CFD simulations of combustible dust dispersion in the 20 L and 1 m^3 standard vessels

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Motivations and aim of the work

- In chemical processes, several accidents are imputable to explosions of flammable dusts, dust mixtures, and hybrid mixtures
- To characterize the sensitivity and the severity of explosion in case of ignition, the explosibility and flammability parameters have to be assessed in the 20 L and/or in the 1 m^3 vessel
- Both vessels should provide the same parameters values once calibration was performed
- There are at least two main requirements for repeatable and reliable measurements of flammability and explosibility parameters of dusts: a uniform dispersion of solid particles inside the test vessels and a homogeneous degree of turbulence, same in both vessels

Visualize the dust dispersion process and the fluid flow established inside the 20 L and the 1 m^3 vessel

Experimental procedures

1. Dust loading in the dust container
2. Pressurization of dust container up to 21 bar with compressed air

20 L vessel

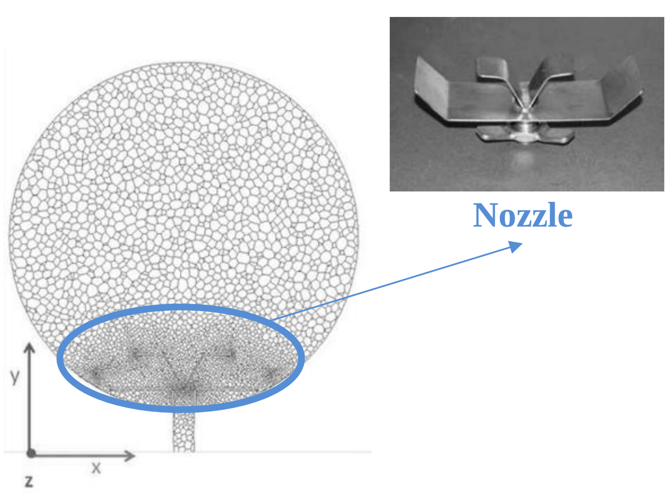
3. The vessel is pre-evacuated at 0.4 bar
4. Dust is injected into the sphere and dispersed through a nozzle
5. Dust cloud is ignited through an electric discharge or pyrotechnic ignitors after 60 ms

1 m^3 vessel

3. The vessel is left at 1 bar
4. Dust is injected into the sphere and dispersed through a nozzle
5. Dust cloud is ignited through an electric discharge or pyrotechnic ignitors after 600 ms

CFD equations, domains and meshes

Time-averaged Navier-Stokes equations (Eulerian approach) + standard k-ε model as turbulent sub-model with standard wall function + SIMPLE method to solve the pressure-velocity coupled equations + Discrete Phase Model (DPM) to solve the flow of the solid phase (Lagrangian approach)

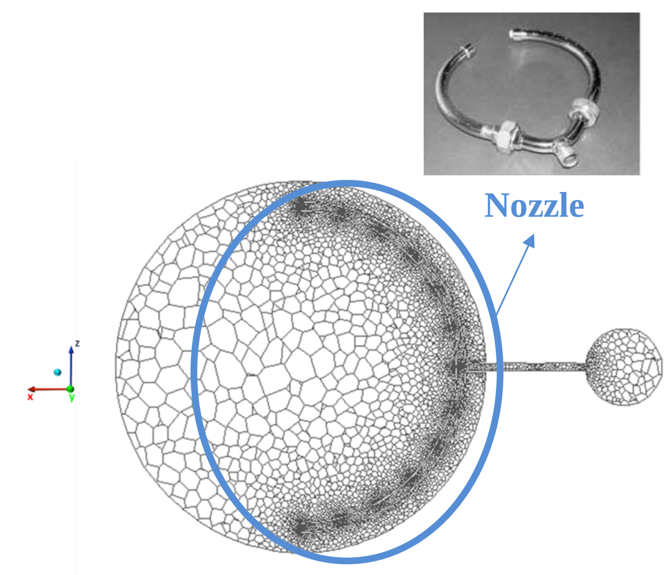


20 L vessel

Geometrical detail	Value
Container volume (m^3)	0.0006
Tube diameter (m)	0.02
Tube length (m)	0.72
Sphere volume (m^3)	0.02

	20 L sphere	1 m^3 sphere
Initial pressure of container (bar)	21	21
Initial pressure of sphere and container (bar)	0.4	1
Dust concentration (g/m^3)	100	100
Dust density (kg/m^3)	2046	2046
Dust diameter (μm)	250	250
Time step (s)	$1•10^{-4}$	$4•10^{-5}$
Number of time steps	600	15000

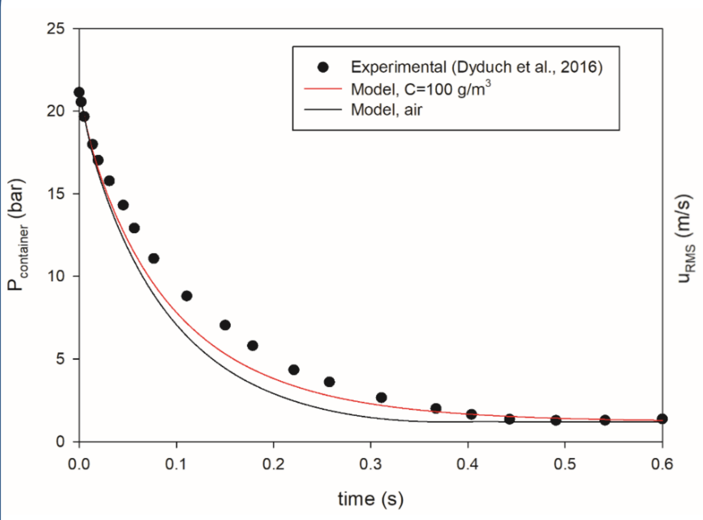
Geometrical detail	Value
Container volume (m^3)	0.0054
Tube diameter (m)	0.02
Tube length (m)	0.35
Sphere volume (m^3)	1



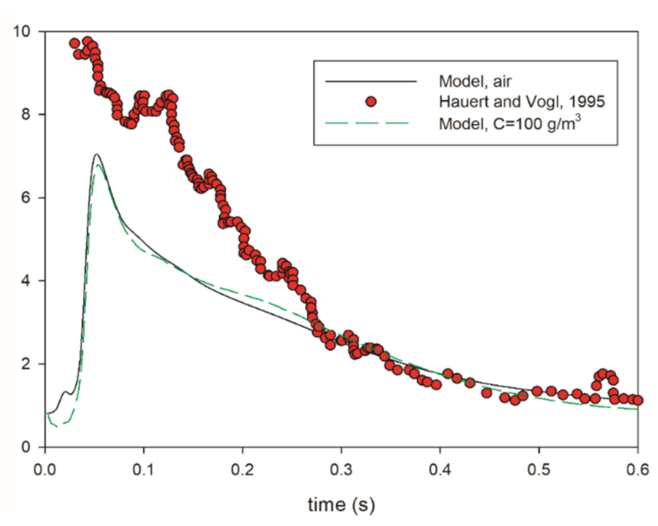
1 m^3 vessel

CFD results

*Validation**



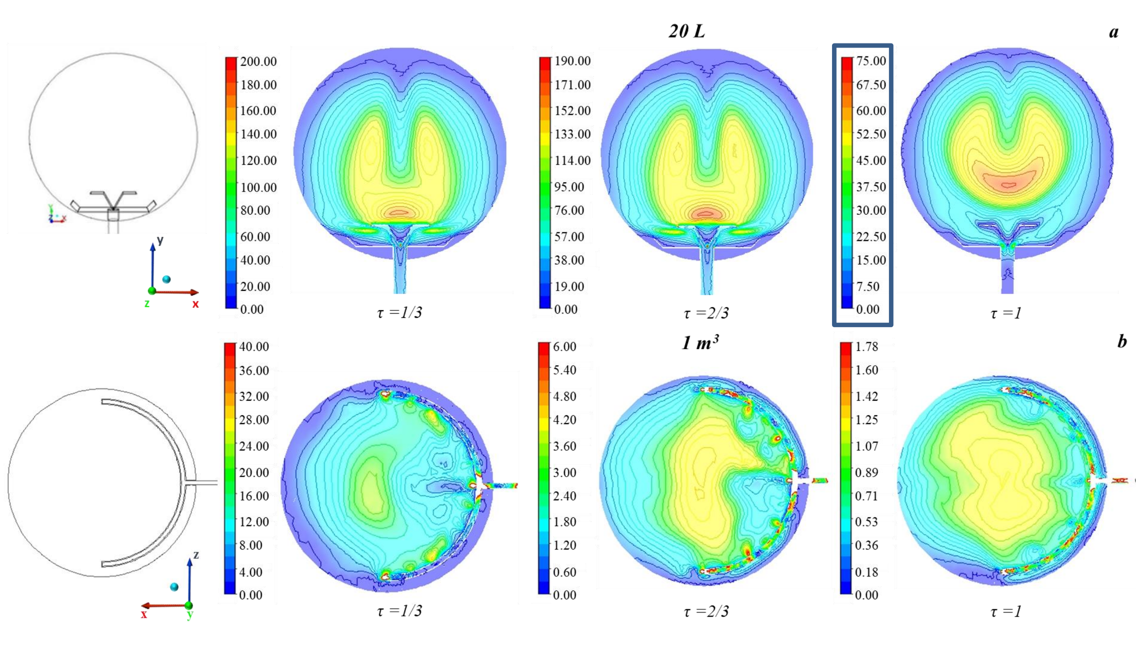
Pressure time histories computed in the centre of the dust container for dust free air and dust-air mixture. Literature data are also shown for the sake of comparison



RMS turbulence velocity (m/s) as a function of the time at the centre of the 1 m^3 vessel for dust free air and dust-air mixture. Literature data are also shown for comparison

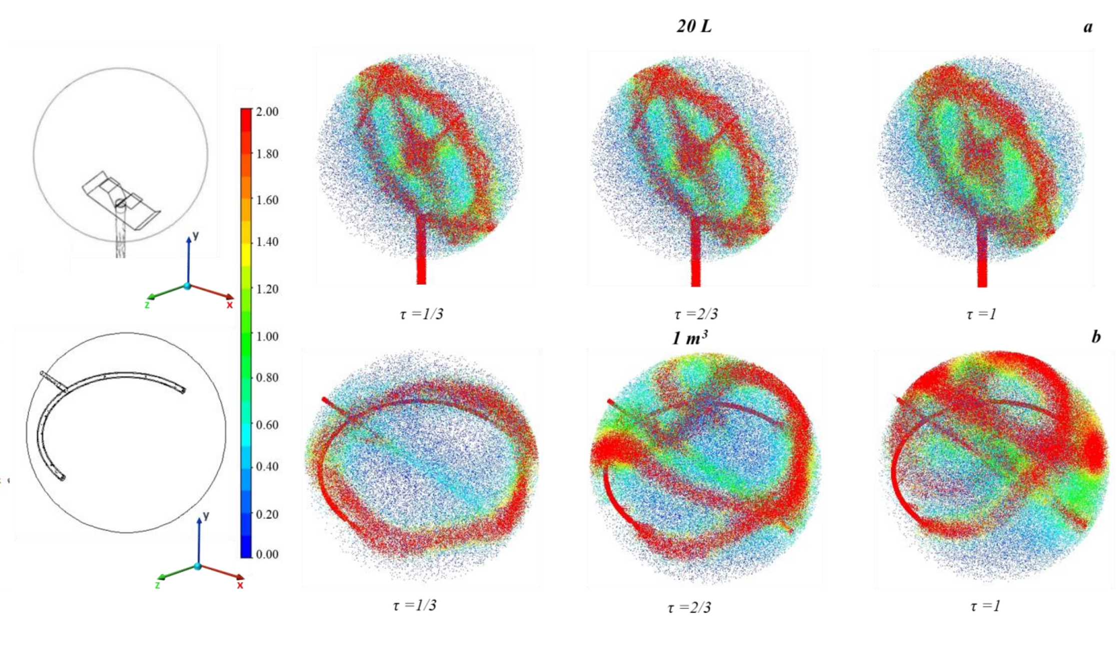
*reported only for 1 m^3 vessel simulations

Not-uniform pre-ignition turbulence level in 20 L sphere!



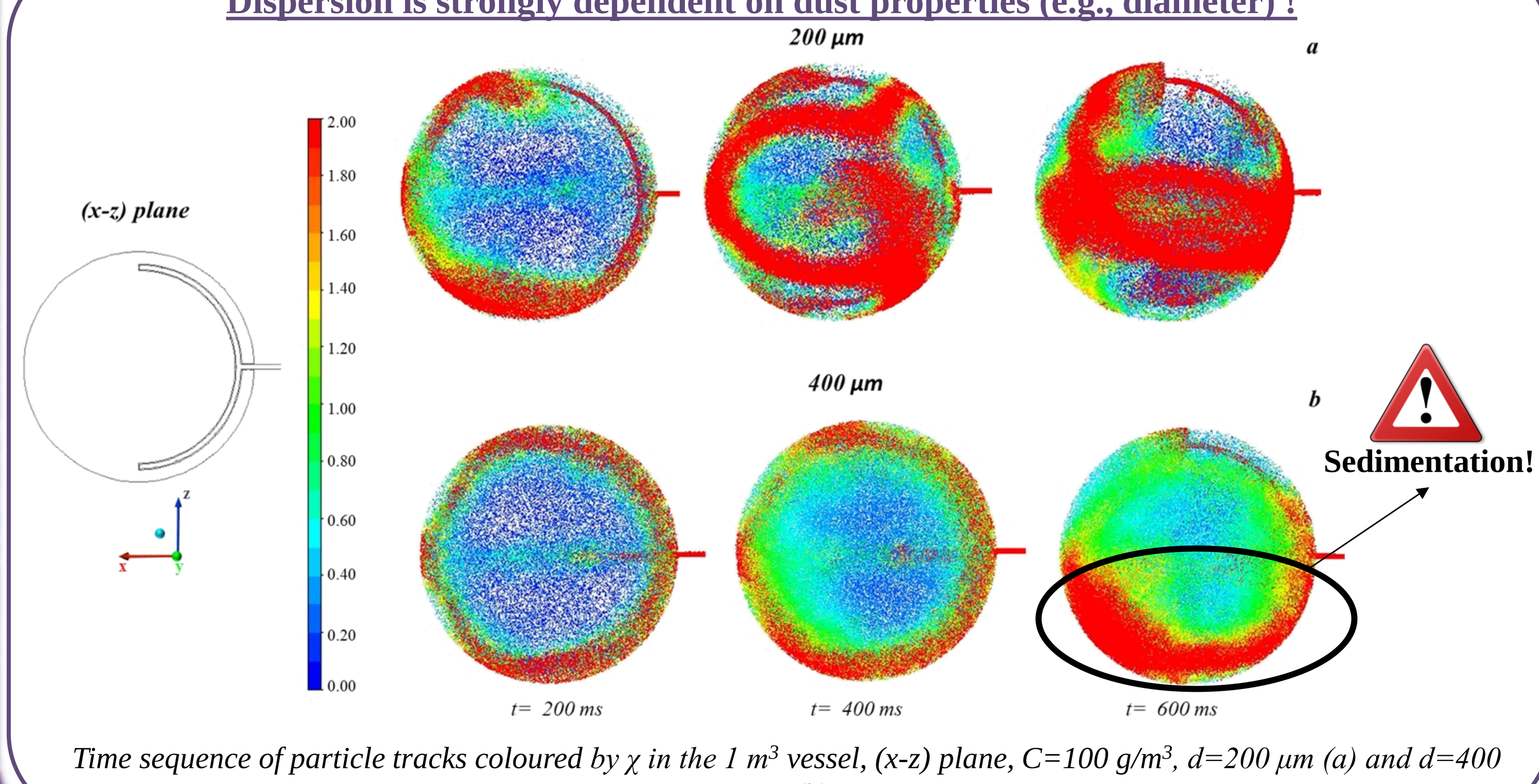
Computed maps of turbulent kinetic energy (m^2/s^2) as function of the dimensionless time τ defined as the ratio between time and ignition delay time: 20 L sphere (a) ((x-y) plane) and 1 m^3 vessel (b), (x-z) plane

Not-uniform dust concentration in both the vessels!



Particle tracks colored by χ as function of the dimensionless time τ defined as the ratio between time and ignition delay time computed in the whole spheres: 20 L sphere (a) and 1 m^3 vessel (b)

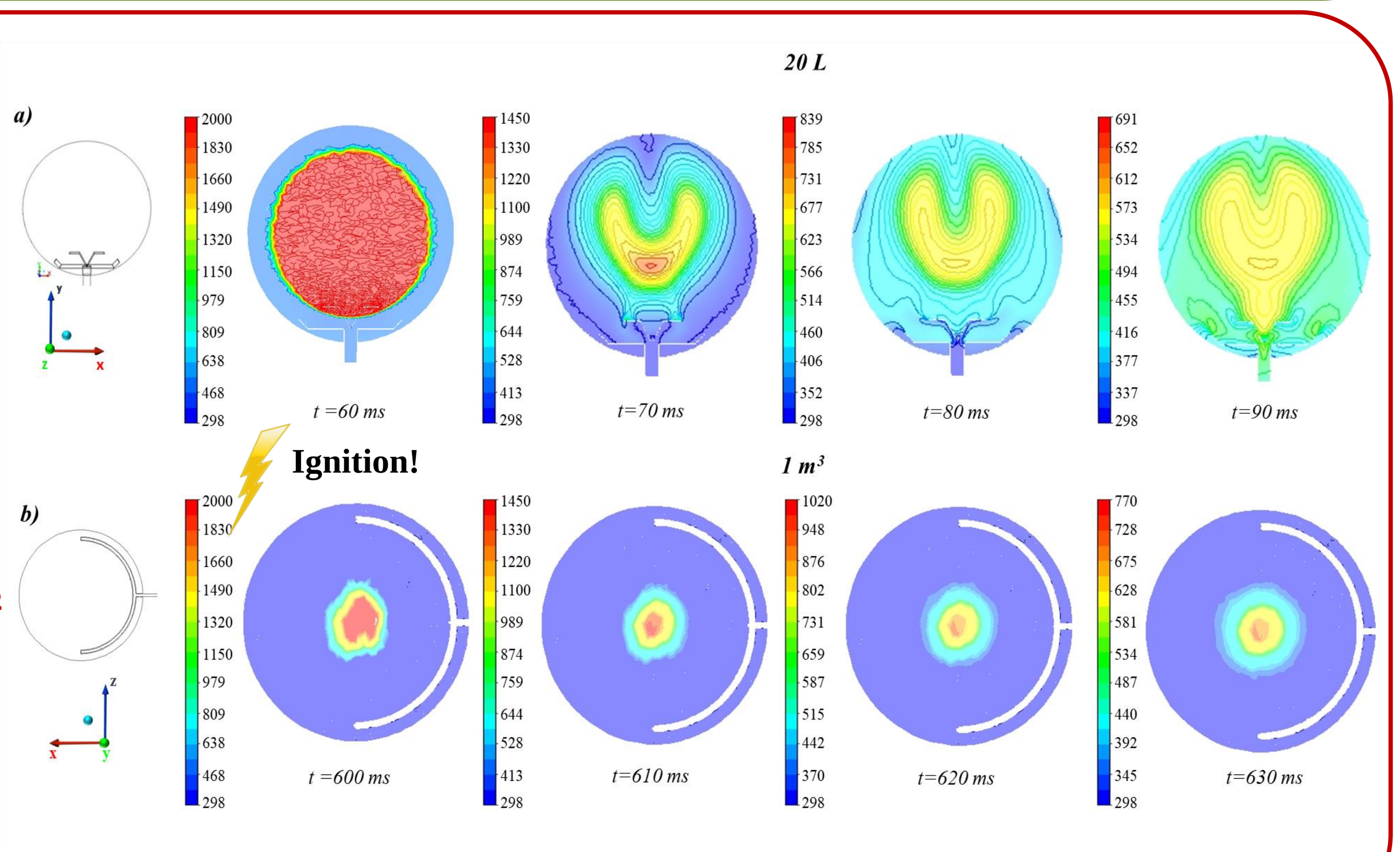
Dispersion is strongly dependent on dust properties (e.g., diameter) !



Time sequence of particle tracks coloured by χ in the 1 m^3 vessel, (x-z) plane, C=100 g/m^3, d=200 μm (a) and d=400 μm (b)

Pre-ignition turbulence level dissipates differently the hot core generated by pyrotechnic ignitors in the standard vessels!

Different response of dusts in the two vessels, depending on the flame propagation mechanism



Temperature maps in the 20 L (a) and 1 m^3 (b) vessels, simulated at different times

Conclusions

- The two main requirements for repeatable and reliable measurements of flammability and explosibility parameters of dusts are not satisfied
- A novel system for dust dispersion has to be developed!

References

- **Portarapillo, M.**, Trofa, M., Sanchirico, R., Di Benedetto, A. CFD Simulations of Dust Dispersion the 1 m^3 Explosion Vessel, Journal of Loss Prevention in the Process Industries, 2020, https://doi.org/10.1016/j.jlp.2020.104274
- **Portarapillo, M.**, Sanchirico, R., Di Benedetto, A. On the pyrotechnic ignitors role in dust explo sion testing: Comparison between 20 L and 1 m3 explosion vessels, Process Safety Progress, e12249, 2021, DOI: https://doi.org/10.1002/prs.12249
- **Portarapillo, M.***, Trofa, M., Sanchirico, R., Di Benedetto, A. CFD simulations of the effect of dust diameter on the dispersion in the 1 m3 explosion vessel, Chemical Engineering Transaction, 86, 2021