room. It is found that, probably because of the overpressure caused by the leakage in the closed room and also because of the locations of the windows, the jet is well evacuated through the windows. The flammable cloud, resulting of the diffusion effect of the main jet, is small and relatively poor in methane. The explosion simulation on that cloud leads to a oscillatory very small overpressure at the roof, which is compatible with the admissible structure constraints.