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BREATHING LOSSES FROM LOW-PRESSURE STORAGE TANKS DUE TO ATMOSPHERIC WEATHER CHANGE

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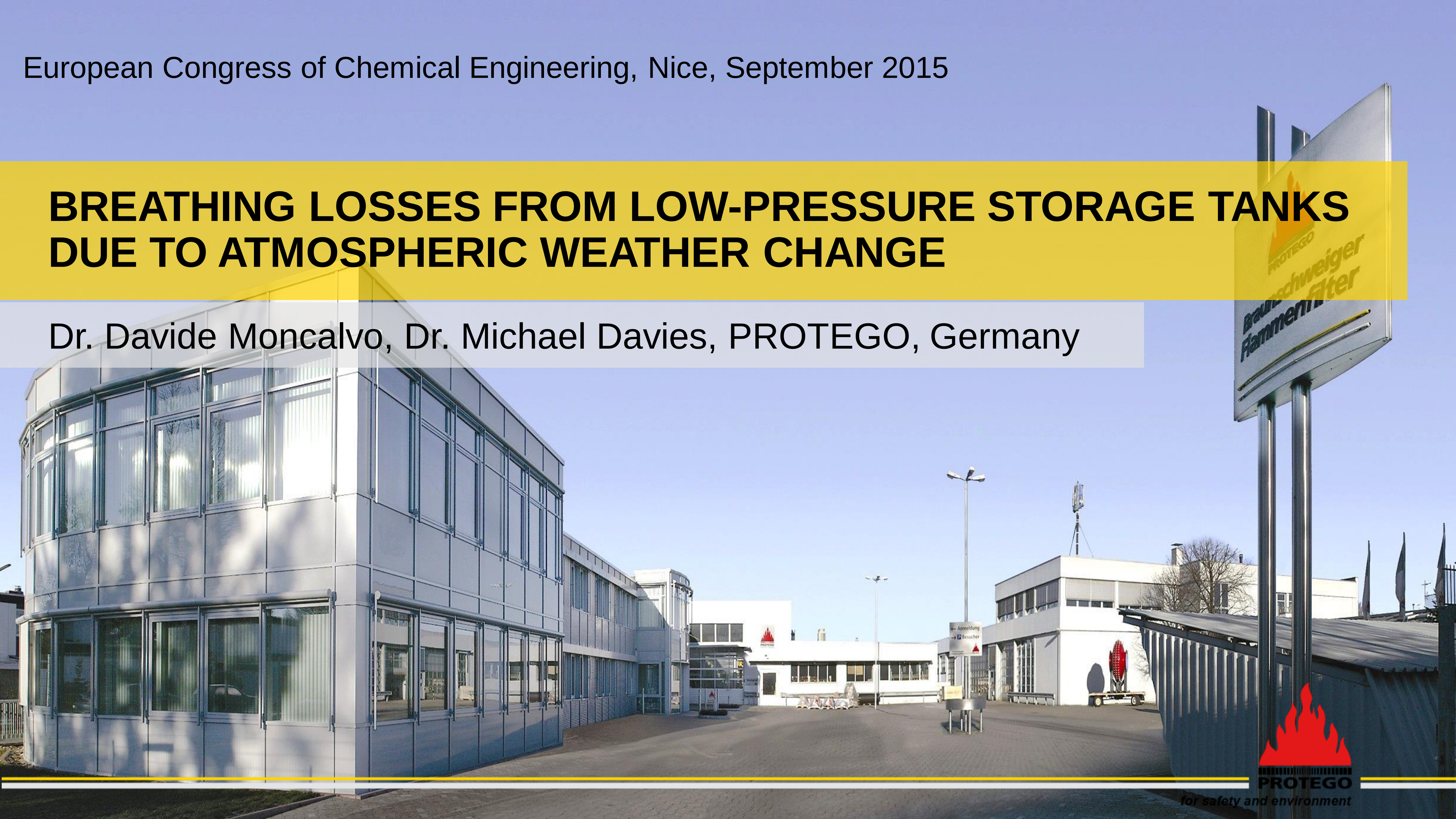

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Agenda

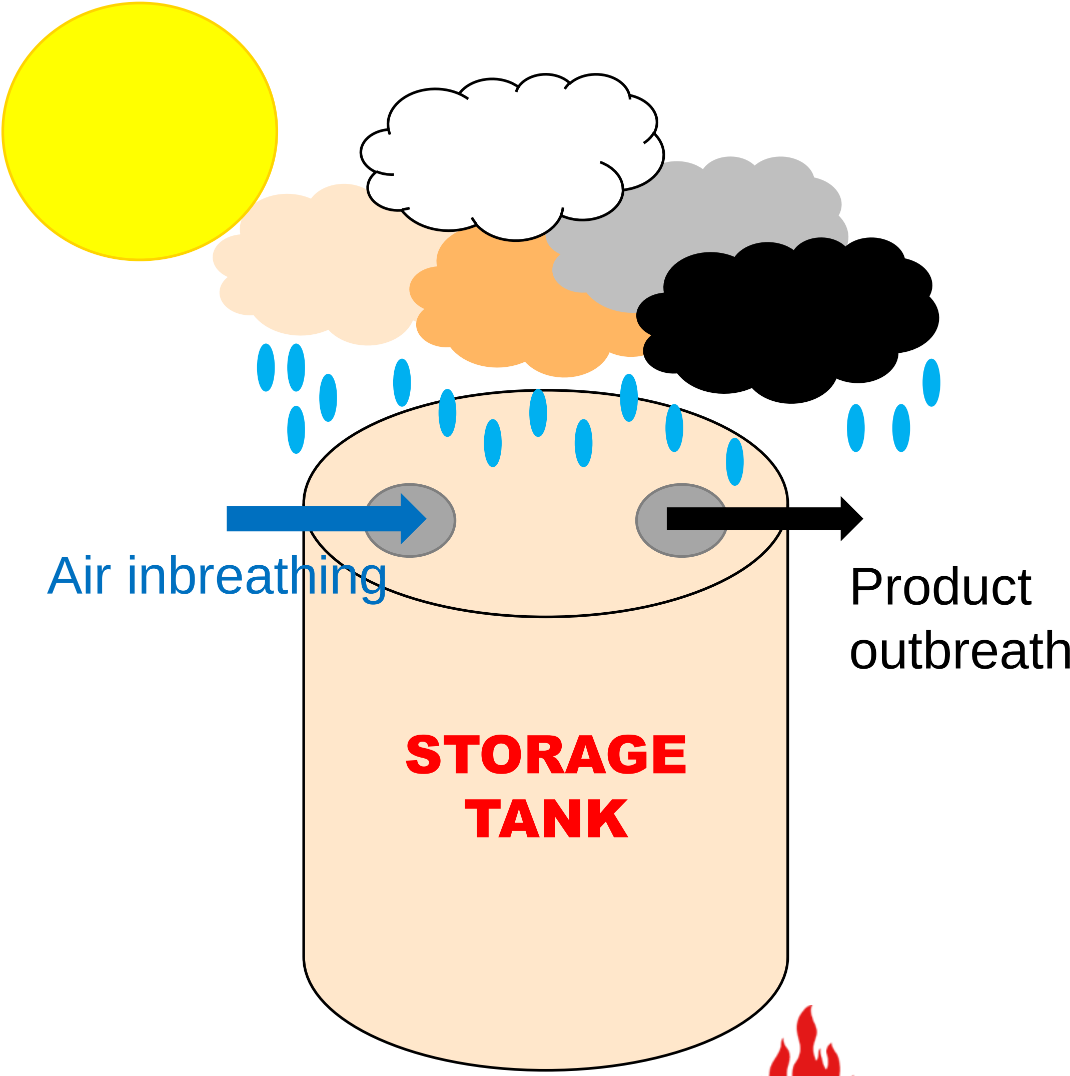
Introduction

- Low-pressure tanks are large open-air storage tanks, containing huge amounts of product within thin walls

- Protection against corrosion and thermal losses caused by weather changes incl. storms is often done by organic *coating*

- A more economical corrosion protection may be *painting* the tank. However, a painted tank lacks of the thermal protection against weather temperature changes or seasonal rainfalls or droughts

- For a tank protected against vacuum and overpressure ambient heat inflow leads to breathing out of valuable product, whereas sudden cooling leads to vacuum, compendsated by in-breathing of ambient air.



State of the art

- Literature sources on this topic
  - „*Naumann formulas*“ (unpublished)
  - “*Höchst paper*” written by Sigel, Kuxdorf, Meiss and Schwarz in Chem. Ing. Tech. 55 (1983)
  - „*PTB Paper*“ alias PTB Bericht W-22 written by Förster, Schampel and Stehen (1984)
  - Salatino, Volpicelli and Volpe in Trans.IChem 77 (1999)
  - ISO 28300 (2008) identical to ANSI / API 2000 6th Ed. (2009)

State of the art / Models and experiments

Model	Model	Experiments	Applicability (Case study)
Naumann (unpublished)	Empirical		Thermal tank heating Thermal tank cooling
Höchst / Sigel et al. (1983)	Analytical	Rain cooling on Air tank (600 m^3)	Short rainfalls
PTB / Förster et al. (1984)	Analytical		Long sun exposure Short and long rainfalls Condensing tank products
Salatino (1999)	Analytical		Sudden rain falls

Note: The methods (measurements) presented here have been derived (performed) for cylindrical tanks

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Naumann formulas

Naumann formulas are <u>conservative</u> empirical estimations of the tank maximum in- and outbreathing to compensate for tank thermal heating and cooling

$$\dot{V}_{max-out} = 1.1\frac{m}{h} \cdot H \cdot D \approx 1.292\ \frac{m}{h} \cdot \left(\frac{H}{D}\right)^{1/3} \cdot (V_{tank})^{2/3}$$

$$\dot{V}_{max-in} = 1.5\frac{m}{h} \cdot (H + 4D) \cdot D \approx 1.762\frac{m}{h} \cdot \left[4\left(\frac{H}{D}\right)^{-2/3} + \left(\frac{H}{D}\right)^{1/3}\right](V_{tank})^{2/3}$$

PTB tank heating model

Tank volume increment following a long sun exposure

$$\dot{V}_B(t) = \frac{V_{tank}}{T_{B0}} \frac{c}{\lambda} \left[exp\left(\frac{\lambda - a}{2} t \right) - exp\left(-\frac{\lambda + a}{2} t \right) \right]$$

$$\lambda = \sqrt{a^2 - 4b}$$

$$a_{PTB} = A_{tank} \cdot \left(\frac{\alpha_B}{C_B} + \frac{\alpha_B + \alpha_{conv} + 0.75\varepsilon_{emis}\alpha_{emis}}{C_E} \right)$$

$$b_{PTB} = A^2{}_{tank} \cdot \frac{\alpha_B}{C_B} \cdot \frac{\alpha_{conv} + 0.75\varepsilon_{emis}\alpha_{emis}}{C_E}$$

$$c_{PTB} = A^2{}_{tank} \cdot \frac{\alpha_B}{C_B} \cdot \frac{I \cdot \varepsilon_{rad} \cdot \varphi_{GEOM} - 0.5 \cdot E_{BLACK} \varepsilon_{emis}}{C_E}$$

This formula foresees a maximum tank shrinking V_{max} at some time

$$\dot{V}_{max} = \dot{V}_B(\tau) \quad \text{with} \quad \tau = \frac{1}{\lambda} \ln\left(\frac{a+\lambda}{a-\lambda} \right) \neq 0$$

Höchst and PTB tank cooling model

Tank volume reduction following rainfall cooling

Unlimited rain (flood, deluge)
Thin rain film thickness (rain)

$$\dot{V}_B(t) = V_B \cdot \frac{T_{B0} - T_{rain}}{T_{B0}} \frac{b}{\lambda} \left[exp\left(\frac{\lambda - a}{2} t\right) - exp\left(-\frac{\lambda + a}{2} t\right)\right]$$

$$\lambda = \sqrt{a^2 - 4b}$$

$$\boldsymbol{a} = A_{tank} \cdot \left(\frac{\alpha_B}{C_B} + \frac{\alpha_B + \boldsymbol{\alpha_w}}{C_E}\right) \qquad \boldsymbol{a} = A_{tank} \cdot \left(\frac{\alpha_B}{C_B} + \frac{\alpha_B + \boldsymbol{\alpha_w(1-k)}}{C_E}\right)$$

$$\boldsymbol{b} = A^2{}_{tank} \cdot \frac{\alpha_B}{C_B} \cdot \frac{\boldsymbol{\alpha_w}}{C_E} \qquad \boldsymbol{b} = A^2{}_{tank} \cdot \frac{\alpha_B}{C_B} \cdot \frac{\boldsymbol{\alpha_w(1-k)}}{C_E}$$

This formula foresees a maximum tank shrinking V_{max} at some time

$$k = \frac{\alpha_w}{\alpha_w + \dot{m}_{rain} c_{rain}}$$

$$\dot{V}_{max} = \dot{V}_B(\tau) \quad \text{with} \quad \tau = \frac{1}{\lambda} \ln\left(\frac{a+\lambda}{a-\lambda}\right) \neq 0$$

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Salatino model

- It considers the different heat transfer intensity between gas and tank shall and the roof in a partially filled wetted tank. Liquid temperature is assumed unchanged.

- His method consists in a thermodynamic analysis of the tank before and after a weather change, f. i. rainfall cooling in a long hot dry summer

- Final gas temperature in function of the final temperature of each surface facing it

$$T_{end,G} = \sum \frac{A_i \cdot \alpha_{iG} \cdot T_i}{A_i \cdot \alpha_{iG}} = \frac{A_r \cdot \alpha_{rG} \cdot T_r + A_s \cdot \alpha_{sG} \cdot T_s + A_L \cdot \alpha_{LG} \cdot T_L}{A_r \cdot \alpha_{rG} + A_s \cdot \alpha_{sG} + A_L \cdot \alpha_{LG}}$$

- He proposed a rigorous numerical method and a simplified model to predict the maximum inbreathing load due to rainfall cooling of a warm tank (Difference 2 %)

$$\dot{V}_{tank} = \frac{R}{p} \cdot \left(T_{hot,G} - T_{cold,G}\right) \cdot \frac{A_r \cdot \alpha_{rG} + A_s \cdot \alpha_{sG} + A_L \cdot \alpha_{LG}}{c_p}$$

ISO 28300 and API 2000 (2009)

- The thermal outbreathing capacity is given by

$$\dot{V}_{out} = Y \cdot (V_{tank})^{0.9} \cdot R_i$$

Latitude	Y Factor
Below 42°	0.32
Between 42° and 58°	0.25
Above 58°	0.2

- The thermal inbreathing capacity is given by

$$\dot{V}_{in} = C \cdot (V_{tank})^{0.7} \cdot R_i$$

Latitude	C Factor			
	Vapor pressure			
	Hexane or similar		Higher than hexane , unknown	
	Storage temperature			
	Below 25°C	Above 25°C	Below 25°C	Above 25°C
Below 42°	4	6.5	6.5	6.5
42° - 58°	3	5	5	5
Above 58°	2.5	4	4	4

PROTEGO® Initial test / Test condition and sensors

Tank data	
Tank diameter	1.15 m
Tank length	4.3 m
Tank volume	4.466 m^3
Wall thickness	10 mm
Medium in the tank	Air
Test environment	
Wall temperature	55°C
Sensors and measuring equipment	
Anemometer Testo 452 (max. 20 m/s ; accuracy ± 0.5 m/s) Test probe diameter 12 mm	
Inner Temperature Thermometer Pt100	
Outer Temperature Thermocouple	

Water poured using two hoses with combined mass flux of 230 kg/m^2h

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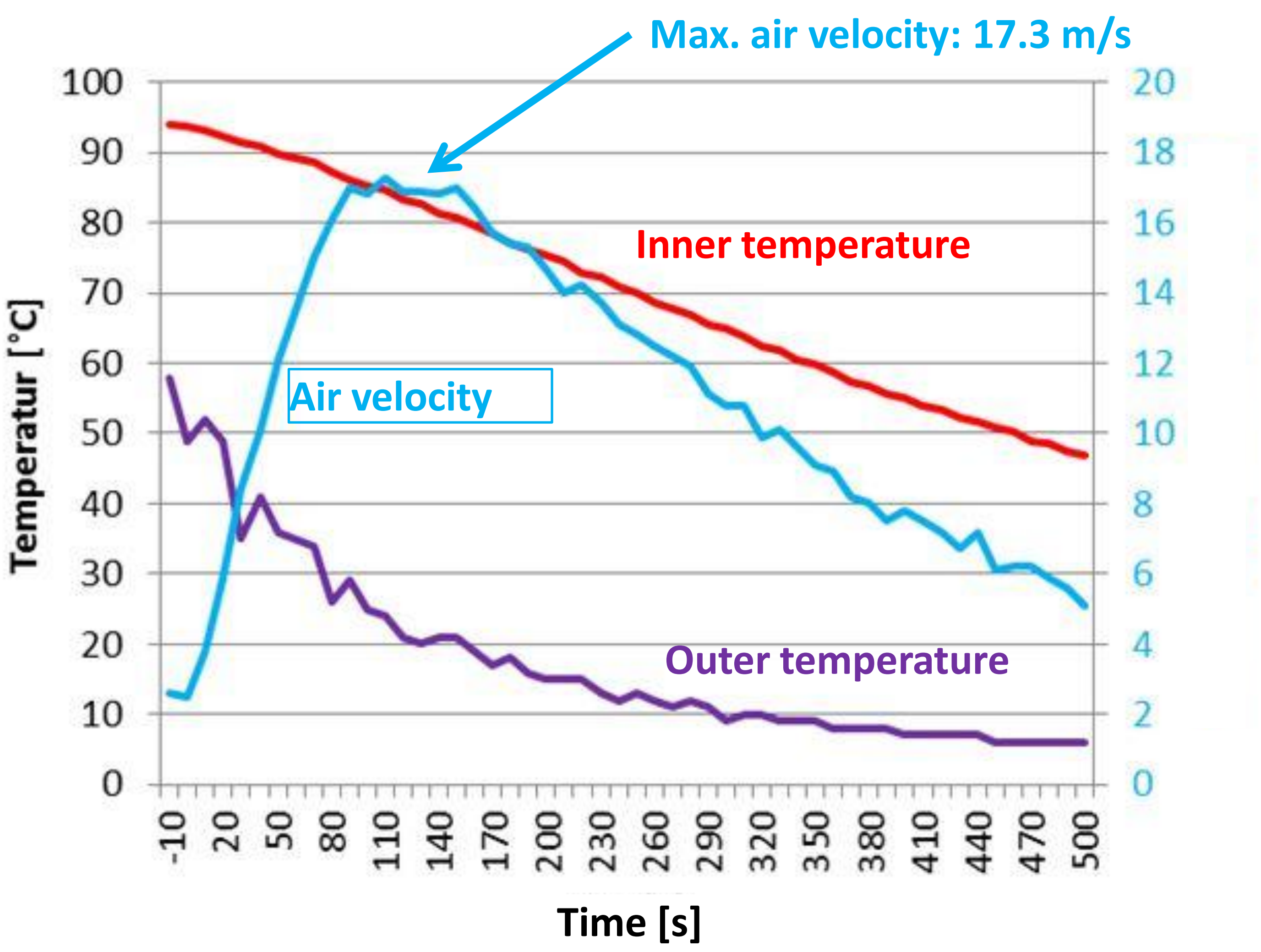
PROTEGO® Initial test / Temperature profiles and inbreathing velocity



Ambient air temperature: 12°C

Barometric pressure: 1.006 bar

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Conclusions about the available data

- Besides ISO 28300 (API 2000), PTB and Höchst models enjoy wide acceptance
- Models have been validated for either gassy or laboratory size tanks
- The tanks are considered as uninsulated and the impact of wall thickness is unaccounted
- Some models predict the maximum inbreathing load occurring as soon as rain falls, while others assume it occurring later on
- Models often rely heavily on simplified assumptions for heat transfer coefficients, see f. i. constant temperature – independent convection coefficients
- Furthermore, most models use convection heat transfer coefficients derived for small diameter piping systems to tanks.
- Inner tank vapor condensation mechanism is usually neglected (Nucleation)

Future work / Targets for future research

- Measurements will be started with small tanks: test tank (4.3 m^2) to API 12F (62 m^2)
- Measurements with hot air, ethanol, methanol
- Filling levels: 10%, 50%, 75%, 90%
- Natural precipitation or water pouring with hoses
- Modeling product condensation (nucleation models), tank wall thickness and insulation

These are our ideas!
We are open for suggestions, critics and inputs

Work in Progress / Roadmap

- 10th European Congress Chemical Engineering, www.ecce.eu
  27. Sept. – 01. Oct. 2015, Nice, France, accepted paper

- DIERS Fall 2015 Meeting,
  05. – 07. Oct. 2015, Houston, TX, USA

- Loss Prevention Conference 2016, www.wp-lossprevention.eu
  05. – 08. June 2016, Freiburg, Germany, accepted paper

- DIERS Spring 2016, tbd

Thank you very much for your kind attention!