Lacome Jean-Marc, Proust Christophe. INERIS - Accident Risks Division, BP 2, F-60550 Verneuil en Halatte, France. Jean-Marc.Lacome@ineris.fr - Christophe.Proust@ineris.fr

Analysis of the dispersion of large unconfined clouds following a massive spillage of liquid helium on the ground

CONTEXT AND OBJECTIVES

One of the obstacles to the expected development of the use of liquid hydrogen is the poor state of knowledge on dispersion and explosion hazard in the event of extensive spillage. In order to better understand spillage scenarios, INERIS has set up a large-scale experiment to study the gas cloud formation and dispersion mechanisms resulting from such a spillage .

For safety reasons large scale dispersion tests have been performed with cryogenic helium presenting similar dispersion characteristics to liquid hydrogen (temperature, buoyancy). Flow rates up to 3 kg/s have been investigated with instrumentation to observe and measure buoyancy effects including internal turbulence. The results bring an original set of data of temperature and velocity fluctuations which can be used as a basis for the development of atmospheric model dispersion in the near field.

EQUIPMENT

The spillage system consisted of two Liquid helium trucks connected to vacuum thermally insulated lines.
The basic instrumentation consisted mainly of K thermocouples that allow fairly quick measurement (10 Hz). Bi-directional probes (Mc Caffrey et al., 1976) has been adapted to obtain some information onto the aerodynamics of the cloud.
The whole instrumentation has been installed on a net of steel ropes held vertical in the wind direction by two cranes. More than 100 sensors were installed on a vertical rectangular frame (60 m x 130 m).

View of a part of the experimental arrangement showing the spill point and vertical steel ropes

Example of a liquid helium cloud (test 7)

SHAPE AND STRUCTURE OF CLOUDS

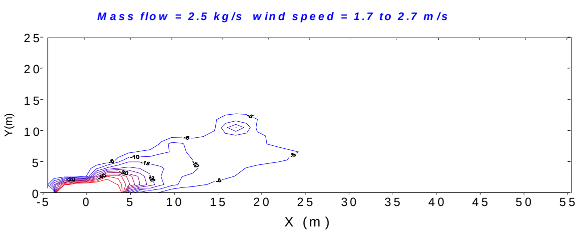
The shape of the cloud is characterized by three parameters :
- L being the length of the cloud on the ground,
- H1 being the height of the base of the cloud,
- H2 being the height at the top of the cloud.

The tests showed that the cloud shape depends essentially on the flow rate and little on the wind speed.

Test n°	Duration (s)	Mass flow rate (kg/s)	Wind speed (m/s) at 3 m height	Humidity (%)	Temp (°C)	H1 (m)	H2 (m)	L (m)
0	60	1,5	6	/	16	3	5	20
1	50	1,4	4,0±1,0	86	17	5	17	50
2	52	1,4	5,2±1,0	90	17	5	17	50
3	52	2,1	3,0±0,5	84	12	12	32	80
4	43	2,1	4,0±0,5	84	12	7	35	75
5	34	2,1	5,5±0,5	88	12	7	30	70
6	43	2,1	4,5±0,5	88	11	7	30	70
7	63	1,2	2,0±0,5	85	12	ND	ND	ND
8	65	1,2	2,0±0,5	85	12	ND	ND	ND
9	71	2,2	2,0±0,5	85	12	ND	ND	ND

(ND : non determined)

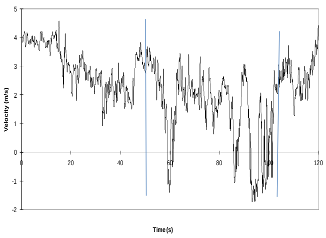
Main parameters concerning the dispersion of liquid helium and shape of the visible cloud



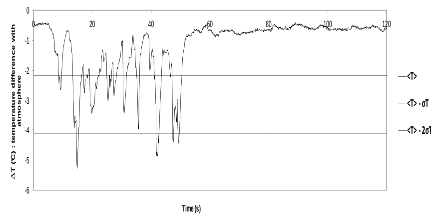
Isotherms far from the spillage point. The plume is driven by an upward motion which gives the cloud an angle of approximately 30° with respect to the horizontal

OBSERVED FLUCTUATIONS AND MIXING MECHANISMS

The internal turbulence of the cloud is responsible from the mixing of the gas with the surrounding atmosphere. A specific analysis of temperature and velocity fluctuations has been conducted to clarify the effect of atmospheric turbulence and buoyancy forces.
When a helium cloud is present, the intensity of velocity fluctuations is between 50% and 100%, i.e. five times greater than intensity of velocity fluctuations due to atmospheric turbulence alone. The same applies to temperature.

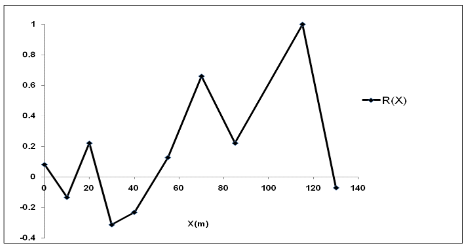


Velocity fluctuations in atmospheric turbulence (before point 40 and after 100) and with the passing of a helium cloud (range 40-100)(test 7; X=40 m, Z = 20 m)



Sample temperature series (test 3) from a temperature sensors located at (X= 2,5 m; Z = 0 m) from the spillage point

Median time duration of this temperature fluctuation is around 5 s. This result is of the same order than those mentioned by Witcofski and Chirivella (1984). The size of the large structures of turbulence at a height of 20 meters is approximately 2.5 m for a flow rate of 1.3 kg/s and 5 m for a flow rate of 2.5 kg/s, irrespective of the distance from the ground.
In order to investigate internal structure of turbulence, spatial correlation coefficient have been calculated.



Temperature spatial correlation along horizontal axe around a receptor located at 120 m from the spillage point and at 30 m from the ground (test 3)

We could observe a pseudo periodic variation of the spatial correlation along horizontal axis. This variation could be explained by the presence of coherent structure in the field of turbulence as an eddy that appears close to the ground and is growing during his advection. Meanwhile such structures don't exist for spatial correlation along vertical axis. The value of the periodicity is around 20 m and independent of the altitude. A periodic variation is also observed in the evolution of the gas curl formed from contact of liquid helium with the plate. The presence of curl is similar to smoke dispersion during a fire where buoyancy forces are crucial parameter.

DISCUSSION AND PERSPECTIVES

Results seem to indicate that buoyancy forces can play a very significant part in the process of cloud formation and not a marginal part as is often considered (mainly as a vertical advection effect). It is therefore estimated, on the basis of current data, that the intensity of turbulent transport (coefficient of turbulent diffusion) in the clouds studied is at least twice as great as that for atmospheric turbulence alone and that this effect increases with the quantity of liquid discharged.

Efforts are currently underway to carry out a complete spectral analysis of sample series in order to reproduce numerically with an appropriate model the physics of the dispersion in the near field of a light cryogenic gas.

Main trends may be already extracted from the present data, in view for instance to highlight in which spillage conditions severe explosions or toxic effects may occur. The starting point is to realize that buoyancy governs the formation of the cloud and its aerodynamics, including turbulence. The larger the flow rate, the larger the size of the cloud, the larger the turbulence intensity.

REFERENCES

Mc CAFFREY et al., 1976. A robust bi-directional low-velocity probe for flame and fire application, Comb. and Flame, vol. 26.

Witcofski, R.D., Chirivella, J.E., 1984. Experimental and analytical analyses of the mechanisms governing the dispersion of flammable clouds formed by liquid hydrogen spills, Int. J. Hydrogen Energy, vol.9, pp.425-435.

These experimental program and analysis have been undertaken with the financial support of the French Ministry of environment

INERIS
maîtriser le risque pour un développement durable