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New acoustic method for relative humidity measurement demonstrated in a dairy

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- Applications
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Acoustics

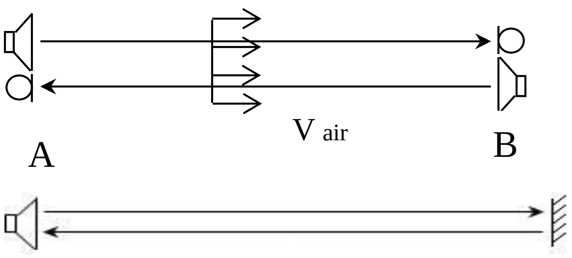
- Acoustic RH measurements
  - Accurate
  - Fast response time
  - Insensitive to dust, contamination
  - higher temperature =>
-> higher speed of sound
-> RH lines big difference
  - Combination with flow
- Behaviour air like syrup
- Instantaneous measurement

Characteristics-1

- Speed of sound depends on
  - temperature
  - humidity of air

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

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



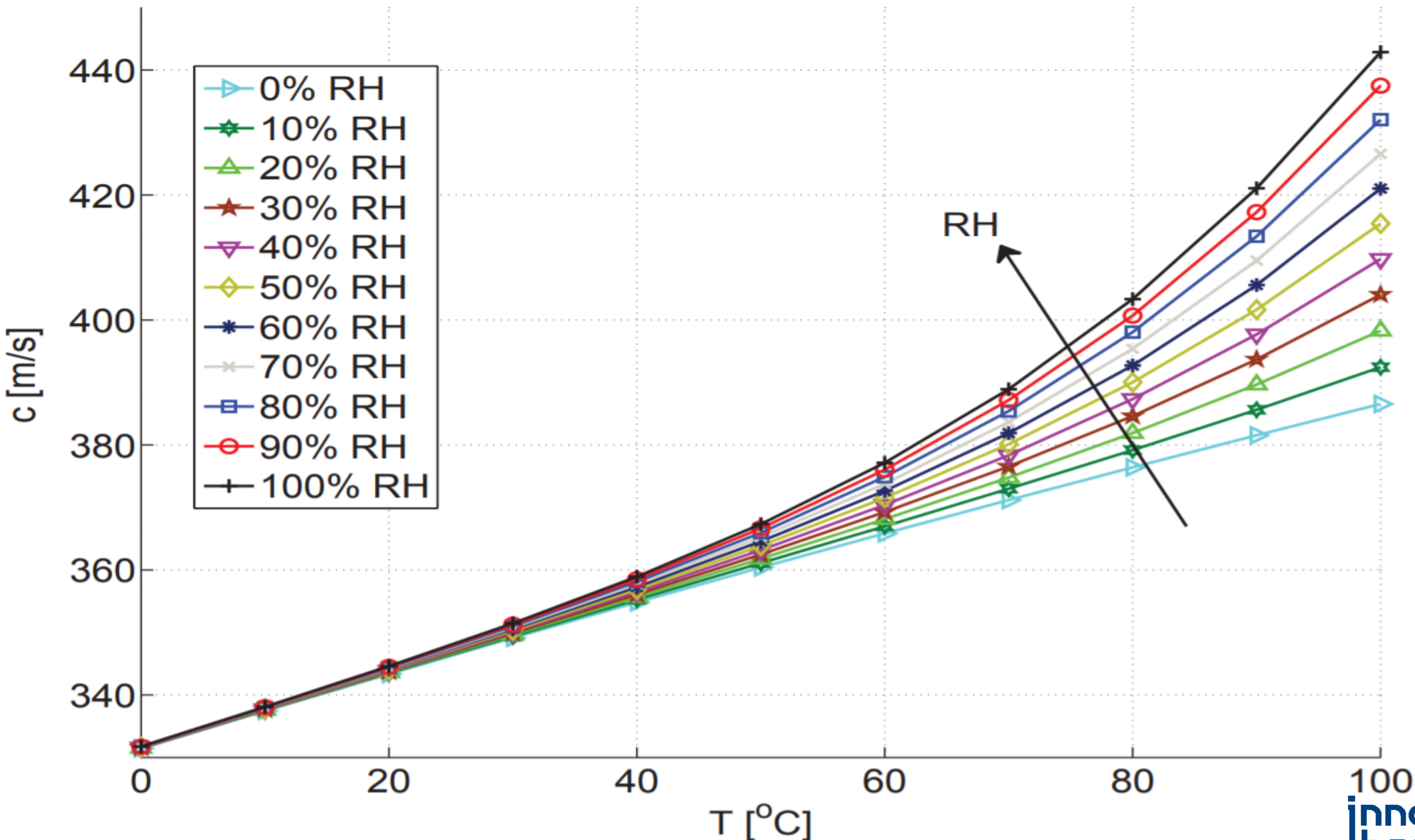
Principles humidity measurements

Surface oriented	Bulk oriented
Psychrometer Evaporation Thermal effect $\Delta T \Rightarrow T_{wet\ bulb} + T_{dry\ bulb}$	**Laser (TDLAS)** *Light ⇒ absorption spectrum*
Impedance sensor *Diffusion* ⇒ impedance ⇒ ε_r permittivity, ⇒ Z sensor + T_{air} diffusion of H_2O or O_2 in material as capacitive sensor and λ probe	**Acoustic wave (HumiTemp)** Speed of sound + T_{air} $C = F(\text{time}, \ell, T_{air})$
Dew point mirror *Condensation* ⇒ dew point mirror ⇒ thermal effect $T_{dewpoint} + T_{air}$	

Relations

- $P_{atm} = \sum p_i$ $(P_{N_2} + P_{O_2} + P_{CO_2} + \ldots + P_{H_2O})$ Dalton's law
- c = f (M, p, T); wave propagation; absolute humidity
- O. Cramer C_0 = …. Isentropic, zero frequency no heat exchange
- Explicit multi-parameter formula; relative humidity
  - Measure the speed of sound and temperature
  - Given C & T => X_w (=> RH)

Speed of sound



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Characteristics-2

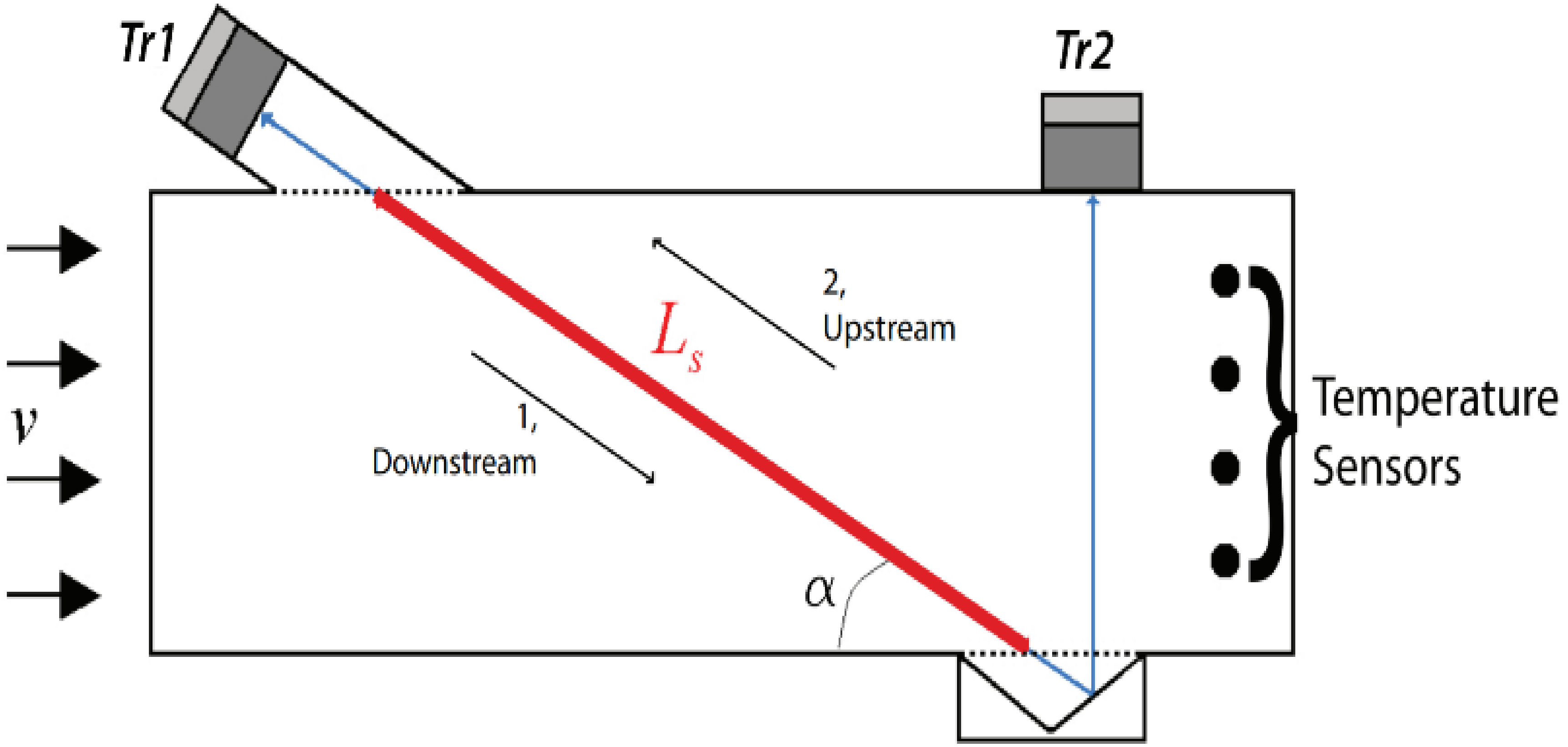
- RH measurements by acoustics
  - Higher temperatures, more sensitive RH measurement
  - Cramer formula valid between $0 \leq t \leq 30$ °C
    calibration needed $t > 30$°C
  - Calibration at: $t < 120$ °C and 100 kPa
  - Calibration at: $t > 120$ °C and $P > 100$ kPa

Applications 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
- Practical applications need simultaneous processing of more quantities
- Energy balance => RH, T, flow =>

  possible with acoustic technology

Test device



Acoustics

- Reliable method, time ***t*** and temperature ***T***
- New complex method, highest accuracies possible
- Candidate for fast humidity calibrations
- Insensitive to dust, contamination, chemicals
- Intermediate and higher temperatures
- Increasing sensitivity at higher temperatures
- Super saturation and condensation
- Derived quantities as flow and energy balance

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Test device

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HIT

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innovation handling

Results

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

HIT

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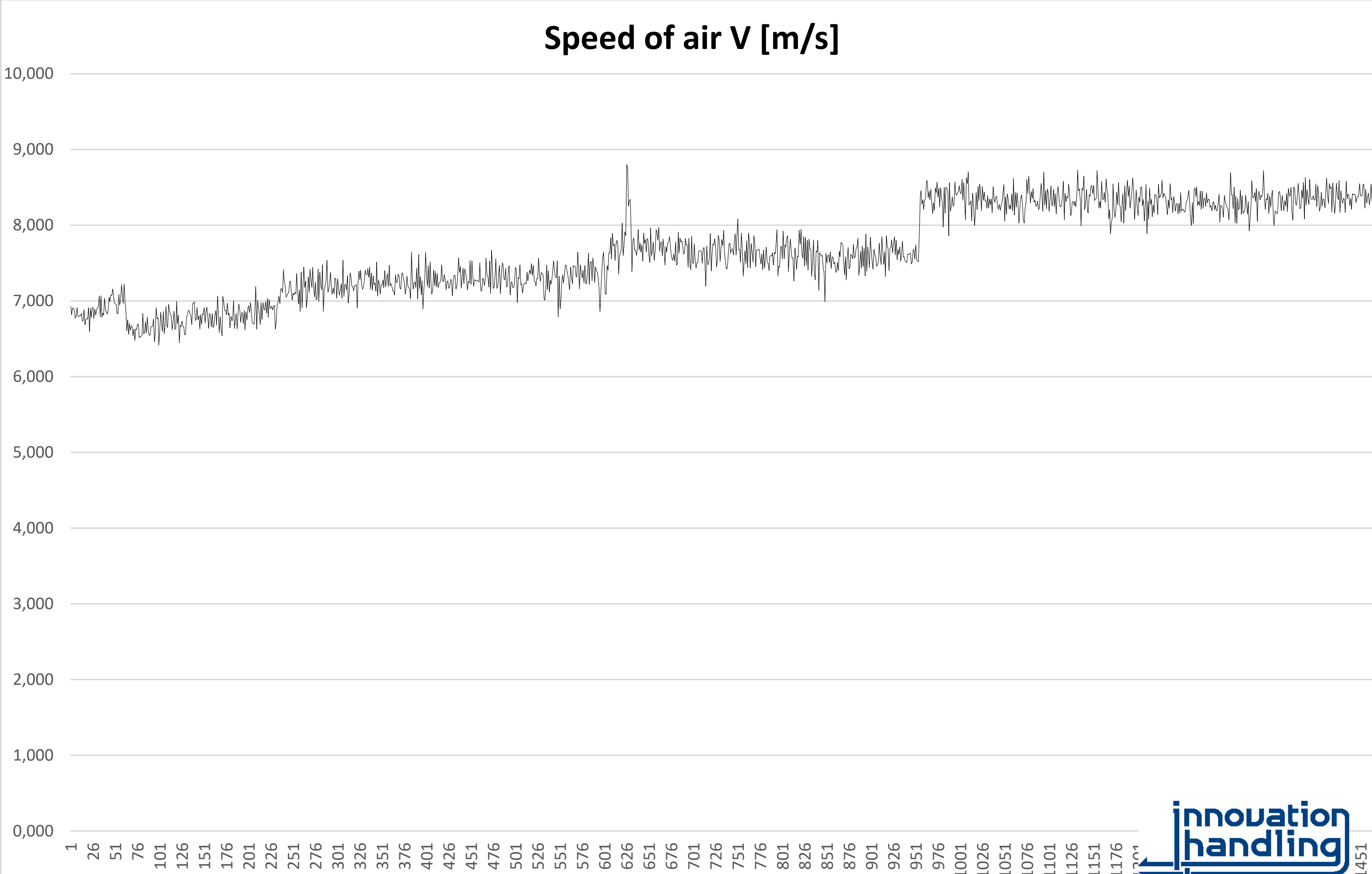

innovation handling

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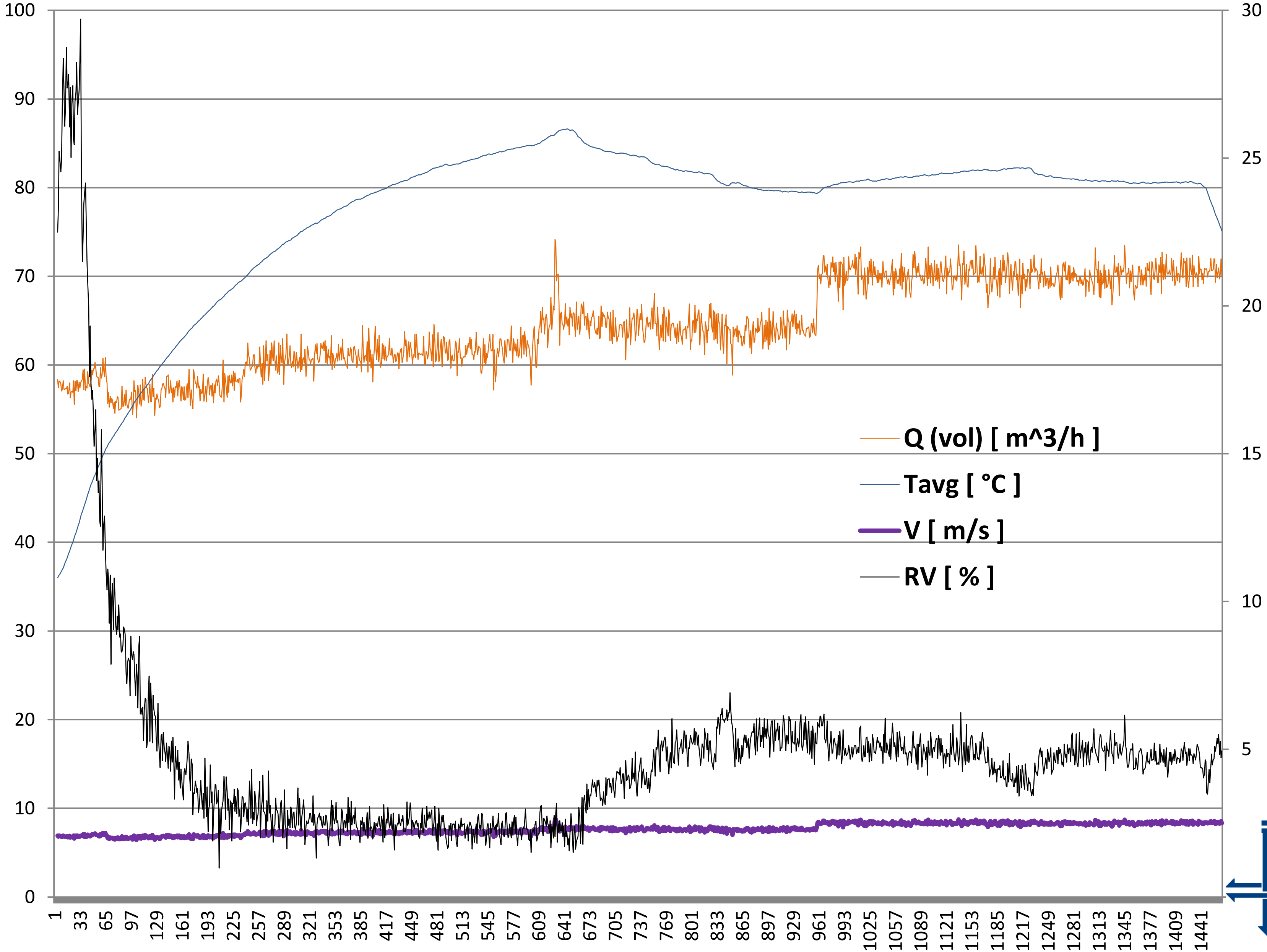

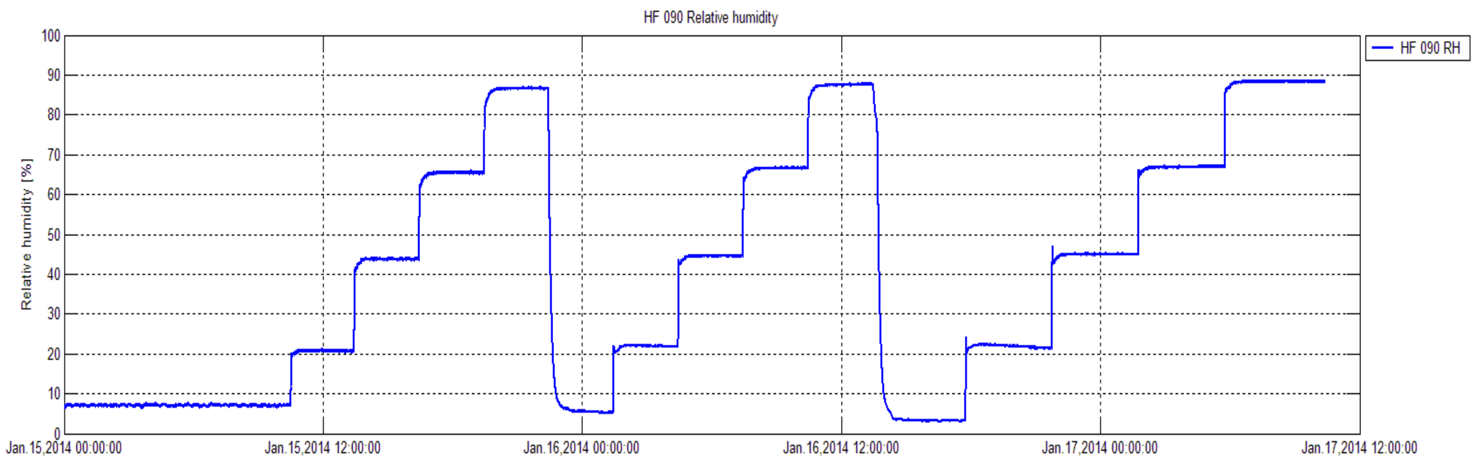

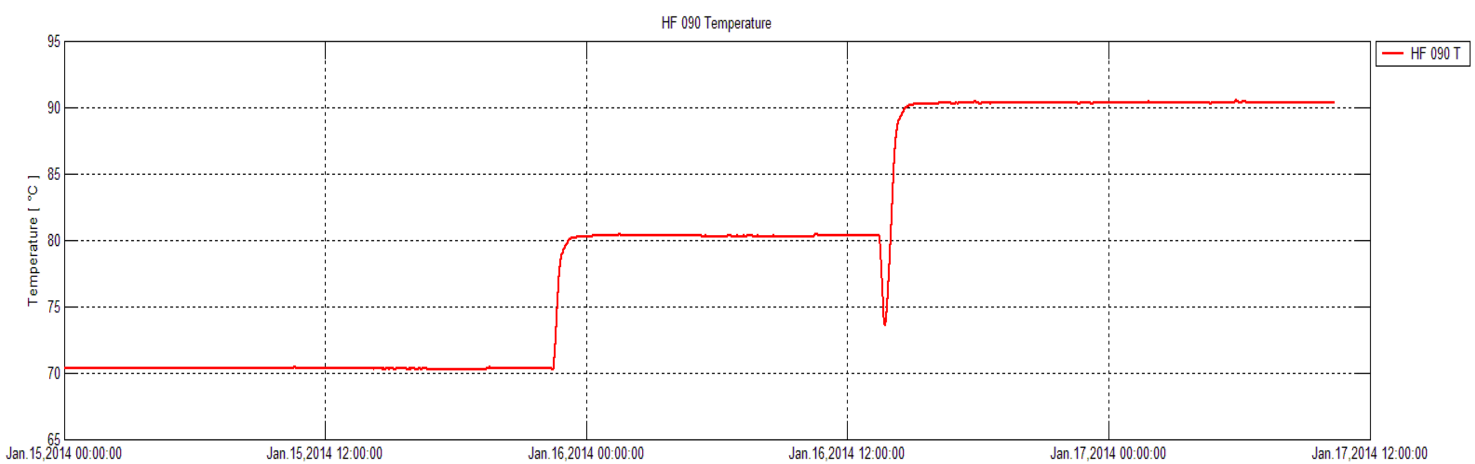

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