

New acoustic method for relative humidity measurement demonstrated in a dairy

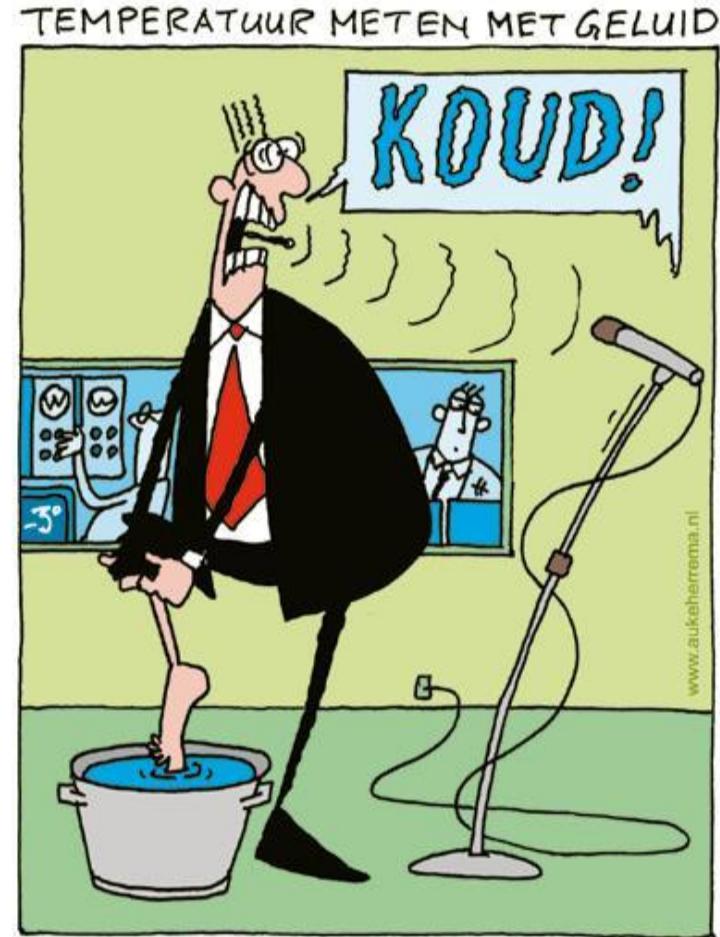
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Acoustics

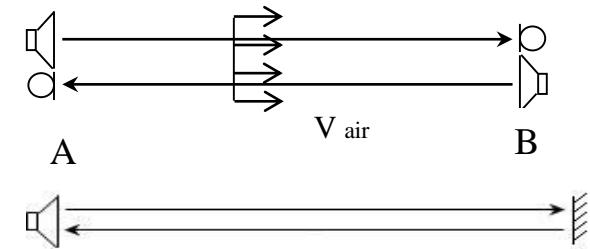
- Acoustic RH measurements
 - Accurate
 - Fast response time
 - Insensitive to dust, contamination
 - higher temperature =>
 - > higher speed of sound
 - > RH lines big difference
 - Combination with flow
- Behaviour air like syrup
- Instantaneous measurement



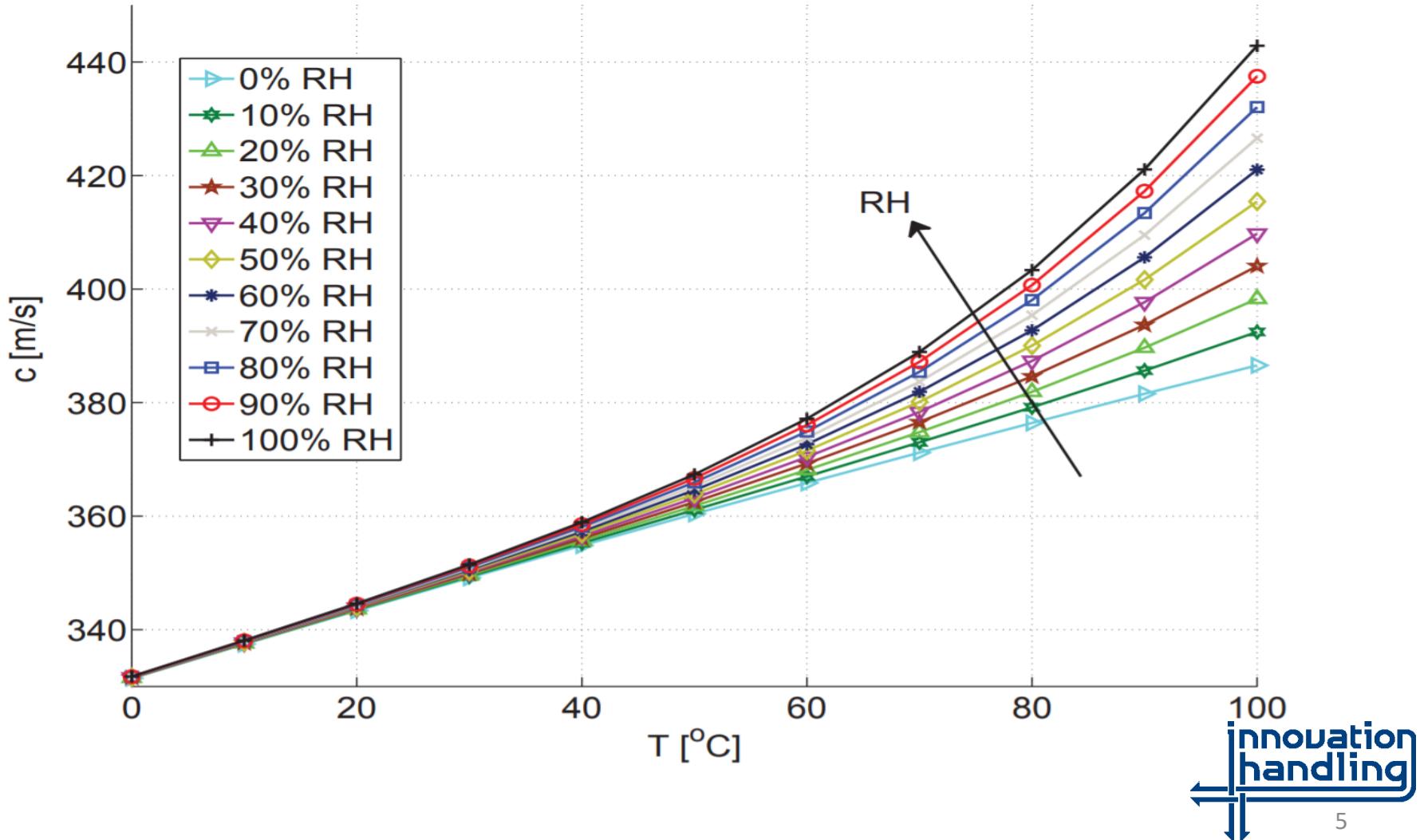
Characteristics-1

- Speed of sound depends on
 - temperature
 - humidity of air
- **Line** instead of **point** measurements
- Real time measurement (340 m/s)
- Air speed and direction determined from
distance and time difference
 $v = |AB| / (t_{AB} - t_{BA})$

$$c \approx \sqrt{\frac{\gamma RT}{M}}$$



Speed of sound



Characteristics-2

- RH measurements by acoustics
 - Higher temperatures more sensitive RH measurement
 - Cramer t < 30 °C; calibration needed t > 30°C
 - Calibration at t < 120 °C and 100 kPa
 - Calibration at t > 120 °C and P > 100 kPa

- ***Evaporation*** ⇒ psychrometer ⇒ thermal effect
 - $\Delta T \Rightarrow T_{\text{wet bulb}} + T_{\text{dry bulb}}$
- ***Diffusion*** ⇒ impedance ⇒ ϵ_r permittivity, ⇒
 - Z sensor + T_{air}
 - diffusion of H_2O or O_2 in material as capacitive sensor and λ probe
- ***Condensation*** ⇒ dew point mirror ⇒ thermal effect
 - $T_{\text{dewpoint}} + T_{\text{air}}$

Bulk oriented

principles humidity measurements

- *light* \Rightarrow *absorption spectrum* \Rightarrow Laser (TDLAS)
- *acoustic wave* \Rightarrow speed of sound + T_{air}

Apps with sound

- Physical properties for practical applications
 - *Measurements in fluids and gases*
 - Pervaporation, 2D and 3D temperature and flow, tomography
 - *Simple quantity combination results*
 - Temperature, humidity, velocity, density, flow, energy
 - *Complex quantity combination results*
 - Physical properties combined with data processing like tomography
 - Temperature, energy flow distributions, spatial temperature mapping as stratification

Apps-

- **Practical applications** need simultaneous processing of more quantities
- **Energy balance** => RH, T, flow => possible with acoustic technology

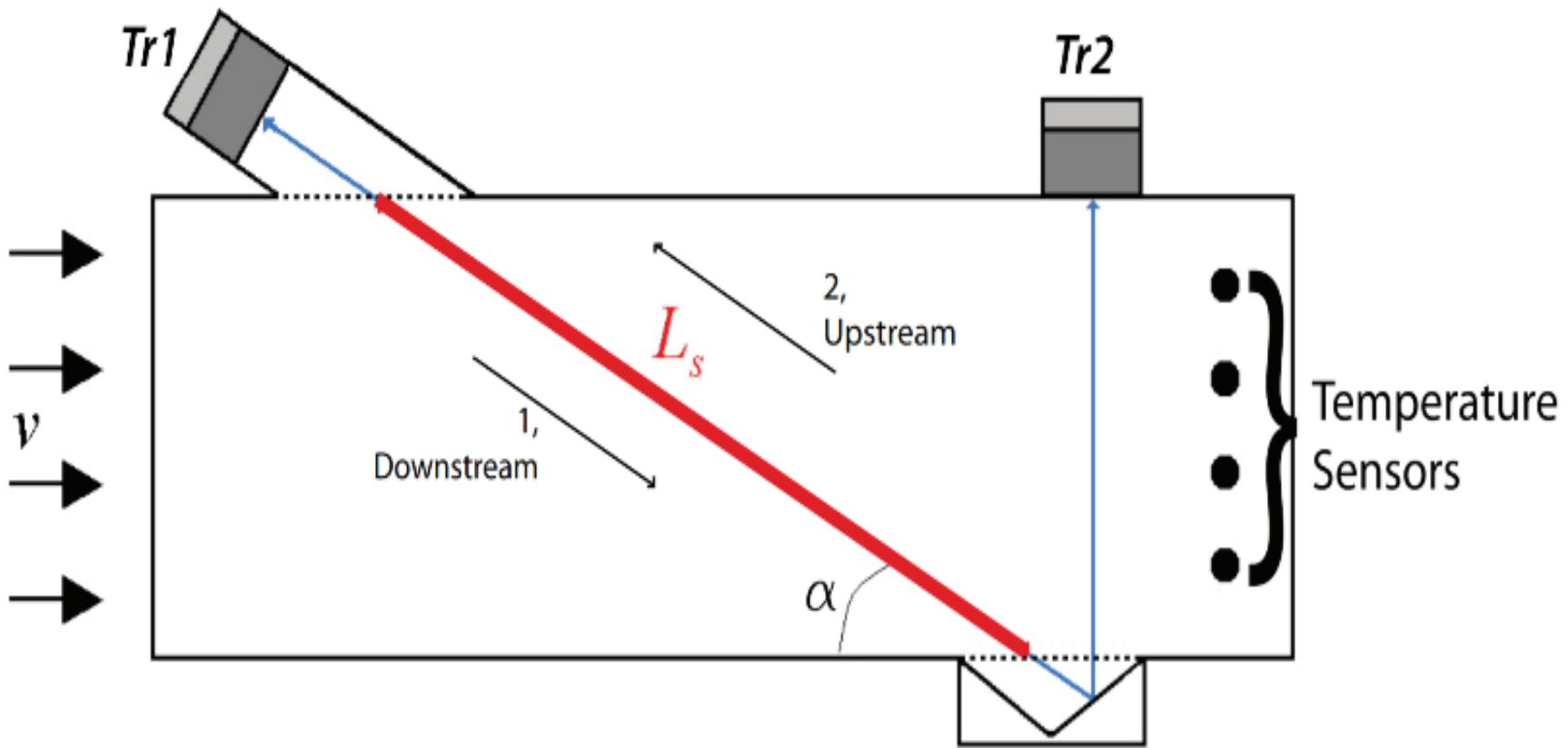
Relations

- Some relations
- $P_{atm} = \sum p_i$ Dalton
- $c = f(M_{Dalton}, p, T)$; wave propagation; absolute humidity
- Relation
 - O. Cramer $C_0 = \dots$ Isentropic no external heat exchange,
- Explicit multiparameter formula; relative humidity
 - Measure the speed of sound and temperature
 - Given C & T => AH (\Rightarrow RH)

Example

- 25°C 100% RH,
 $20 \text{ [g/kg]} \Rightarrow 20/1000$
 $\Rightarrow 2\% \text{ mass fraction H}_2\text{O}$
- 14 °C 100% RH,
 10 [g/kg]
 $\Rightarrow 1 \% \text{ mass fraction H}_2\text{O}$

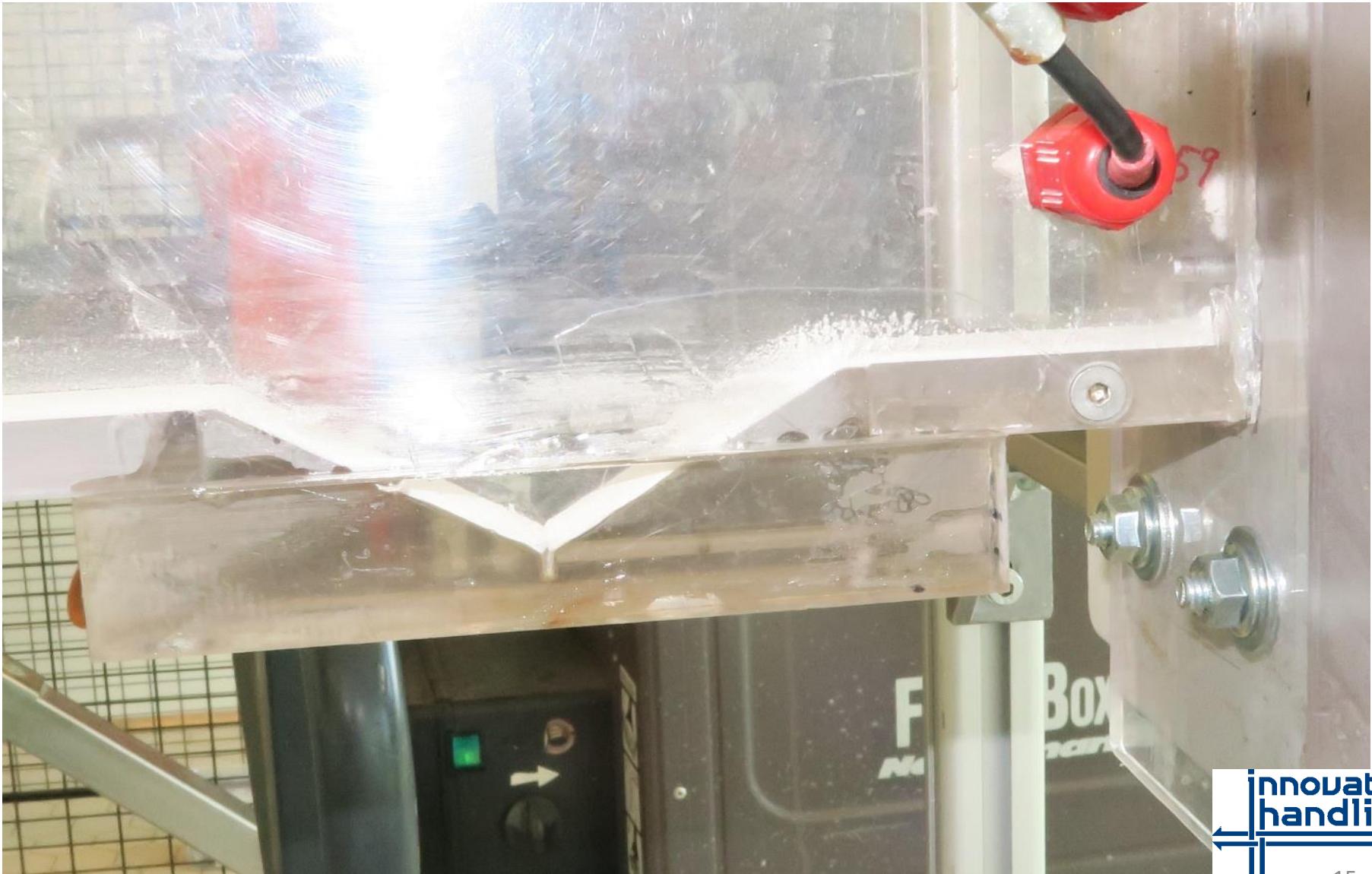
Test device



Applicability acoustics

- Reliable method, time t and temperature T
- Complex method, highest accuracies possible
- Candidate for fast humidity calibrations
- Insensitive to dust, contamination, chemicals
- Intermediate and higher temperatures
- Increasing sensitivity at higher temperatures
- Supersaturation
- Calibration at any temperature with generator
- ATEX and CIP
- Derived quantities as flow and energy balance

Test device









Results

- Test in spray dryer
- Process parameters:
 - accurate measurement of air flow from dryer
 - Temperature 50 – 100 °C
 - RH 25% - 4.5%

Speed of air V [m/s]

