

ME-474 Numerical Flow Simulation

Exercise: Safety analysis of N₂ transport in a laboratory test room

Fall 2021

1. Overview

Many research laboratories use gases or cryogenic liquids daily. These are generally stored in pressure cylinders or in cryogenic tanks, but accidental leaks or spills cannot be excluded during handling or storage. A risk of asphyxiation or poisoning is therefore present.

This exercise considers a specific accident situation involving the spill of a large quantity of liquid nitrogen (N₂) on the floor of the BCH 1438 laboratory (Annex A). The exercise is part of a larger study, whose final goal is to determine, with numerical flow simulation using the actual room geometry and ventilation, the optimal position of the gas detectors. It is also intended to validate the simulations using experimental data recorded at a several locations in the room.

2. Technical description

2.A. Test laboratory

The main geometric features of the BCH 1438 laboratory have been retained in a simplified 3D model (figure 1). A CAD file describing this geometry can be downloaded from Moodle. The laboratory is instrumented with several sensors (temperature, oxygen etc.) that will be used for validation purposes (Annex B).

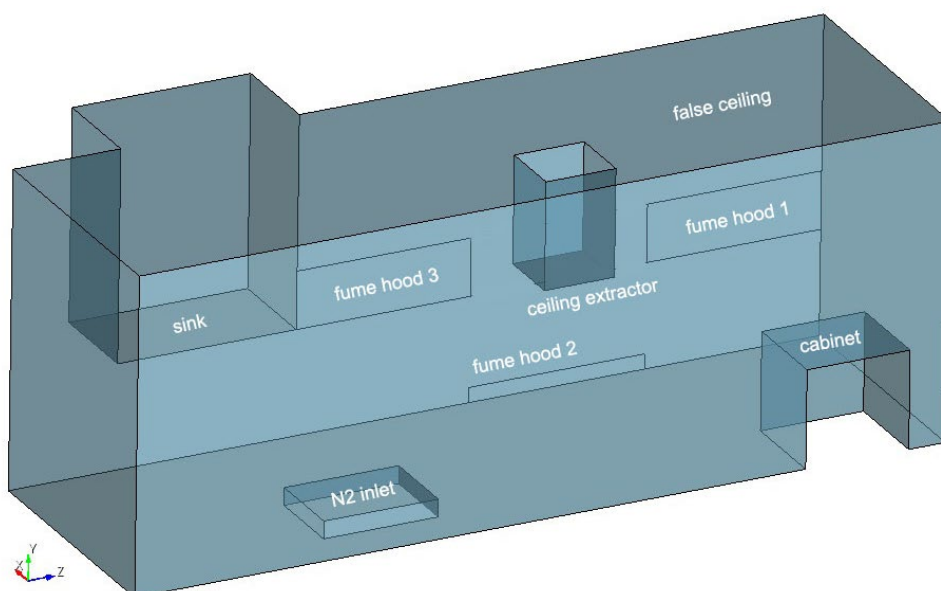


Figure 1: Simplified geometry of the BCH 1438 laboratory used for this exercise

2.B. Operation and boundary conditions

The false ceiling provides an inflow of air (and possibly areas of backflow), while the three fume hoods and the ceiling extractor assure the continuous exit of gas. The cabinet and sink are passive items, to be considered as solid walls. The combination of all these items creates a rather complex steady-state flow at standard room conditions.

At time $t = t_0$, an accident is simulated by pouring liquid N_2 into a low rectangular container located on the floor. Evaporation results in an inflow of cold gaseous N_2 at the upper surface. For this study, the mass flux of N_2 at the container's upper surface is assumed to be constant in space and time.

For the present study, the following values are provided:

- *Standard room conditions:*
 - walls and floor
 - no-slip conditions, $V_w = 0$
 - fixed wall temperature, $T_w = 292$ K
 - inflow through false ceiling
 - ventilation system
 - ceiling extractor: mass flow rate = 0.0276 kg/s
 - fume hoods 1, 2, 3 : mass flow rates = 0.0968, 0.0086, 0.1700 kg/s
 - air pressure, $p_\infty = 96830$ Pa
 - air density, $\rho = 1.225$ kg/m³
 - air temperature, $T = 292$ K
 - gravity, $g = 9.81$ m/s² in -y direction
- *Accident conditions:*
 - N_2 inlet: mass flow rate = 0.00924 kg/s, temperature $T = 202$ K
 - start / stop time: $t_0 = 14.0 / 51.5$ min (for comparison with experimental data)

Since the evaporated liquid N_2 is at a temperature lower than the ambient room temperature, thermal and buoyancy effects play a central role in the transport of the gas in the room. An appropriate choice of the equation of state relating the local values of fluid density and temperature should be considered.

All other physical quantities required to perform the numerical simulations should be determined using reasonable estimations.

2.C. Computational mesh

For this exercise, a basic and rather coarse (approx. 86,500 elements) 3D computational mesh can be downloaded from Moodle.

3. Procedure and questions

Numerical simulations are to be performed by a RANS approach using Fluent. Simulations of suitable accuracy are required to extract qualitative and quantitative physical insight.

A. Determine suitable physical modelling: it is important to include in your simulation set-up all the essential physical phenomena involved in the flow.

B. Determine appropriate numerical method: to obtain a sufficiently accurate numerical solution, an appropriate numerical method should be employed.

C. Compute steady flow for standard conditions: initially, the steady-state flow in the laboratory under standard conditions is to be examined using a single-species model (i.e. air only). The computed flow fields should be analysed in detail by using the available visualization techniques (e.g. contour plots, velocity vectors, streamlines).

D. Compute unsteady flow for accident conditions: the standard steady-state solution can be used as an initial condition (at $t = t_0$) for the unsteady simulation. An appropriate multi-species model for the two miscible, non-reacting gas phases (i.e. air and N_2) is to be employed. At $t = t_1$, the N_2 source is depleted and, although there is no longer any inflow of N_2 , convection and diffusion continue to occur.

To enable comparison with experimental measurements, the time evolution of the mixture temperature T and of the oxygen mass fraction $Y(O_2) = 0.21 * Y(\text{air}) = 0.21 * [1 - Y(N_2)]$ should be monitored for (at least) detectors 7 and 10.

- Analyse in detail the flow field should at selected times during the simulation, from a physical point of view.
- Compare the computed and measured values of available quantities (at least T and $Y(O_2)$ at detectors 7 and 10).
- Comment on the effectiveness of the gas extraction systems. Suggest how they could be improved.
- Suggest appropriate locations of the gas detectors.

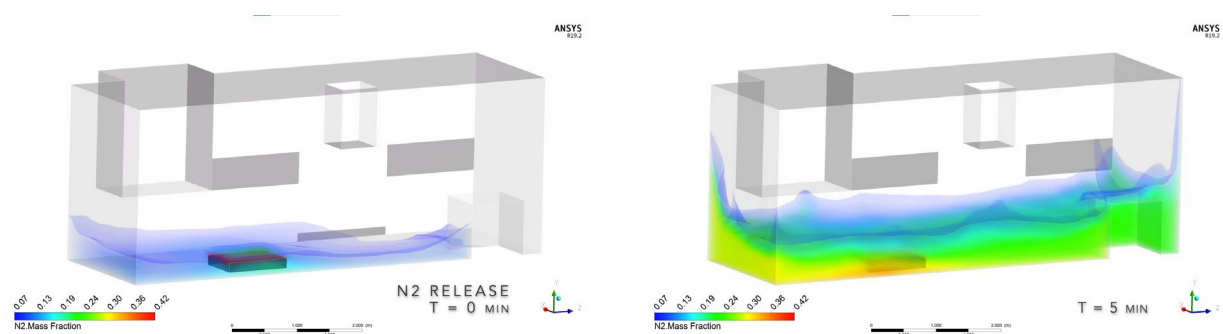


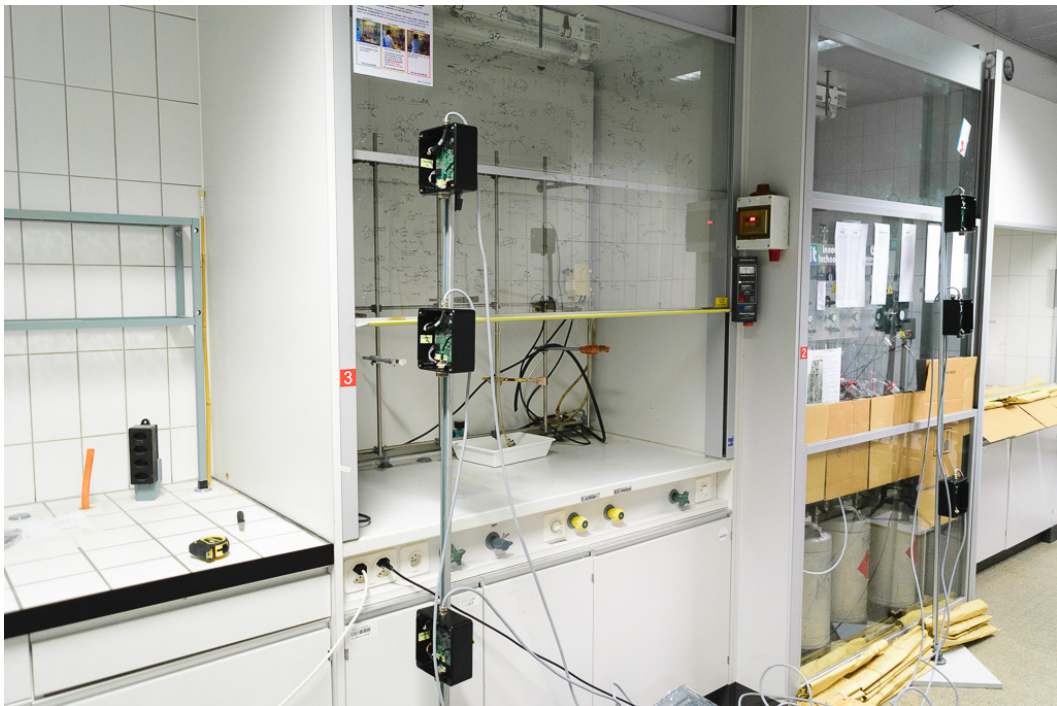
Figure 2: Example of simulation results: nitrogen mass fraction at different times.

Acknowledgement

The present exercise is based on the experimental studies of Damien Stricker, Riccardo Iannarelli & Anna Maria Novello of the EPFL Safety Competence Center (SCC) and relies on their expertise in this field, as well as their experimental data for the validation studies.

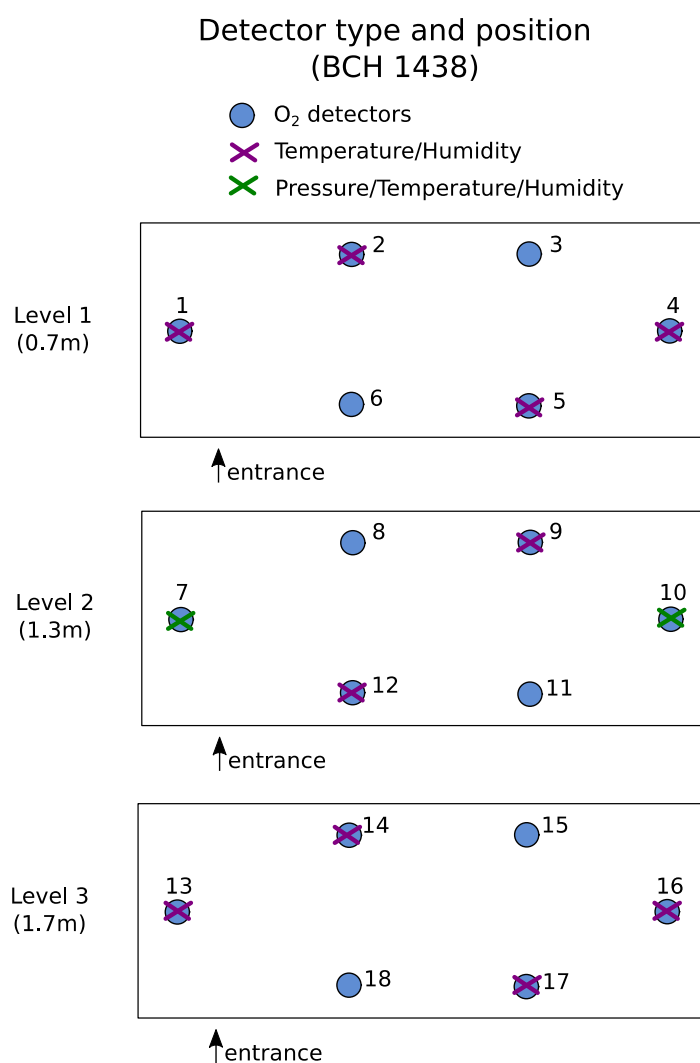
ANNEX A

Details of the BCH 1438 instrumented laboratory



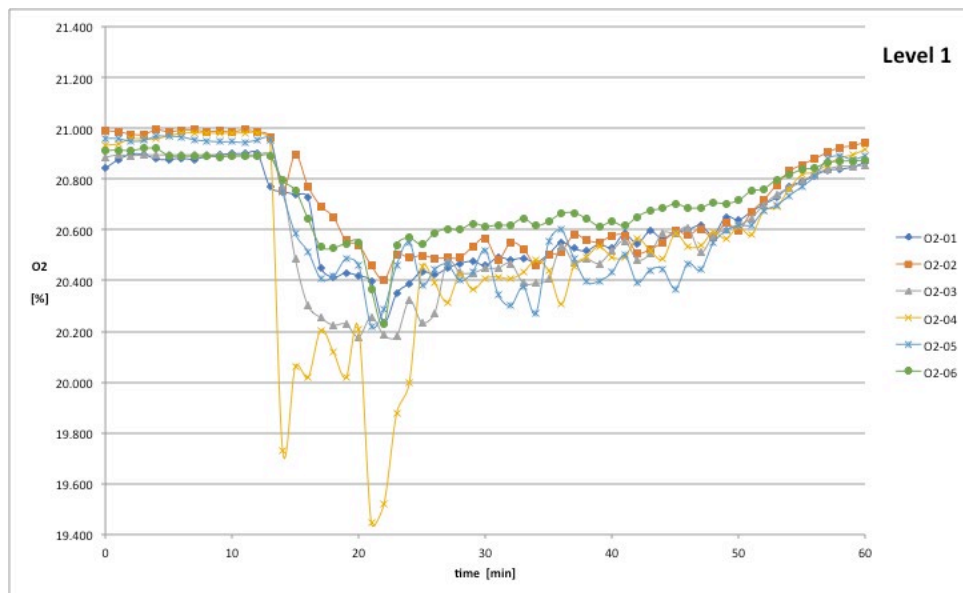
ANNEX B

Experimental measurements in the BCH 1438 laboratory

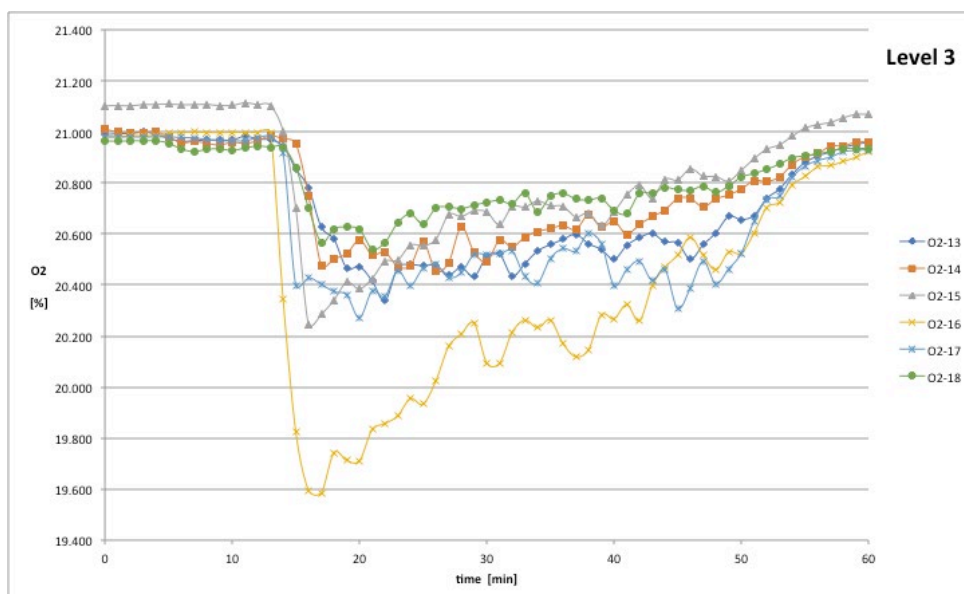
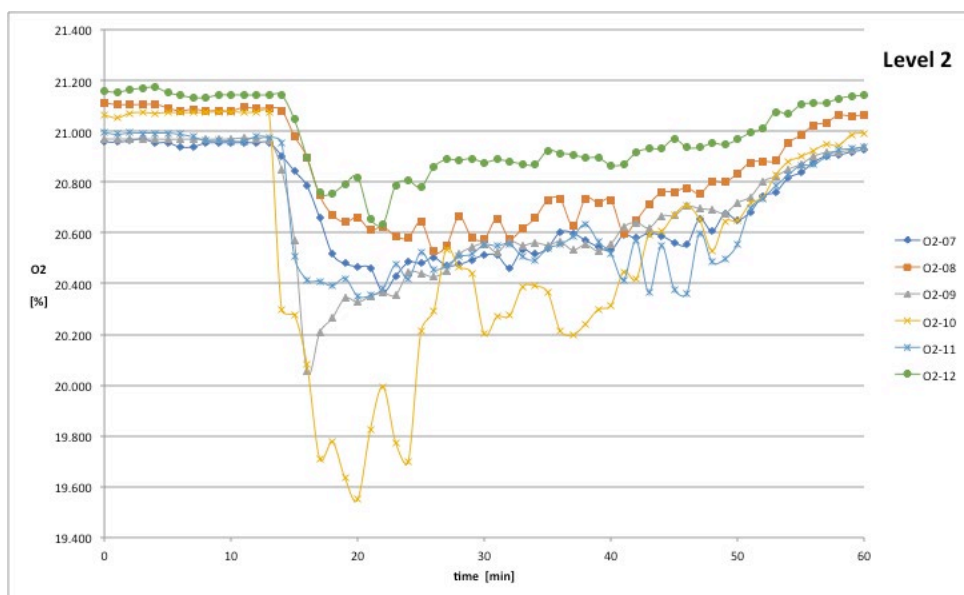


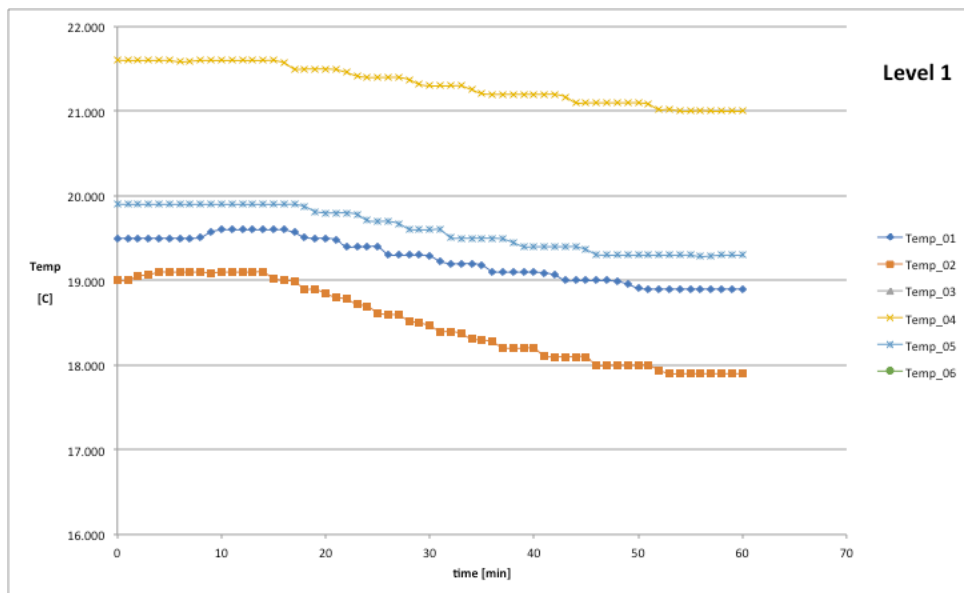
Spatial location of the detectors

Detector Triplet	Position (z, x) [cm]
1 - 7 - 13	(45, 118)
2 - 8 - 14	(264, 209)
3 - 9 - 15	(485, 193)
4 - 10 - 16	(655, 115)
5 - 11 - 17	(477, 26)
6 - 12 - 18	(304, 25)

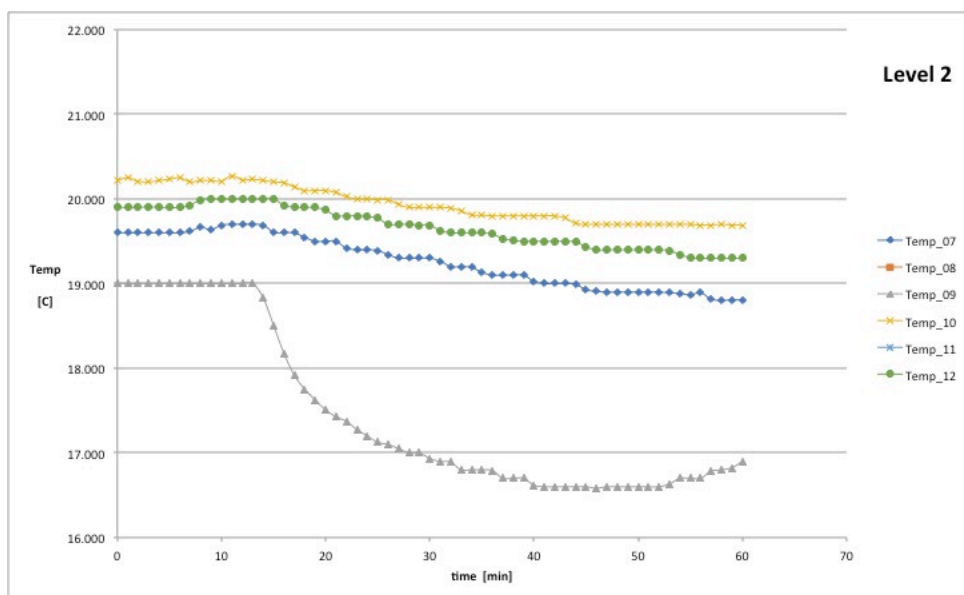


Mass fraction
of O₂
measured at the
3 detector levels





Temperature
measured at the
3 detector levels



*Note: detector 9 is
suspected to be
malfunctioning*

