Wrocław University of Technology

Cryogenic Safety – HSE Seminar

Numerical study of emergency cryogenics gas relief into confined spaces

Ziemowit M Malecha, Artur Jędrusyna, Maciej Grabowski, Maciej Chorowski and Jaroslaw Polinski

Department of Cryogenic, Aeronautic and Process Engineering
Wroclaw University of Science and Technology, Poland

Motivation

- Unexpected ejection of a cryogen into large confined spaces can result in hazardous consequences (Oxygen Deficiency Hazard, cold injury of living tissue).

- Need for monitoring the development of the event in real time and with minimal time delay.

- Need for determination of a minimal range of physics, which should be represented by a sufficient and trustworthy model (very rapid expansion of the cryogenic gas, non-trivial mixing, importance of condensation ?).

- Verified model can be exploited with confidence to evaluate the consequences of an incident in arbitrary geometry, amount of the released cryogen, location, size, etc...

- Knowledge about propagation velocity and the composition of the gas mixture cloud is crucial for a proper evaluation of a risk

Aim and Scope

- Conduction of the real scale experiment: controlled release of liquid helium into the LHC tunnel at CERN.
- Usage of novel, in-house manufactured (WUST), ultrasonic helium detectors.
- Presentation of a minimal mathematical model and its numerical implementation. Validation with the experimental results.
- Numerical investigation of consequences of the helium spill with different mass flows.
- Usage of an open source CFD toolbox – OpenFOAM.

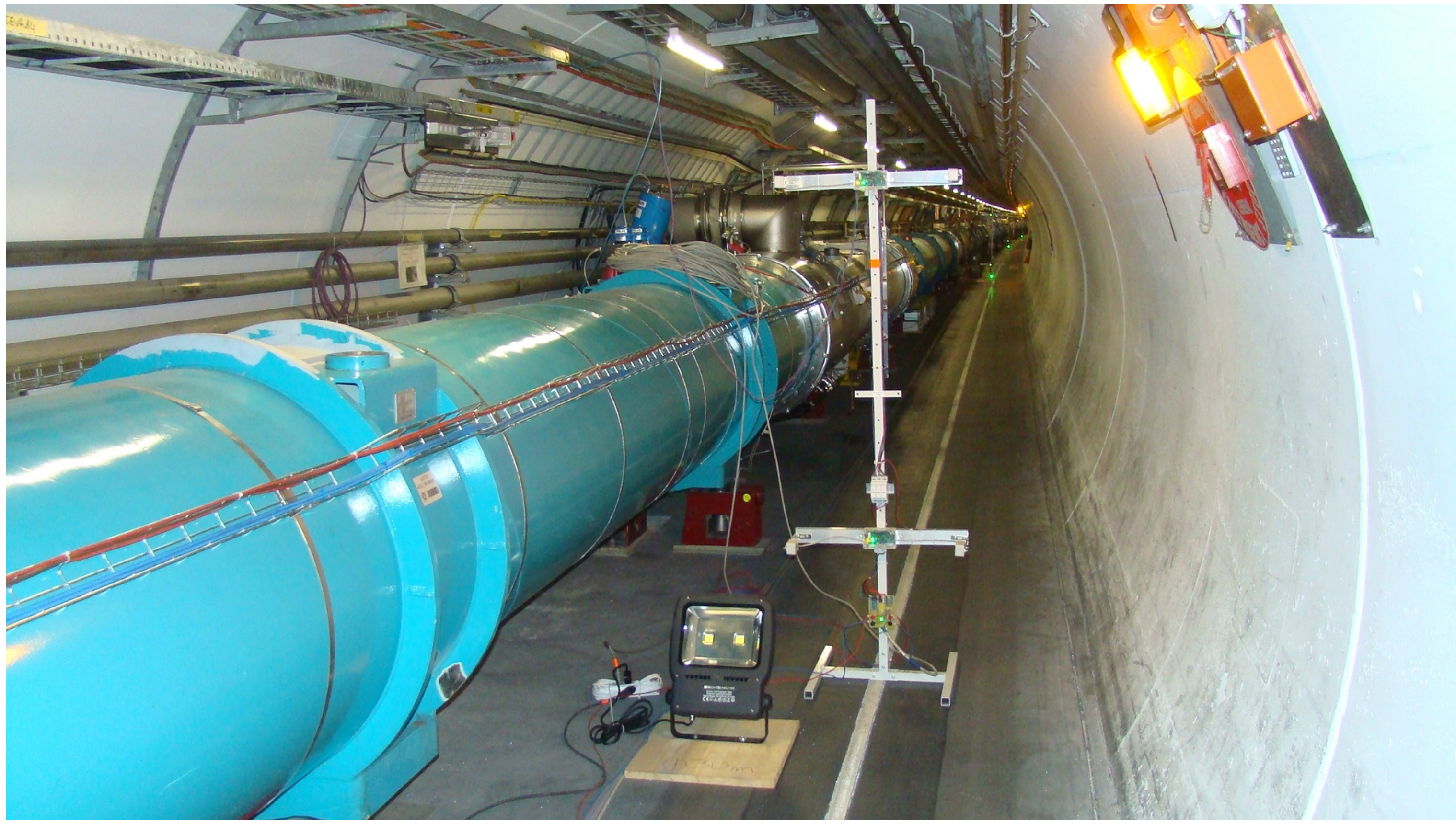
Experiment: CERN & PWr

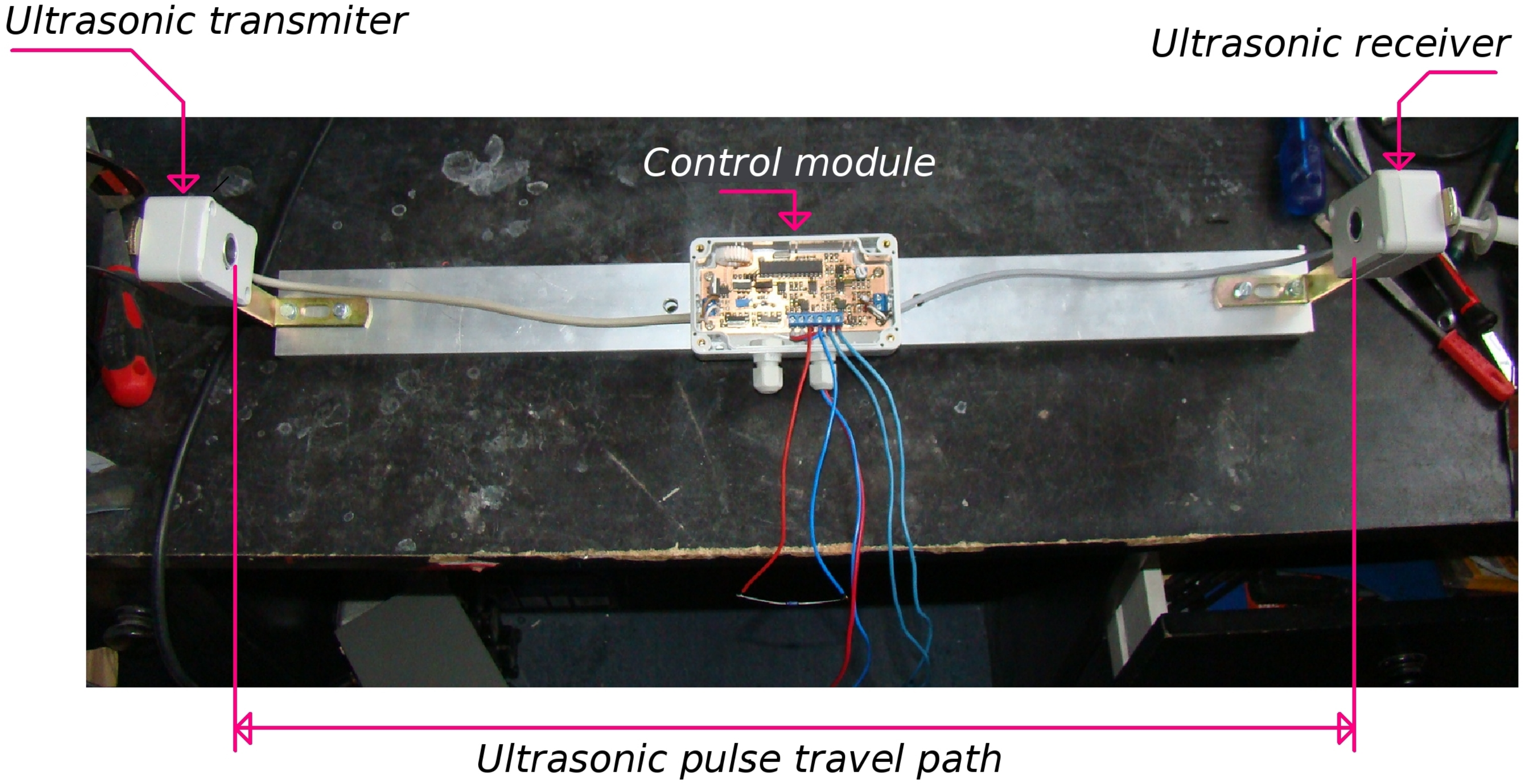
T. Koettig, J. Casas-Cubillos, M. Chorowski, L. Dufay-Chanat, M. Grabowski, A. Jedrusyna, G. Lindell, M. Nonis, N. Vauthier, R. van Weelderen, T. Winkler, J. Bremer, *Controlled Cold Helium Spill Test in the LHC Tunnel at CERN*, **Physics Procedia**, Volume 67, 2015, Pages 1074-1082, ISSN 1875-3892, http://dx.doi.org/10.1016/j.phpro.2015.06.203.

Numerics: PWr

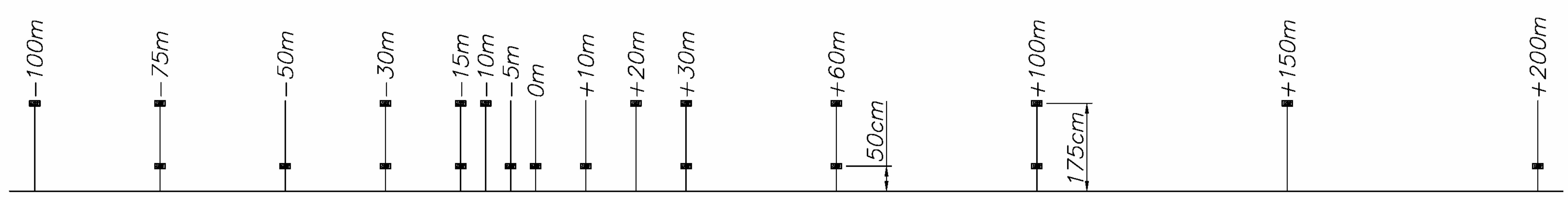
Z. M. Malecha, A. Jedrusyna, M. Grabowski, M. Chorowski, R. van Weelderen, *Experimental and numerical investigation of the emergency helium release into the LHC tunnel*, **Cryogenics**, Volume 80, Part 1, December 2016, Pages 17-32, ISSN 0011-2275, http://dx.doi.org/10.1016/j.cryogenics.2016.09.005.

Experimental setup

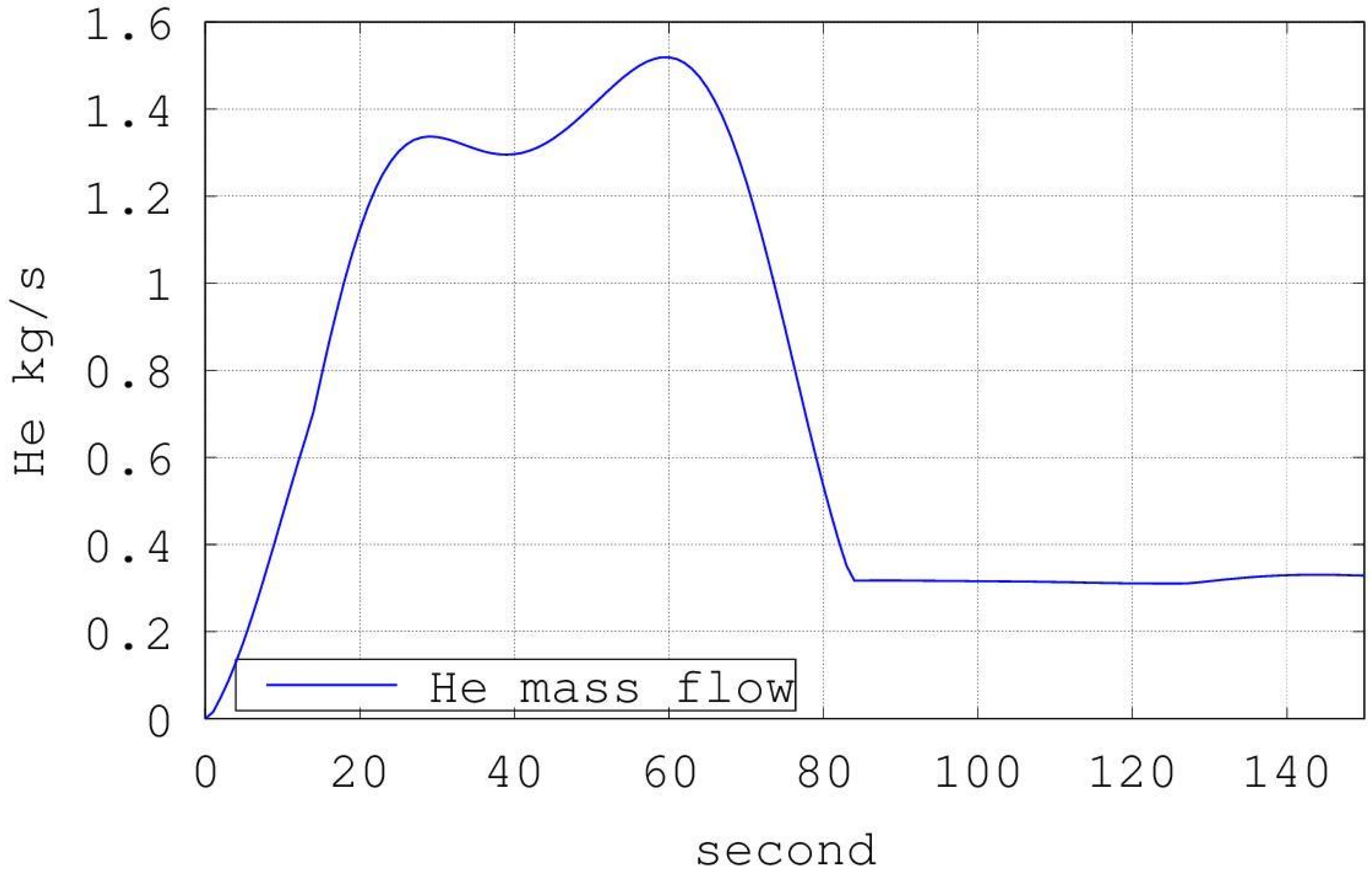




c)

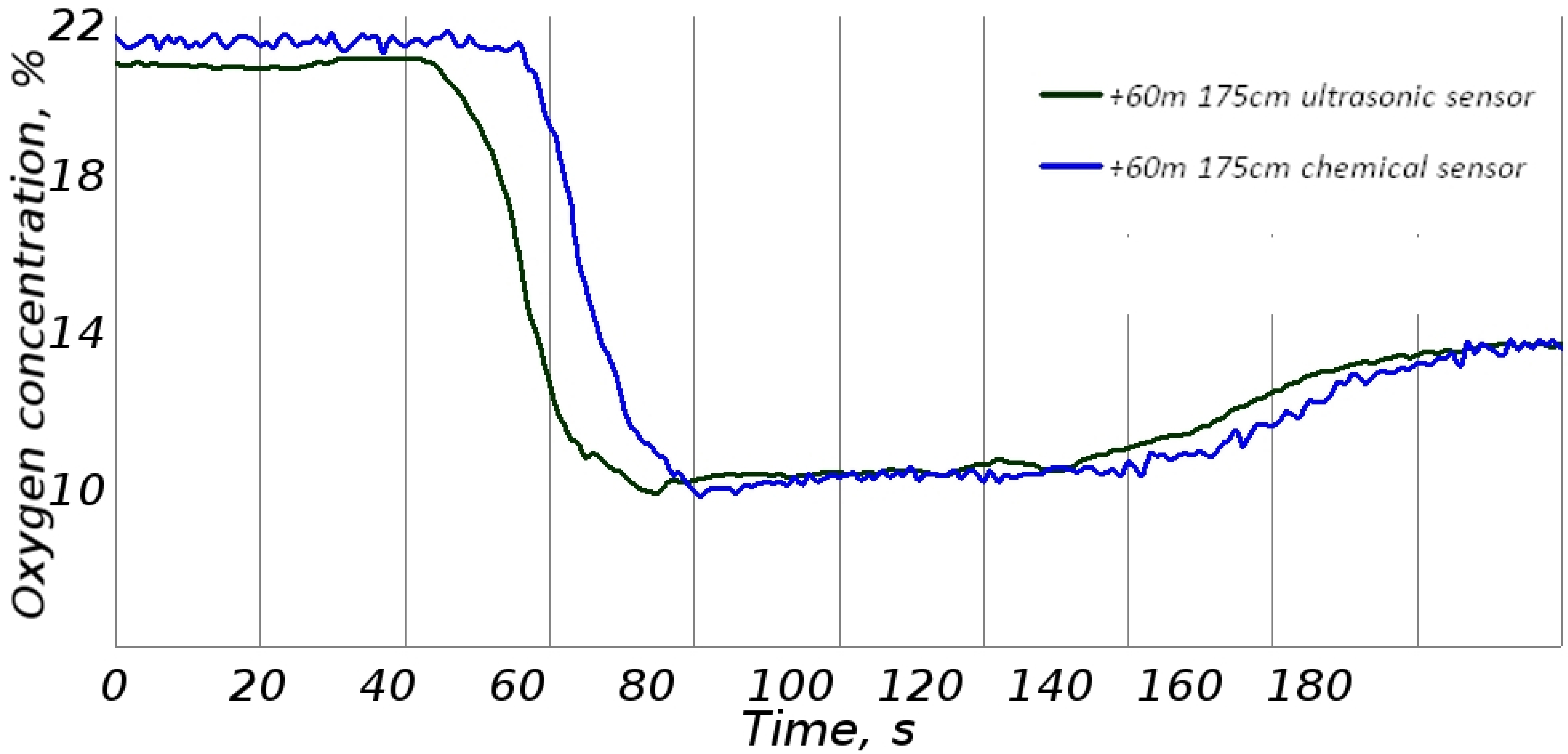


Experimental measurements of the helium release into the LHC tunnel



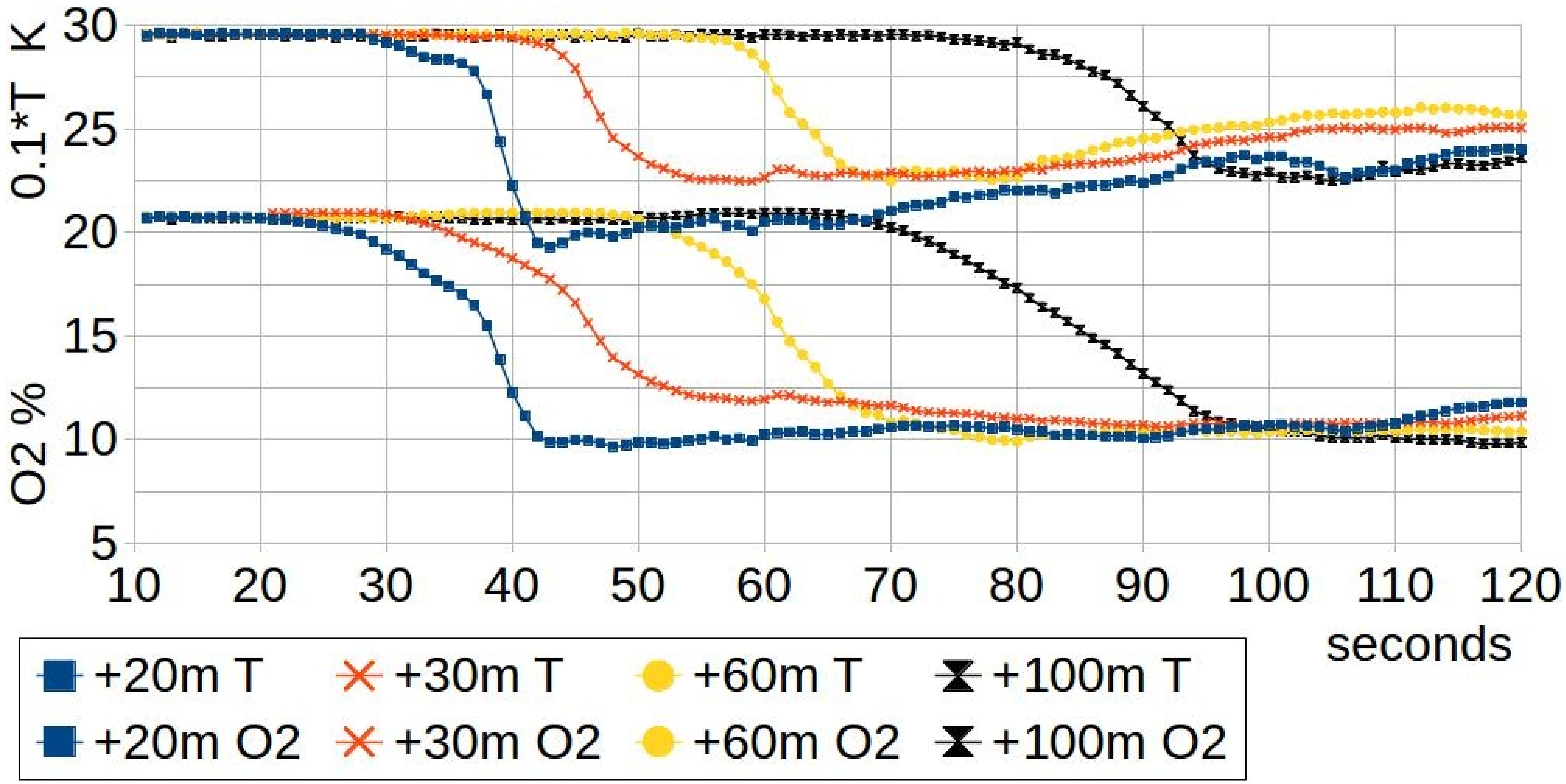
Helium mass flow in time, ejected into the LHC tunnel during the large leak experiment.

m_1.5 ~ 1.5 kg/s – helium mass flow
M = 100 kg – total mass ejected to the tunnel



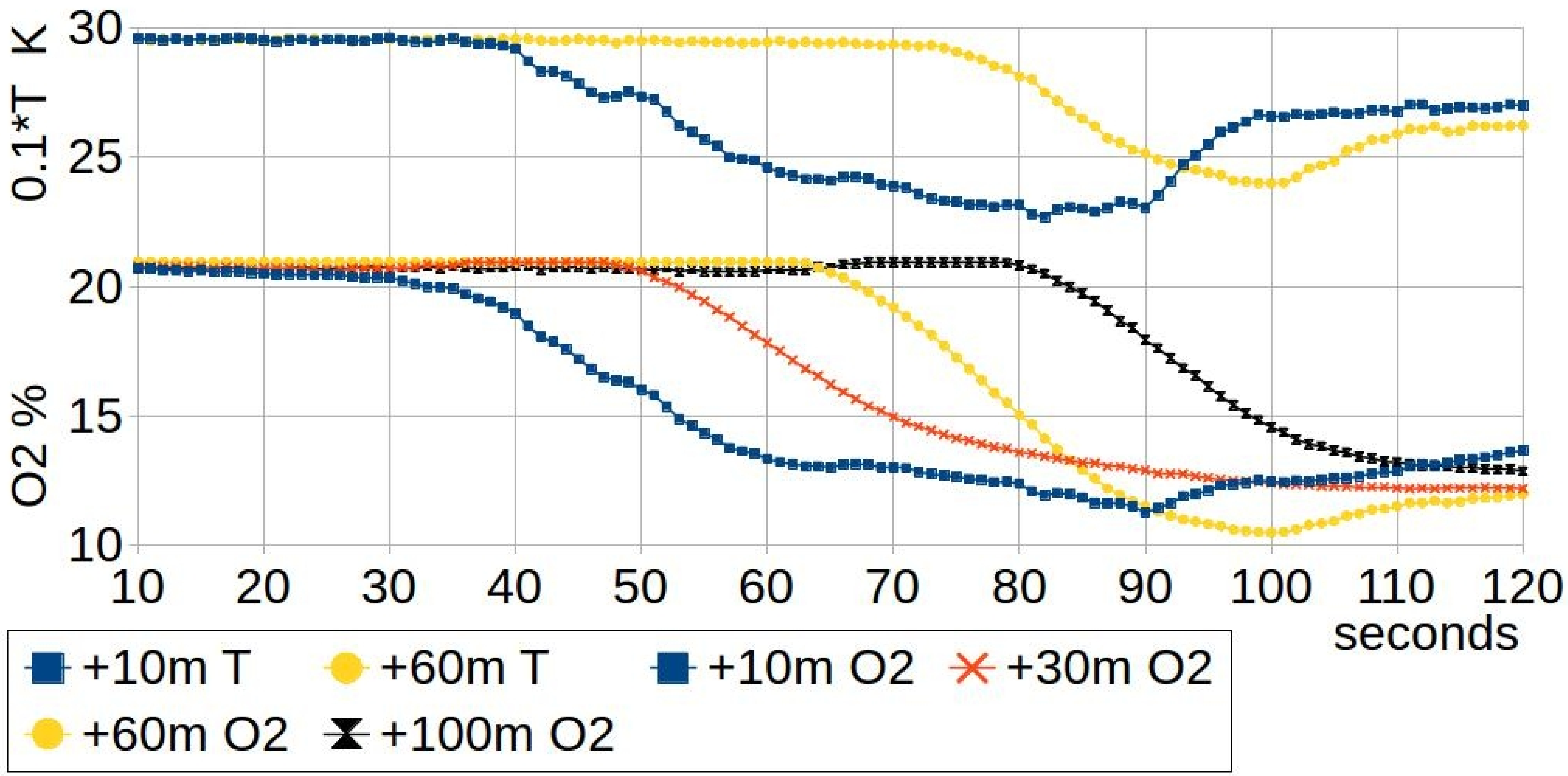
A comparison of dynamic oxygen content measurements produced by ultrasonic detector (black line) and electrochemical detector (blue line).

Experimental measurements of the helium release into the LHC tunnel



1.75 m above the ground

The distance in-between the individual curves define the speed of helium-air cloud propagation



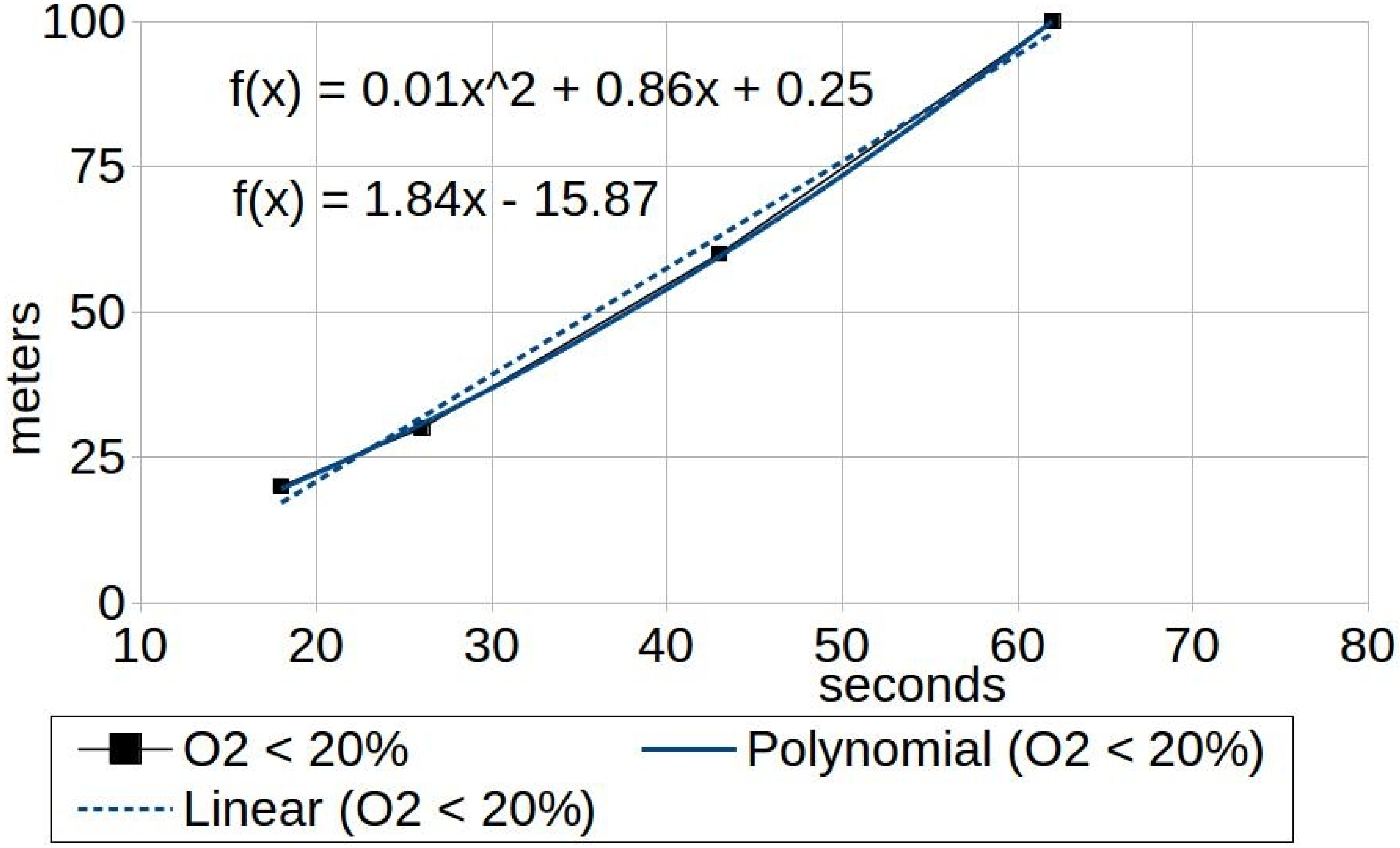
0.5 m above the ground

temperature sensors delayed ~ 10 s comparing to ultrasonic helium sensors

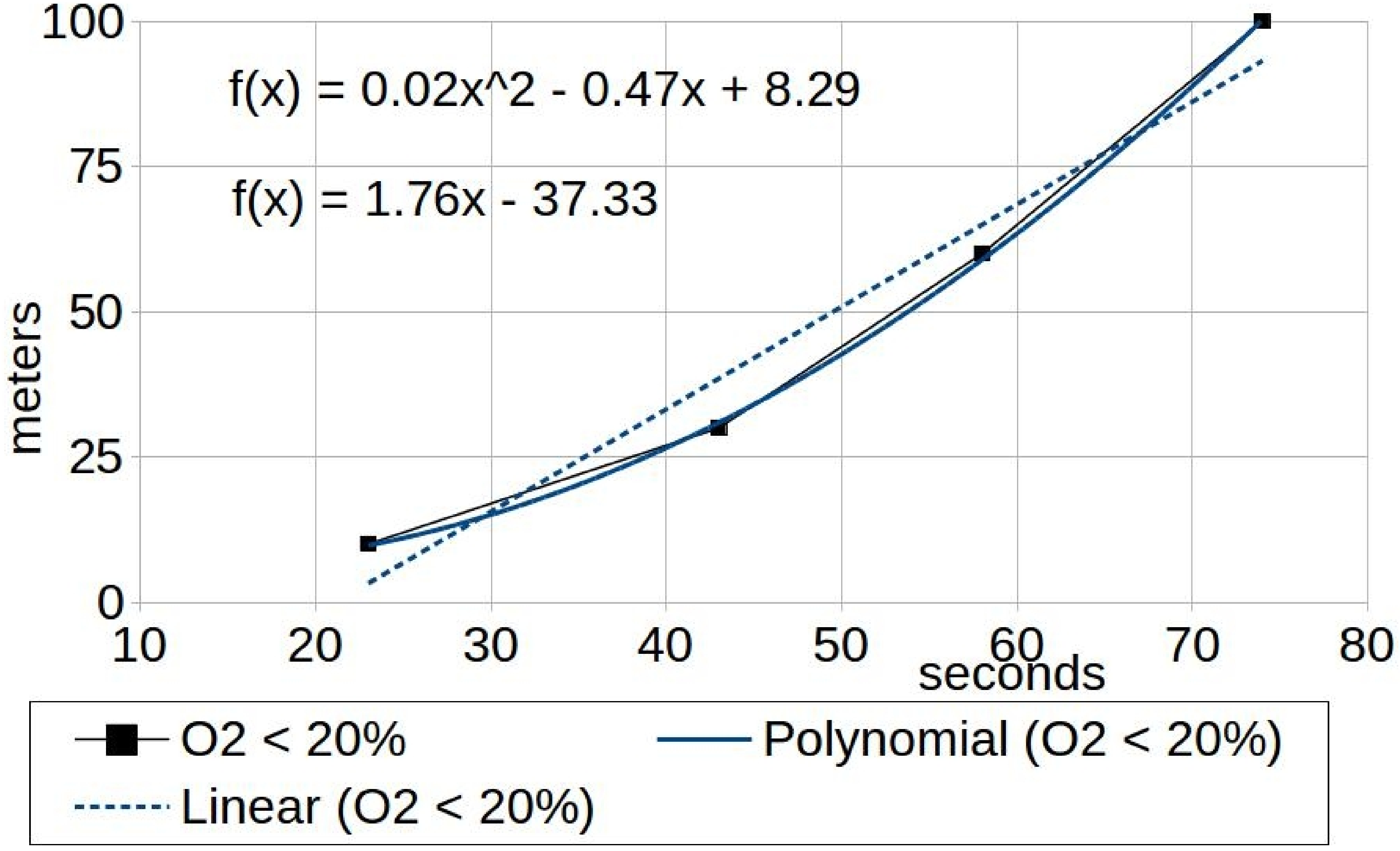
Experimental measurements cloud propagation

1.75 m above the ground

Cloud moves faster



0.5 m above the ground



Mathematical model and numerical implementation

OpenFOAM (Open Source Field Operation and Manipulation) CFD toolbox

- **E**ffectively used in diverse and challenging applications
- Compared with analytical solutions and experimental data
- ***ReactingFOAM*** solves for heat transfer and mixing of compressible gases

Finite volume discretization and the PISO (Pressure Implicit with Splitting of Operators)

$$\frac{\partial \rho Y_i}{\partial t} + \nabla \cdot (\rho \boldsymbol{u} Y_i) = \nabla \cdot (\mu \nabla Y_i) \qquad \sum Y_i = 1$$

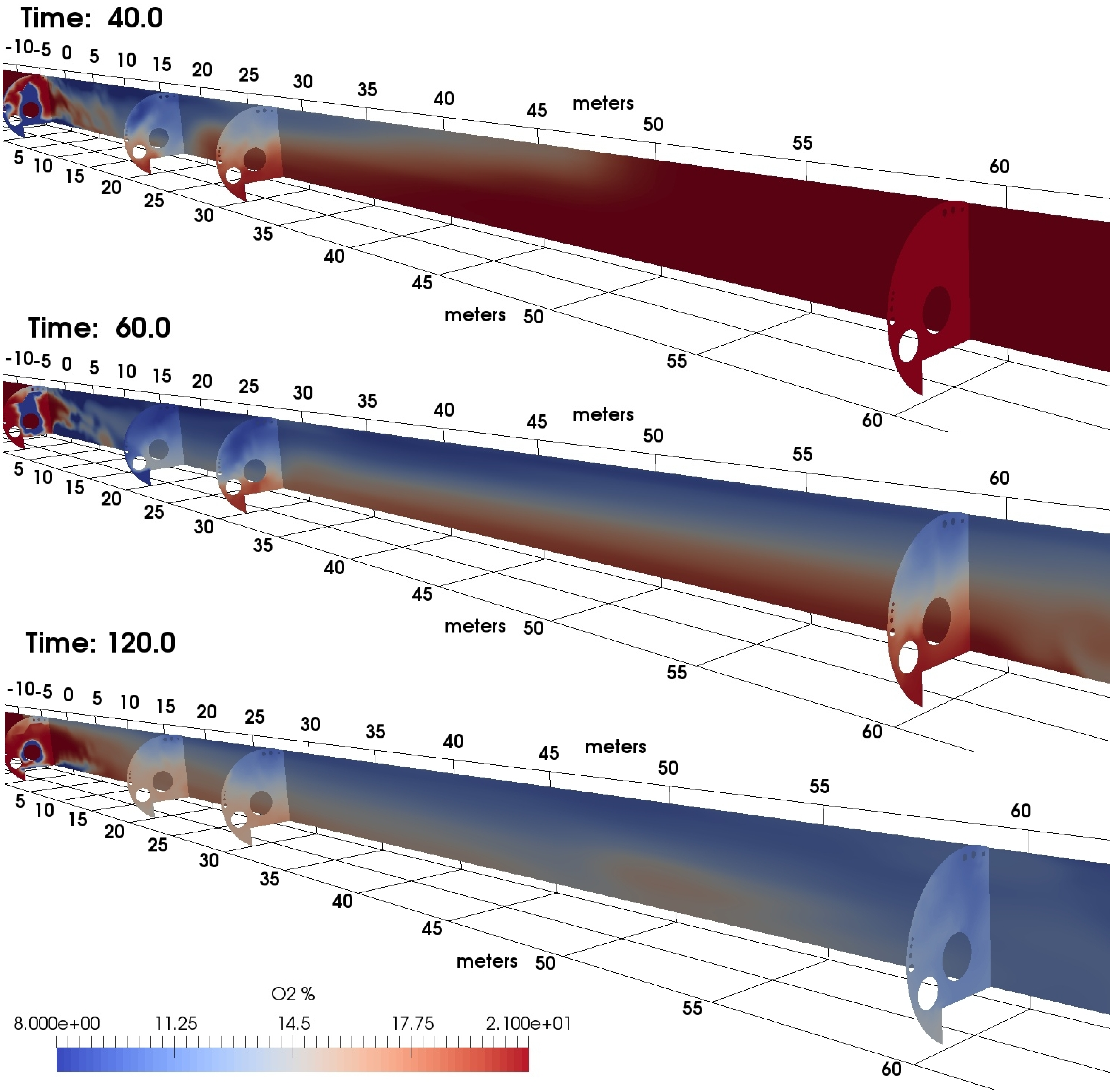
$$\frac{\partial \rho \boldsymbol{u}}{\partial t} + \nabla \cdot (\rho \boldsymbol{u} \boldsymbol{u}) = -\nabla p + \nabla \cdot (\mu \nabla \boldsymbol{u}) + \rho \boldsymbol{g} \qquad \boldsymbol{u} = (u, v, w)$$

$$\frac{\partial \rho}{\partial t} + \nabla \cdot (\rho \boldsymbol{u}) = 0 \qquad \rho = \frac{p}{rT}$$

$$\frac{\partial \rho h}{\partial t} + \nabla \cdot (\rho \boldsymbol{u} h) = \frac{Dp}{Dt} + \nabla \cdot (\frac{k}{C_p} \nabla h) \qquad h = C_p T$$

$$\sum Y_i \mu_i = \mu \qquad \sum Y_i \rho_i = \rho$$

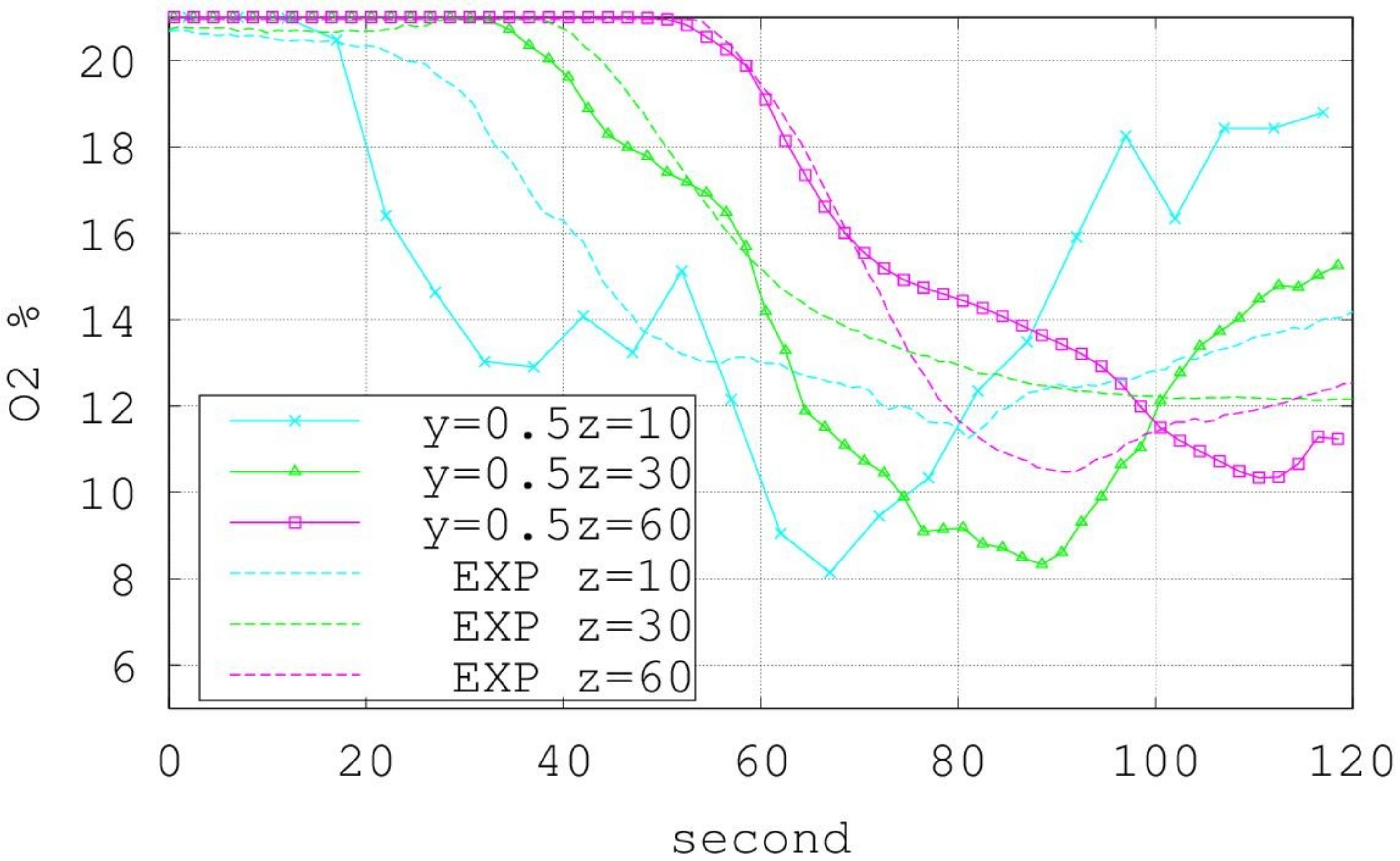
Linear mixing approximation

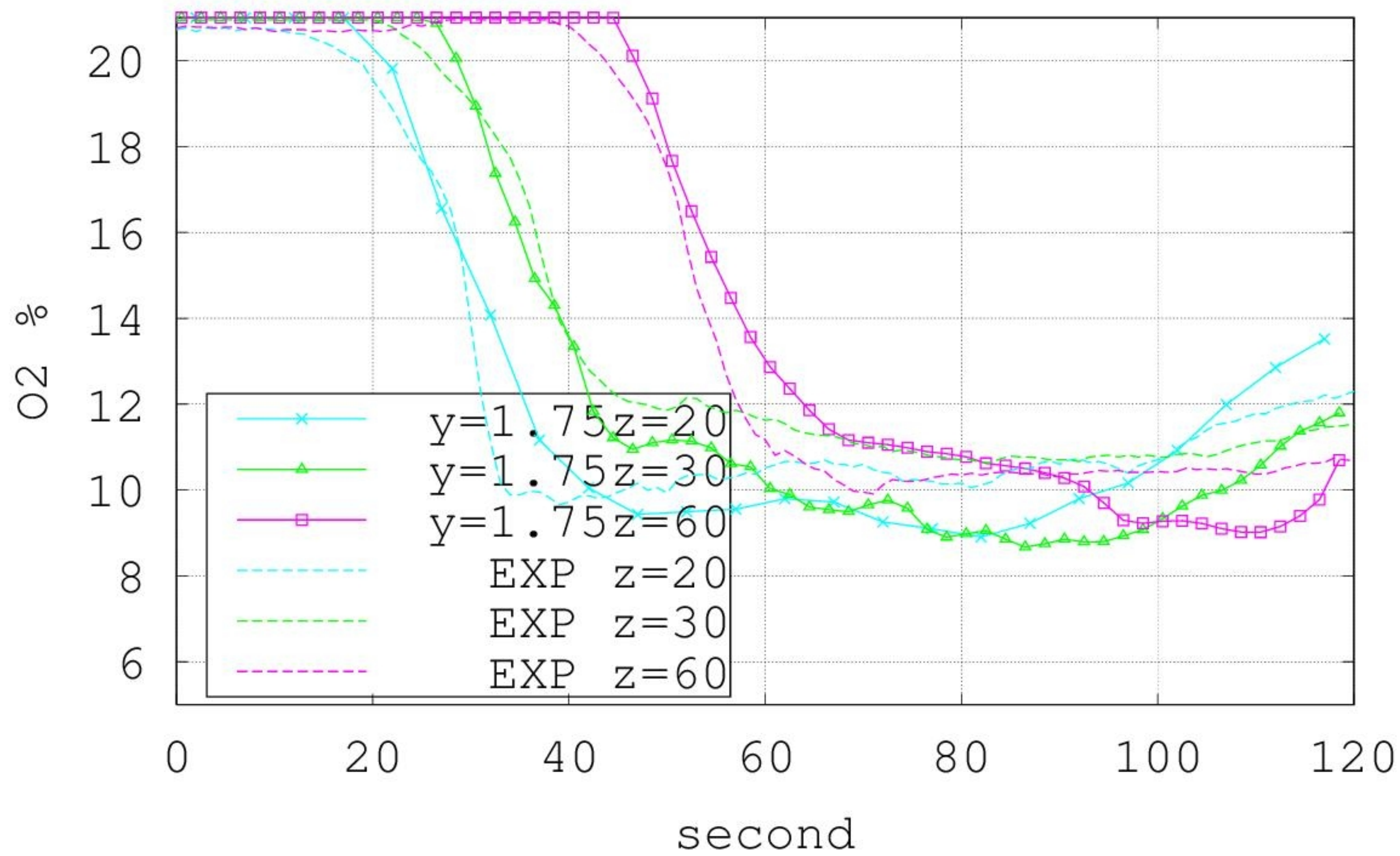


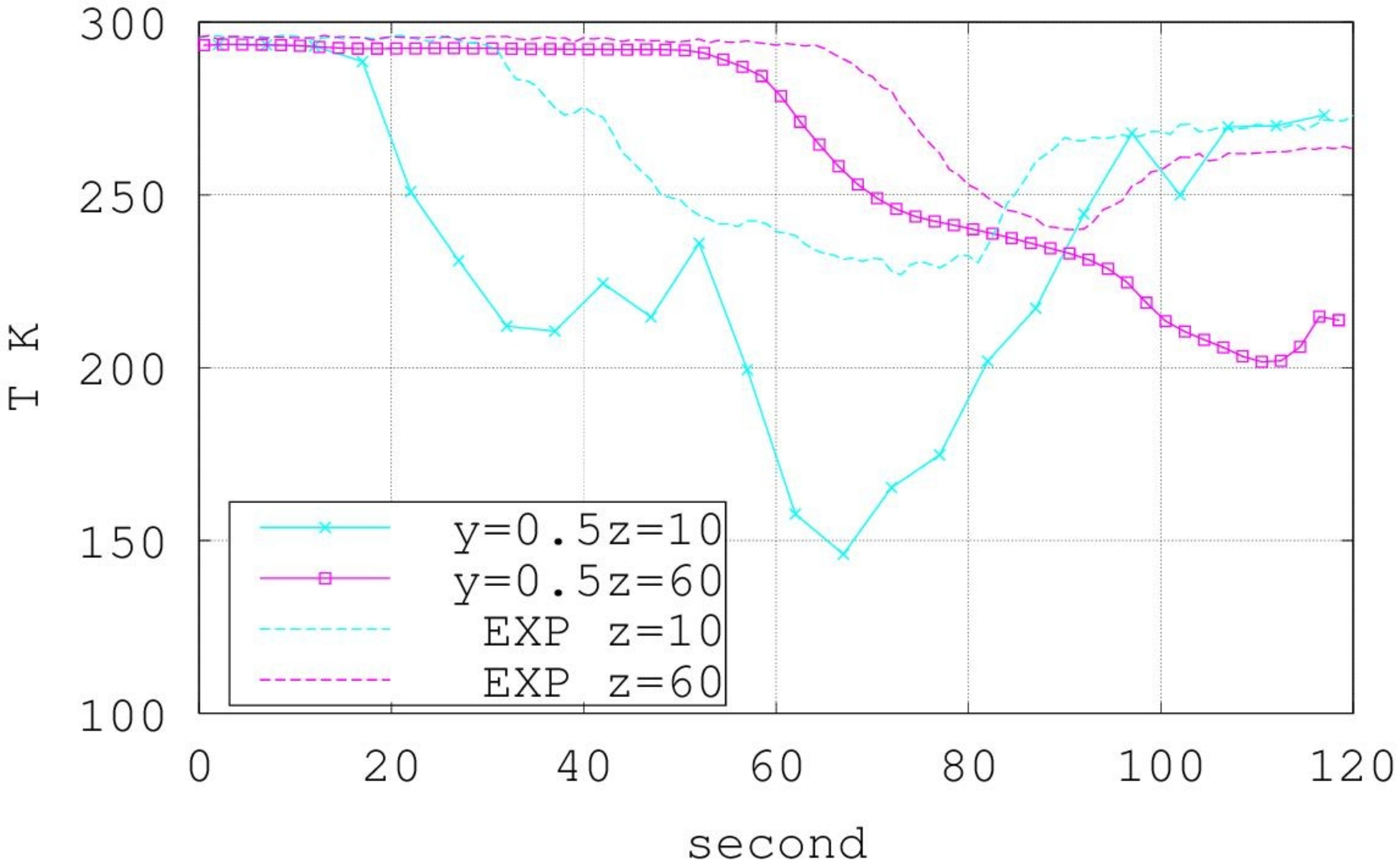
Stratification
only initially, after short time whole tunnel covered by the cloud

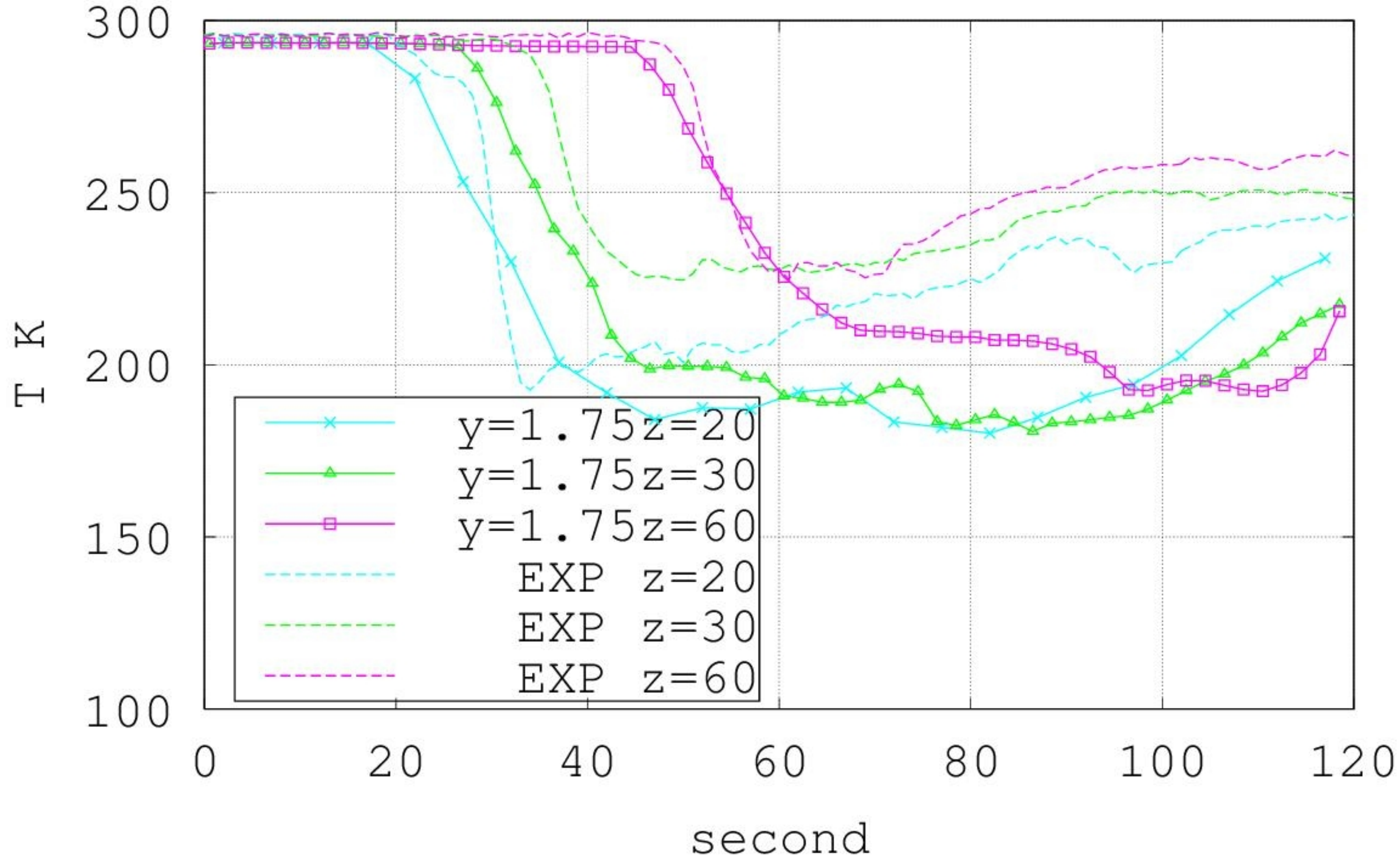
ANIMATION

Comparison with experiment

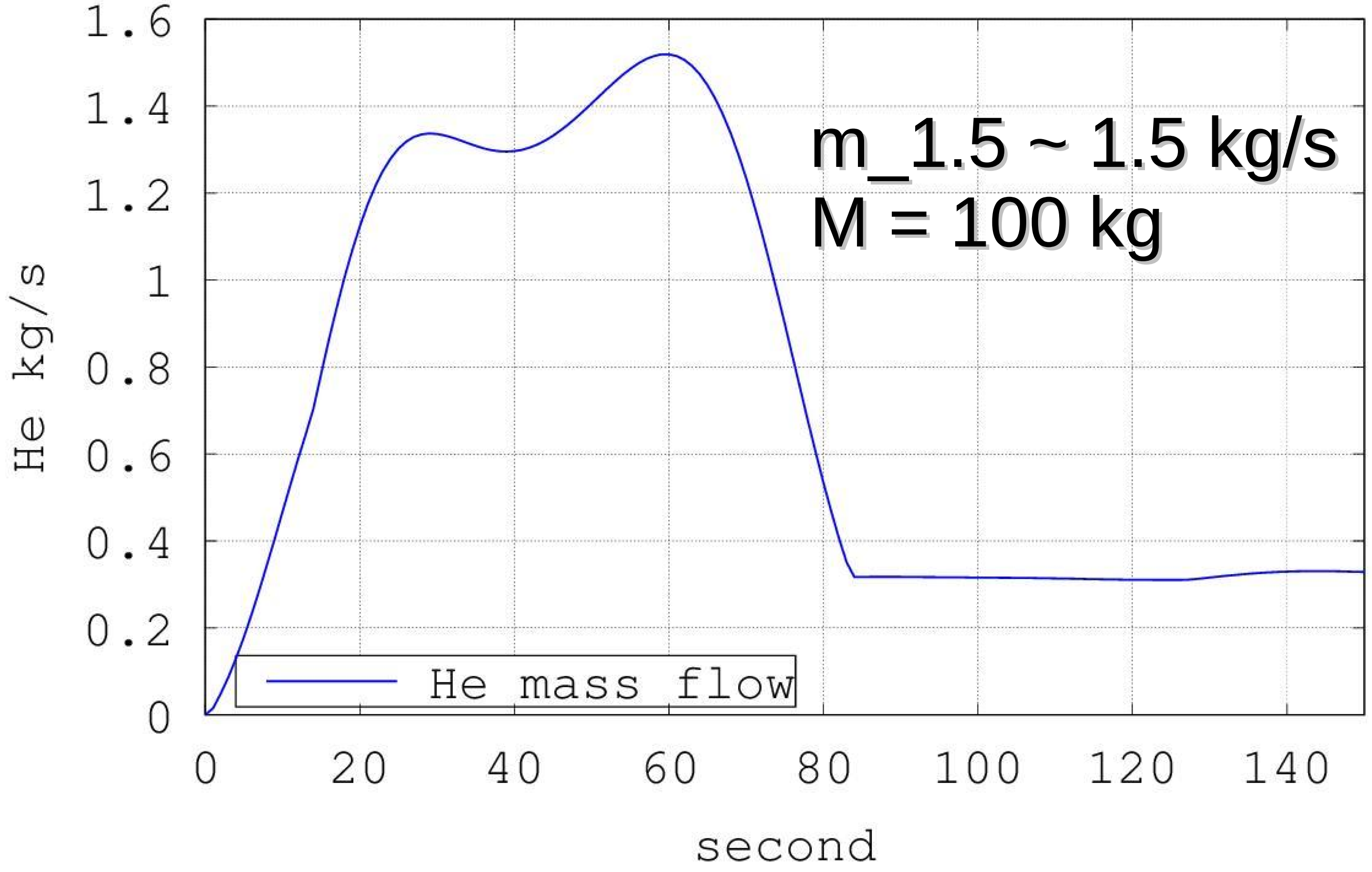


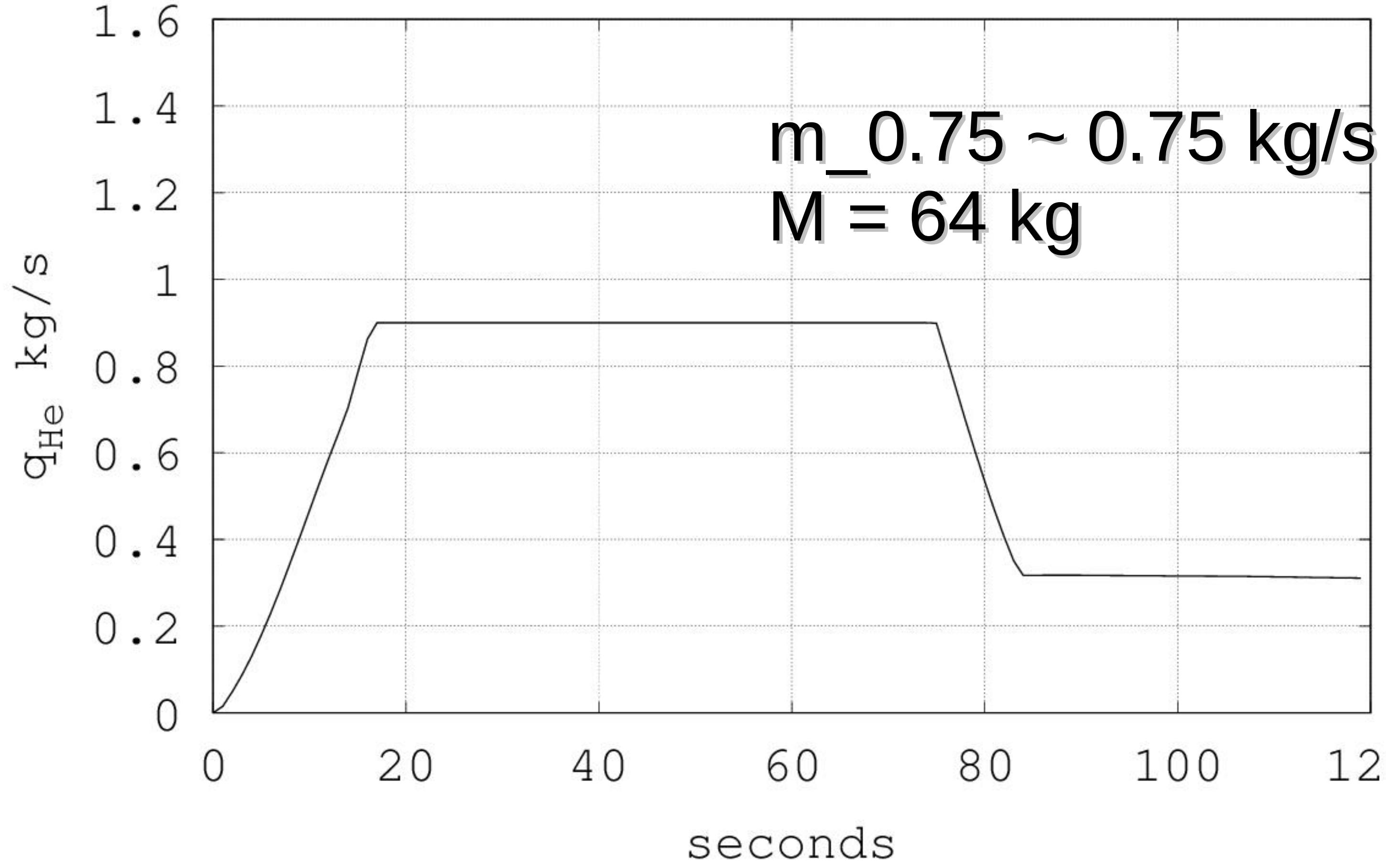


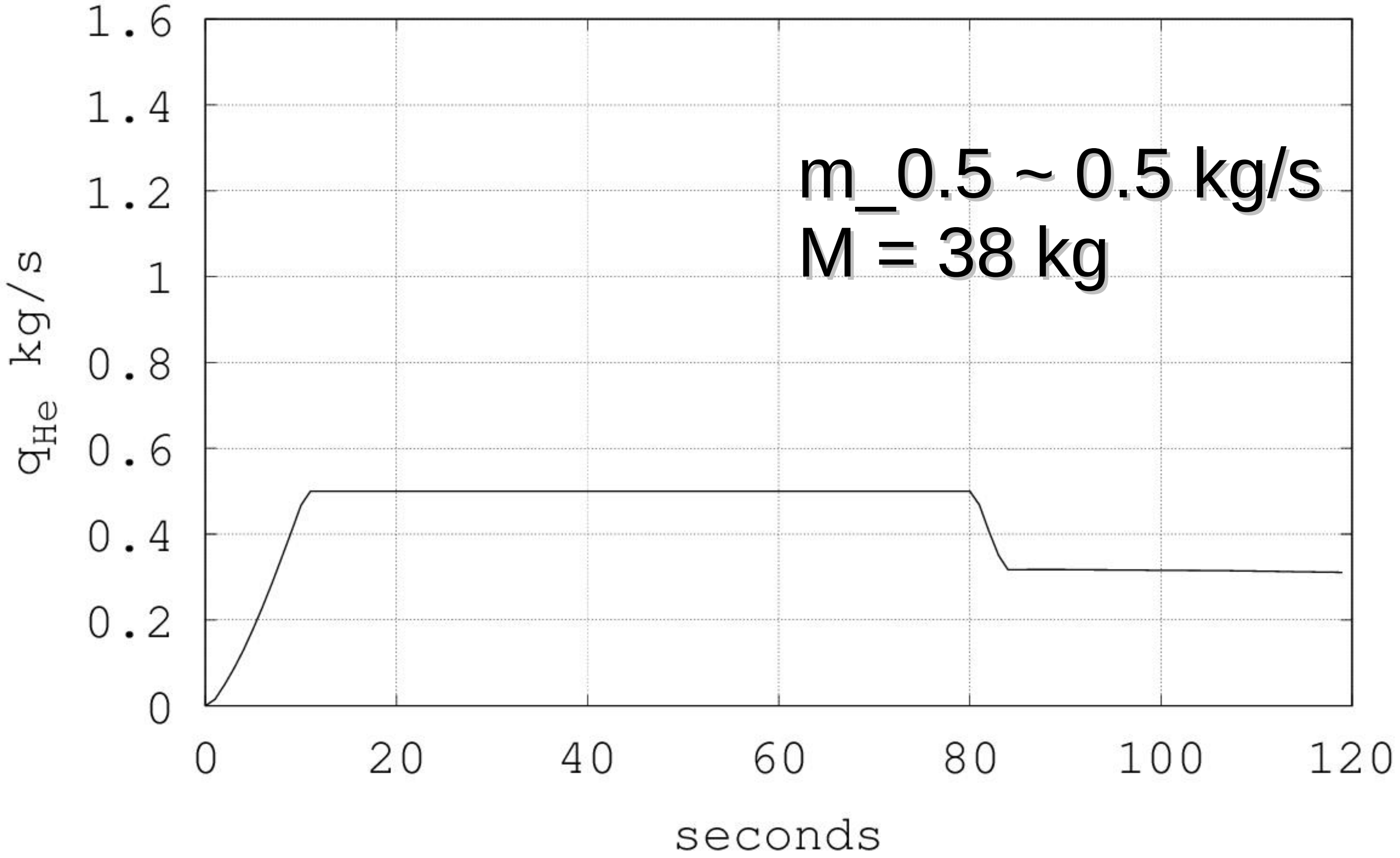




Numerical calculations for different he mass flow

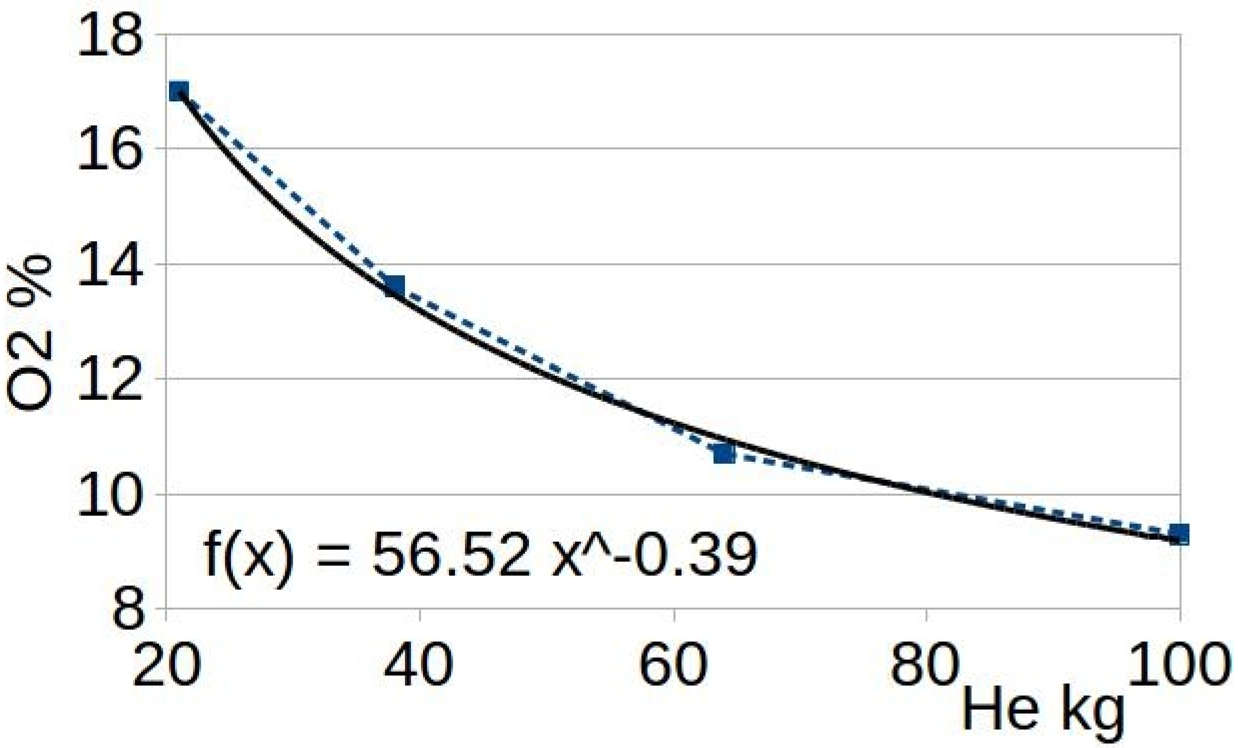


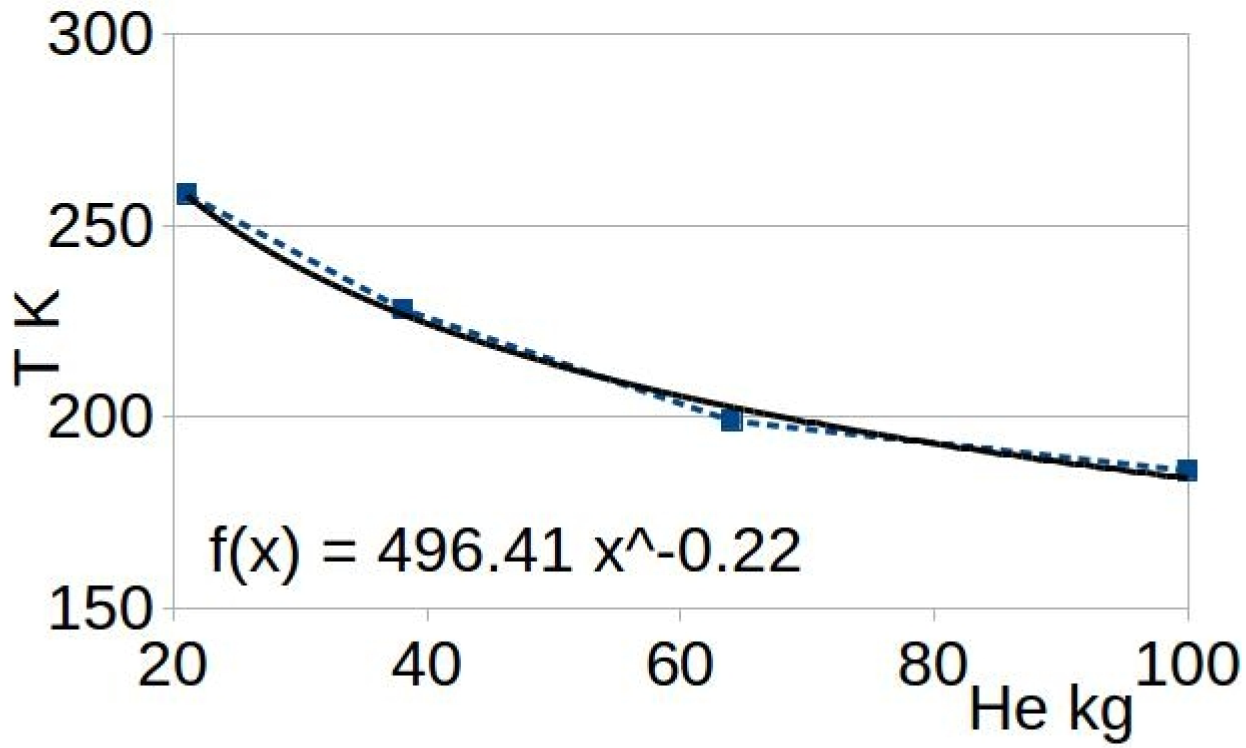




m_0.25 = 0.25 kg/s
M = 21 kg

Numerical results for different helium mass flow – minimal values of O2, T

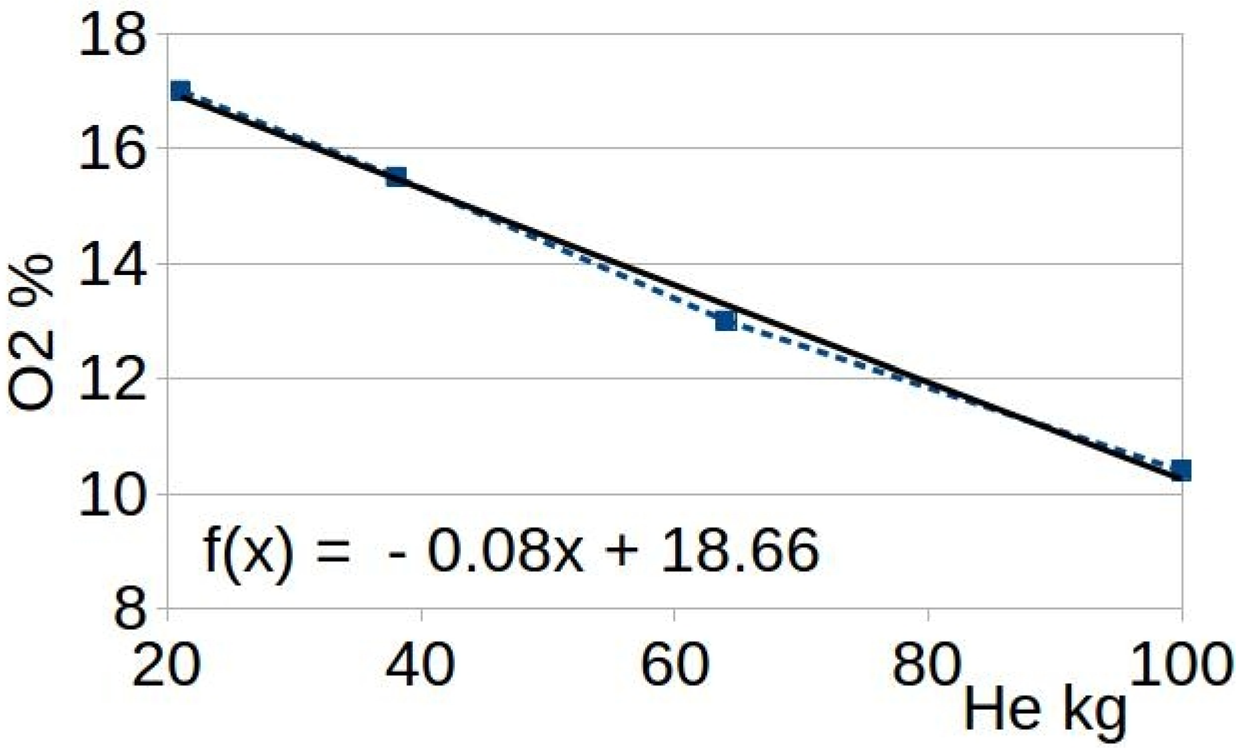


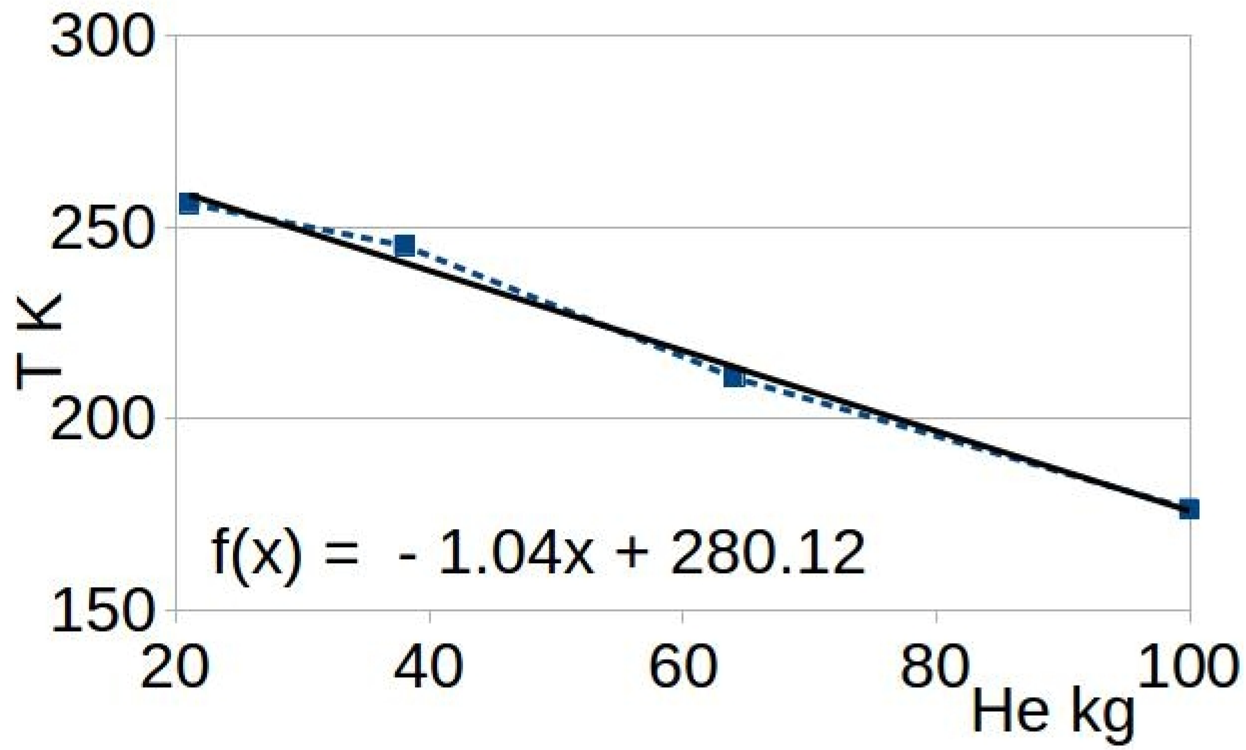


1.75 m

$O_2 < 16\%$, 25.5 kg

$O_2 < 18\%$, 18.8 kg



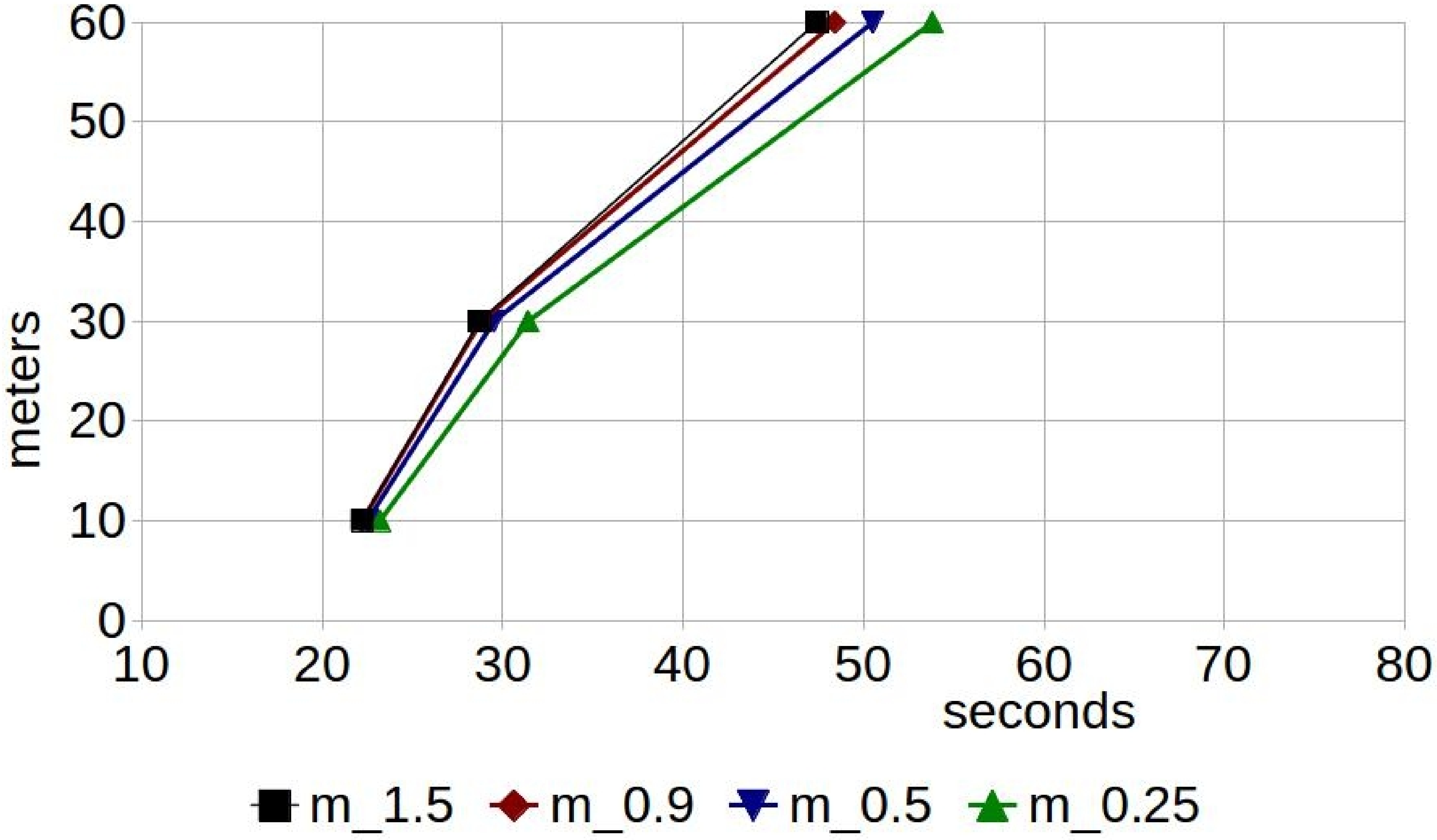


0.5 m

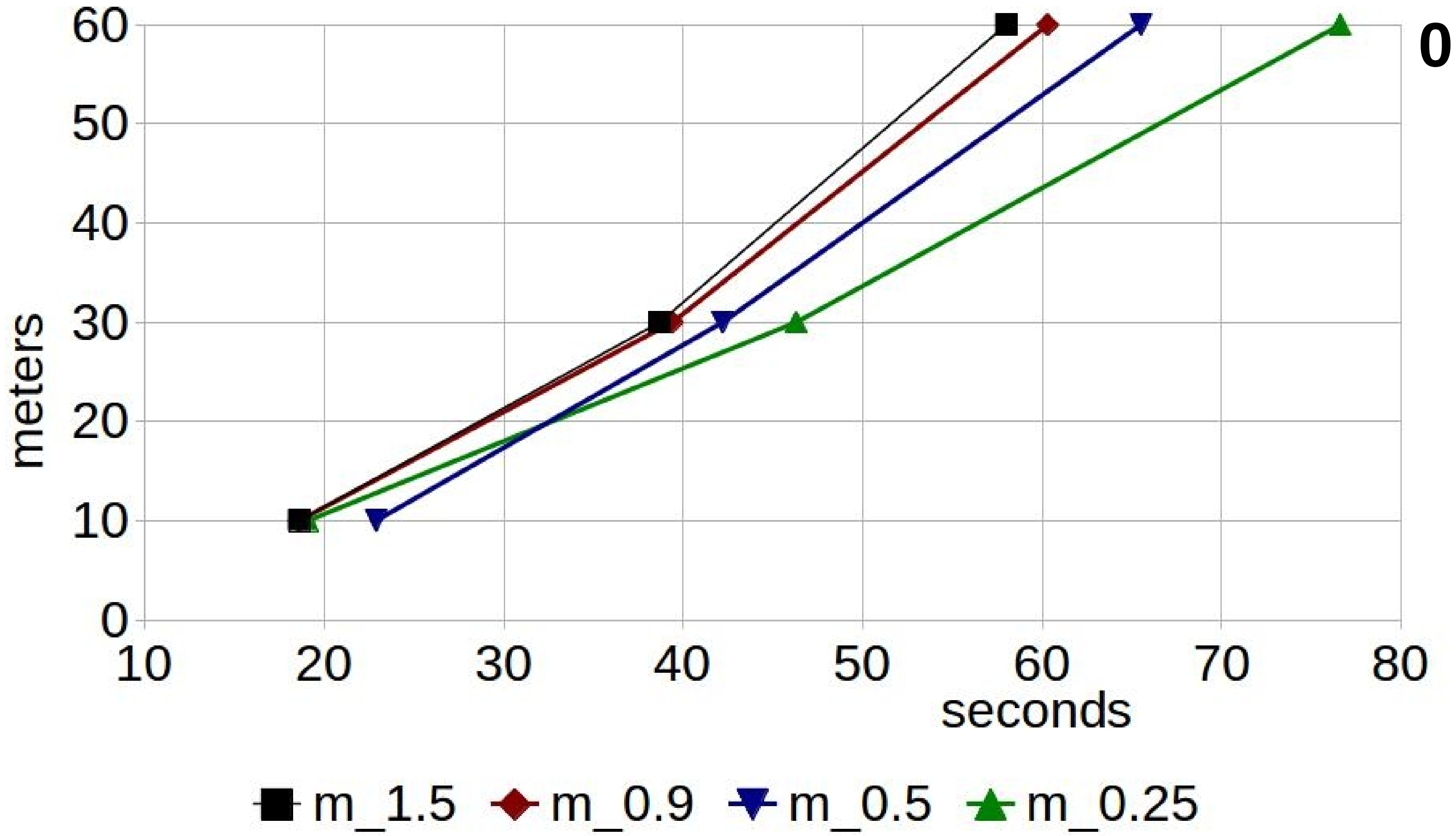
$O_2 < 16\%$, 33 kg

$O_2 < 18\%$, 8.5 kg

Numerics for different helium mass flow – Propagation of the he-air cloud



1.75 m
Cloud moves faster ~ 20% than at 0.5 m



0.5 m

The front of the cloud is assumed to be for oxygen deficiency of 20%

$U_{av} \sim \ln(m)$

Conclusions

- Generic approach for the emergency spill of cryogenics gases into confined spaces was presented.
- It can be predicted that the O2 can drop below 16%, for the helium mass of 25.5 kg or 33 kg, at the locations of 1.75 m or 0.5 m respectively
- Considered formulas can be used for the extrapolation. It can be predicted that the O2 can drop below 18%, for the helium mass of 18.8 kg or 8.5 kg, at the locations of 1.75m or 0.5m respectively.
- He cloud moves faster for larger leaks. The velocity increase is of **log**, it suggests that a limit of the velocity of the cloud. This limit can be related to e.g. the geometry of a tunnel.