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Project Report

# Research on continuous and instantaneous gas clouds. Part 2

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**Abstract**

Interim results are presented on the dense gas field experiment supported under the Major Technological Hazards Programme of the Commission of the European Communities and the Bundesministerium für Forschung und Technologie (BMFT) and the Danish Environmental Protection Agency. The following conclusions are arrived at: (1) The dilution effect of the solid wall was around 50% with the plume and obstacle height of the same order of magnitude and the ground level plume concentration about 1 vol.%, while the porous fence had little effect; (2) the behaviour of the jet seems to be very different from that of the cyclone, producing a lot of turbulent kinetic energy, entraining more ambient air on its way; and (3) with a wind direction approximately parallel to the street canyon, small changes of the wind direction affected the dispersion strongly. Deviation from the direction straight downwind introduced a vortex in the space between the two walls, causing an asymmetrical gas distribution with the highest concentrations under the lee of the upwind wall.

## 1. Introduction

In a previous article in this journal [1], we presented a project report on a dense gas field experiment supported under the Major Technological Hazards Programme of the Commission of the European Communities and the Bundesministerium für Forschung und Technologie (BMFT) and the Danish Environmental Protection Agency. All field experiments have now been concluded and we would like to report on the final layout, the experiments actually carried out and our experience in general. The analyses of the field trials are not yet completed, of course, but they are well underway and will be reported subsequently, as will the concurrent wind tunnel and theoretical studies.

The test facility is situated in a flat terrain near Lathen in Northwest Germany and constructed for continuous releases of liquefied propane, see Heinrich et al. [2] and Heinrich [3] for further details. The purpose of the exper-

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iments was to study the effect of obstacle geometry on continuous dense gas releases. The obstacles consisted of 2 m high poles carrying curtains which could be removed by a release mechanism during the experiment. In this way we were able to measure dispersion of the dense gas plume or jet with and without obstacles under the same wind conditions. In some cases the obstacles formed solid fences, in other cases we left open each second gap between the poles, giving an overall porosity of 50%. The gas source was either a horizontal jet of flashing liquid propane or a cyclone giving a plume without momentum, and normally we used rates around 3 kg/s. We performed three experimental campaigns, each with a duration of about one month. The first one in October 1988 was a little shorter and was used mainly to test instruments exposed to gas under field conditions.

## 2. The experiments

In this kind of experiments, depending on the wind direction, a strategic problem is how to arrange the setup. To be on the safe side as to favourable wind conditions we used two alternative obstacle arrays with the curtains removed on the side not used. In the May 1989 campaign the configurations were two 60° arches at a distance of 48 m from the source, see Fig. 1. The vertical profiles were measured at a distance of 10 m in front and 15 m behind each arch, using 6 m masts. Each mast was equipped with 5–8 thermocouples, 3 catalytic gas sensors, 3 cup anemometers, a wind vane and up to 3 sonic anemometers, see Fig. 2. We developed a method to estimate fast concentration fluctuations, using the sonic anemometer and thermocouple temperature signals, which were capable of reproducing the mean concentration levels in the somewhat slower catalytic sensors. The principle of these concentration esti-

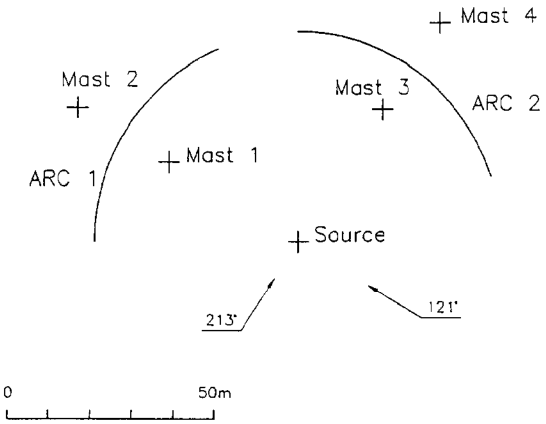


Fig. 1. The obstacle configuration of the May 1989 campaign, consisting of two alternative obstacle arrays, the one not used was removed during the experiment.

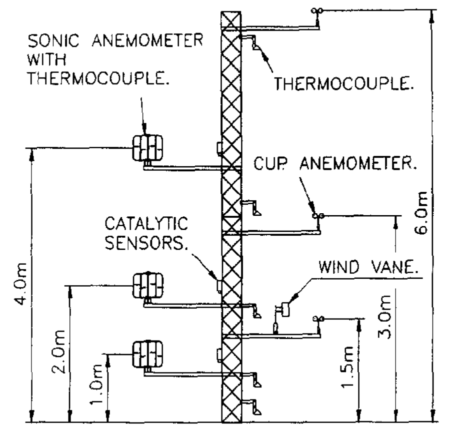


Fig. 2. Instrumentation of the meteorological masts.

mates is that the sonic anemometer temperature reflects the speed of sound which is dependent on the gas concentration.

The method was presented at the Euromech 253 colloquium on concentration fluctuations in turbulent diffusion (Ott et al. [4]). Furthermore, the horizontal mean gas concentration distribution was measured with an array of up to 36 catalytic gas sensors with a response time in the order of 10 s, and 8 additional sensors based on a principle of infrared light absorption. The sonic anemometers and the array of ground-based concentration sensors were moved between the two obstacle configurations according to the weather forecast.

In spite of the successful October 1988 campaign we discovered several new technical problems on our return in May. The thermocouples amplifiers now had a periodical stability problem and the battery power for cup anemometers and wind vane ran low on far too many occasions — a solution neccesitated by the danger of explosion. The time required to move sonic anemometers was also a problem and we never succeeded in having all the instruments on the ideal site during a gas release.

In wind directions unfavourable to the planned experiments, the spare time was used for additional tests. On one occasion the jet was used to shoot against the wind. It was interesting to see how the jet was stopped by the obstacle, directed upwards by the stagnation pressure, and bent backwards by the ambient wind. The concentrations in the built-up gas mountain were relatively high and the dimensions were 10 m in height and 50 m in diameter. This scenario may be a serious hazard with a flammable gas, even though an often used risk parameter such as the lower flammability distance is short! Vertical jet releases were also conducted under low wind conditions with concentration measurements at the point of ground contact.

The best experiments were made during the final Augustus–September 1989

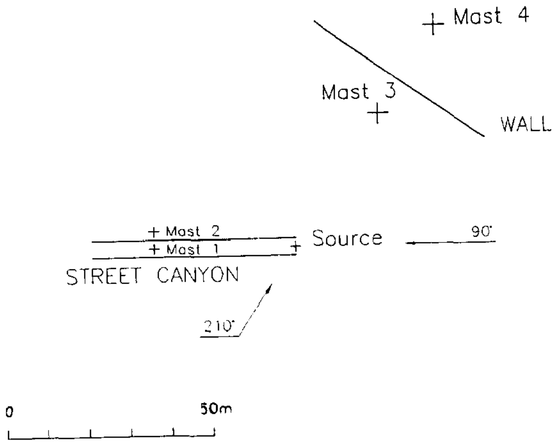


Fig. 3. The obstacle configuration of the August–September 1989 campaign. In this campaign a small mobile source was used for releases across the street canyon which served as a double wall.

campaign with the two arrays of obstacles now arranged as a straight wall perpendicular to the gas flow and as a street canyon with the source in one end, see Fig. 3. The wall setup and adjacent masts were arranged with distances similar to the arc 2 in the May campaign. The street canyon consisted of two 2 m high and 50 m long fences 4 m apart and parallel to the wind with the release source at the center line at the end. The masts were placed 35 m downwind at the center line and 2 m outside the canyon. In this last campaign most of the technical problems were overcome; the thermocouple amplifiers were now stable, battery power was routinely checked, and one of the infrared concentration sensors was rebuilt to a new light absorption wavelength, avoiding disturbances from ice crystals. The wind direction remained a problem but we developed a mobile source which was able to release 0.1 kg/s for about 3 minutes. With this improvised source releases were made from the rear end of the street canyon, and even a third type of releases was performed from the north across the two parallel walls. In this situation the masts were closer to the fence than in the perpendicular wall experiments originally planned, and we therefore measured near-obstacle fluctuations. With the small release rate the fence is high compared to the plume, and the density near the fence is presumably lower.

## 3. Conclusions

The data are being processed currently for distribution among the other BA-project partners. We have not yet examined the bulk of the data but the following preliminary observations may be stated:

(1) The dilution effect of the solid wall was around 50% with the plume and

obstacle height of the same order of magnitude and the ground level plume concentration about 1 vol.%, while the porous fence had little effect.

(2) The behaviour of the jet seems to be very different from that of the cyclone, producing a lot of turbulent kinetic energy, entraining more ambient air on its way. With release rate and flow forces of 3 kg/s and 208 $N$, estimated by Nyrén and Winter of the Swedish Defence Research Establishment, FOA [5], the jet effect was still present 50 m downwind. Both source types are relevant to accidental dense gas releases.

(3) With a wind direction approximately parallel to the street canyon, small changes of the wind direction affected dispersion strongly. Deviation from the direction straight downwind introduced a vortex in the space between the two walls, causing an asymmetrical gas distribution with the highest concentrations under the lee of the upwind wall.

In addition to the qualitative measurements, a video film has been prepared, covering a number of the interesting cases described above. A study of a subset of the data dealing only with profiles in absence of obstacles is presented in Ott et al. [6]. With the momentum-free source, turbulence and stress were found to be damped inside the gas cloud, while the flashing jet had a large production of turbulence and upward flux of momentum even 50 m from the source. The peak frequency in the power spectra was around 1 Hz with the jet source and a little lower for the momentum-free release. In both power and concentration spectra we observed inertial subranges for frequencies higher than that of the peak. Co-spectra of concentration and vertical velocity showed that the turbulent work against gravity is related mainly to low frequencies, and this is consistent with the highest frequencies or small eddies forming an equillibrium range.

## Acknowledgement

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