Near-infrared product moisture sensors: Cost-effective and ultra-compact technology for inline monitoring

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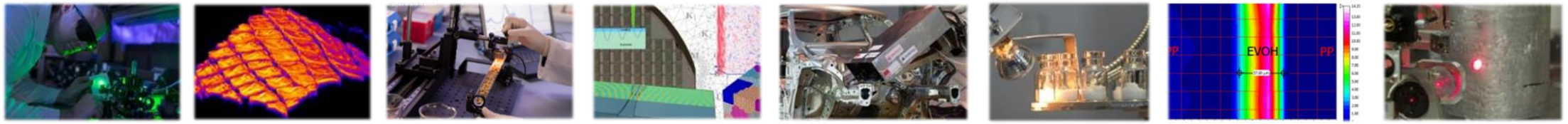


Introduction

- Research project: **EDDY – Enhanced Drying**
  - Cost-effective sensors for inline process analysis combined with advanced numerical models to enable energy efficient drying processes
  - Use of renewable energy sources (e.g. heat pumps)

- **Drying process**
  - Most **wide-spread process** in industry
  - **12-25%** of industrial energy consumption
  - Predominantly relying on **fossil fuels**
  - Processes are carried out without actual knowledge about moisture
  - Fluctuation of the drying process due to weather conditions

- **Benefits of (inline) product moisture measurements:**
  - **Save energy** by optimizing drying processes and avoiding over-drying
  - **Avoid mold** induced spoilage due to increased moisture
  - **Strong economic factor** due to the trading according to **product weight**
  - **Ensure high product purity and quality**
  - **No errors during sample collection** (samples stay in process instead of transferring them to laboratory)

How to Measure Product Moisture – State of the Art

- Moisture is mostly determined **offline using gravimetric measurements** (moisture balance)

  → **No possibility for real-time measurement**

  → **No process control possible**

moisture balances

- Inline-capable alternatives are often based on **measurement of dielectric properties**

  – **Sensor needs to be in close vicinity of the sample**

→ **often not possible or desirable**

FDR moisture sensor

radar-based moisture sensor

capacitive moisture sensor

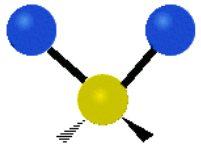
NIR-based Product Moisture Measurement

- Moisture can also be measured using **near-infrared (NIR) spectroscopy**

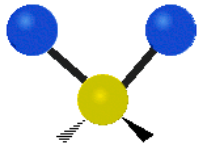
→ Strong **absorption of water in NIR** is exploited to measure water content

Fundamental vibrations of the H_2O-Molecule:

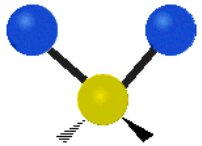
ν_1 O-H symmetric stretching

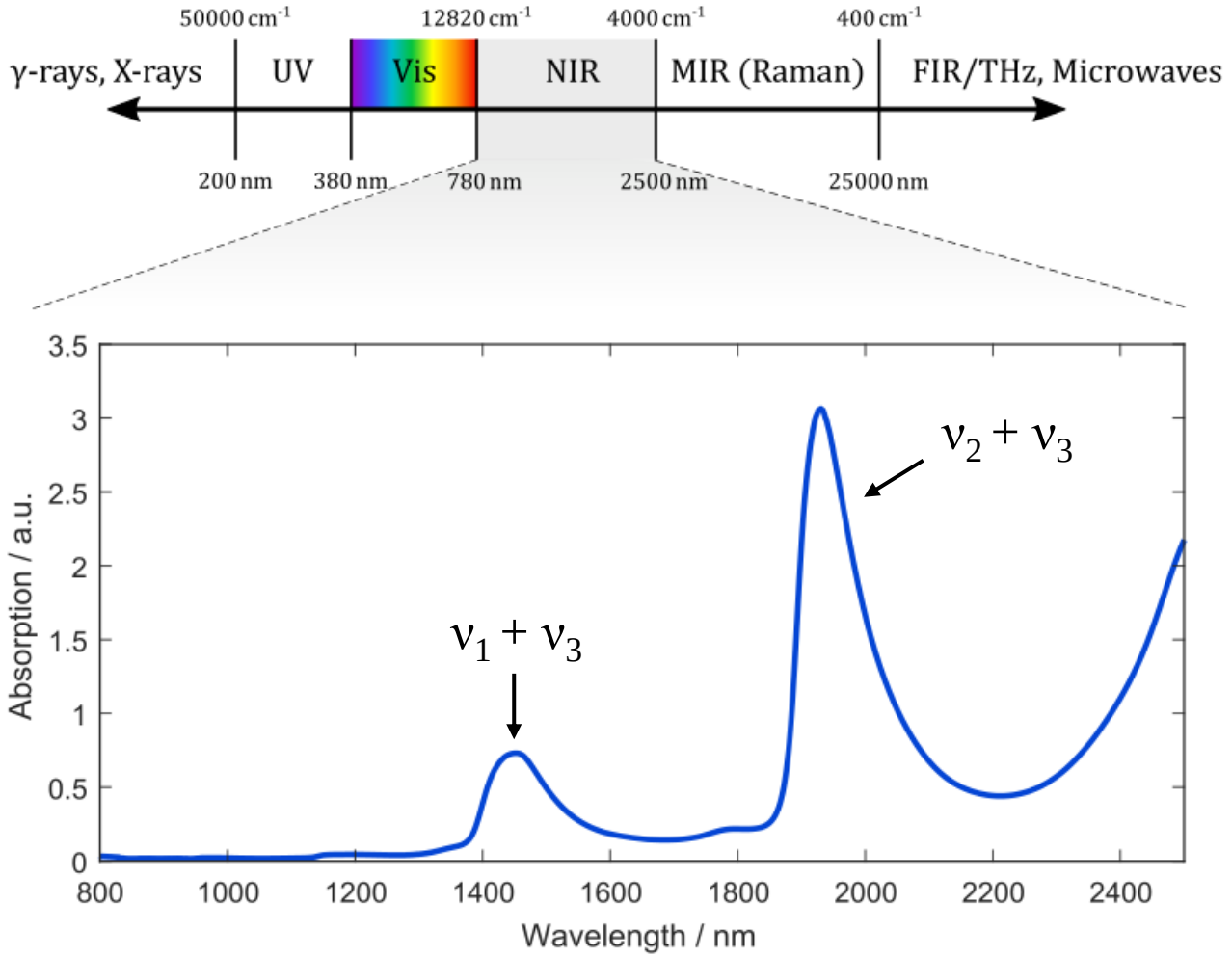


ν_2 H-O-H bending



ν_3 O-H asymmetric stretching

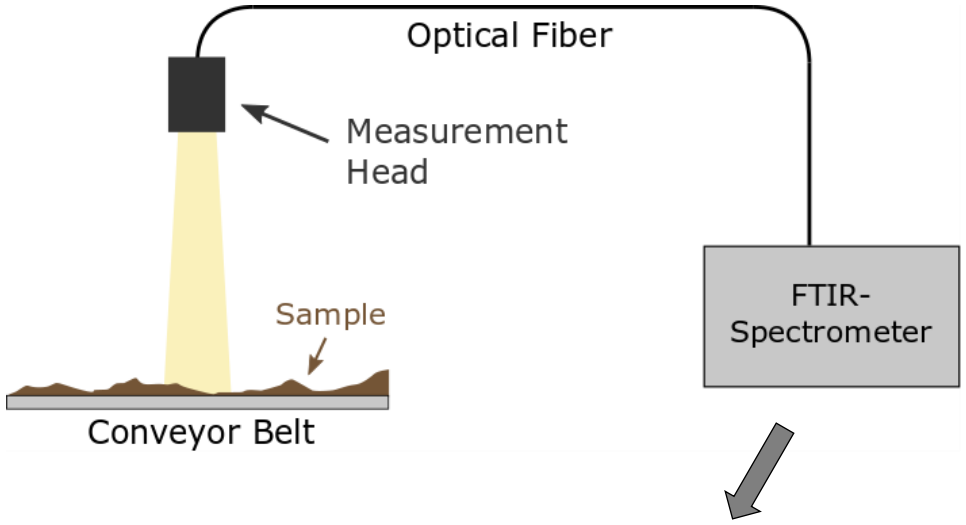




NIR-based Product Moisture Measurement – Setup

- Moisture can also be measured using **near-infrared (NIR) spectroscopy**

- Light source (halogen) is used to **illuminate sample**
- **Reflected light is collected** and spectrally resolved
- Collected **spectrum is analyzed** to get moisture value (machine learning)

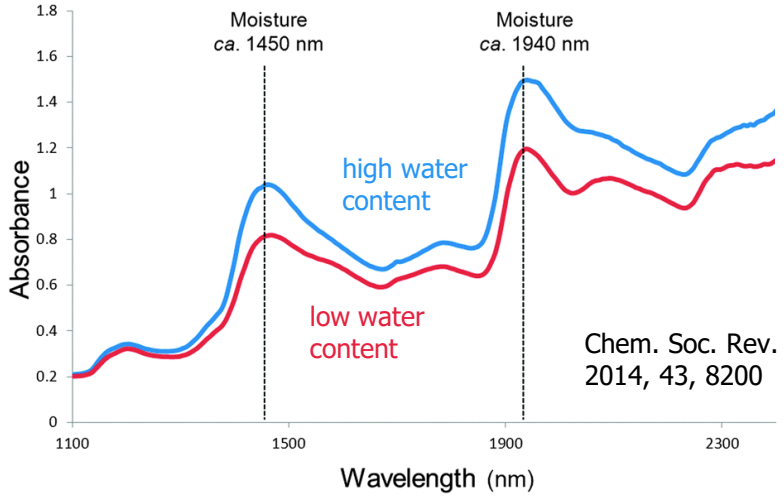


→ **Large measurement distances are possible**

→ **Real-time capable**

→ **Automated measurements**

→ **Additional information can also be extracted** from spectra (protein content, fat content, ash content, …)



Chem. Soc. Rev. 2014, 43, 8200

Conventional NIR-Spectrometers vs. MOEMS-based

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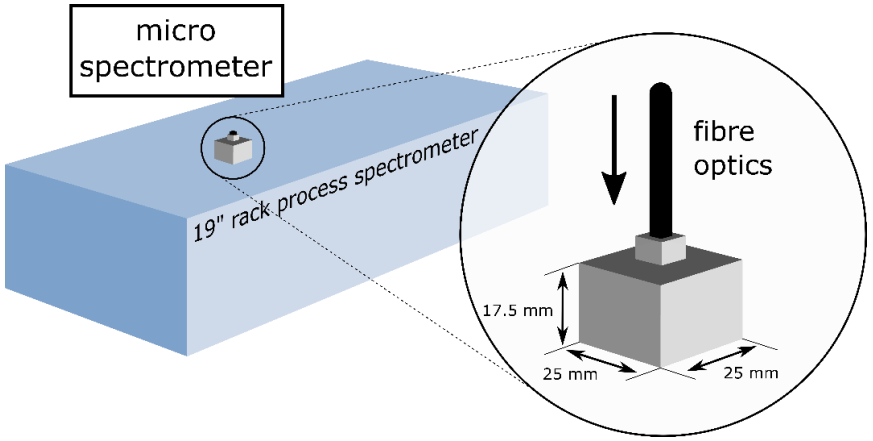
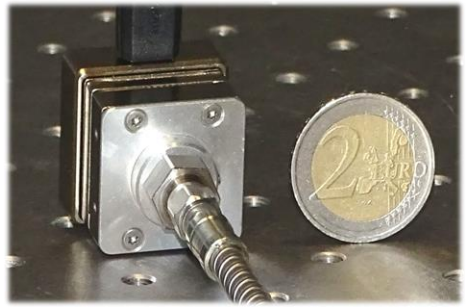
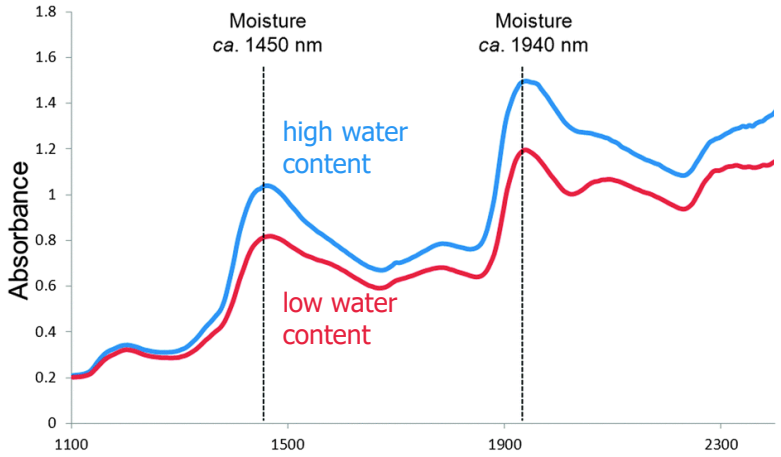
- **Conventional NIR-Spectrometers**
  - Sensitive and broadband
  - Rather expensive (typically >40 k€)
  - Sensitivity to vibrations due to moving parts





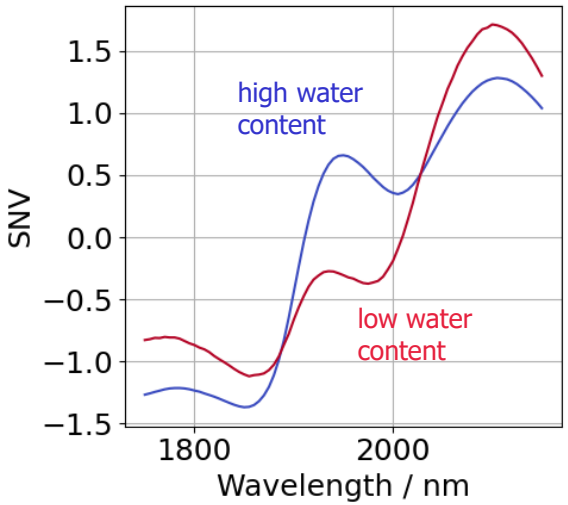
- **MOEMS-based NIR-Spectrometers**
  - Higher **cost efficiency** / lower price (>3 k€)
  - More **compact** hardware
  - Higher ruggedness / **less maintenance**
  - **Narrowband** (Different modules available)

Conventional NIR-Spectrum



Chem. Soc. Rev. 2014, 43, 8200

MOEMS NIR-Spectrum

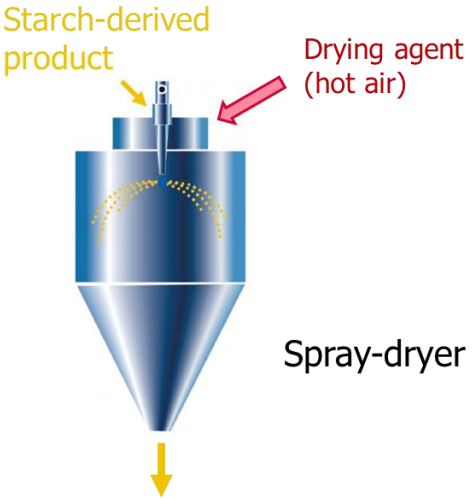


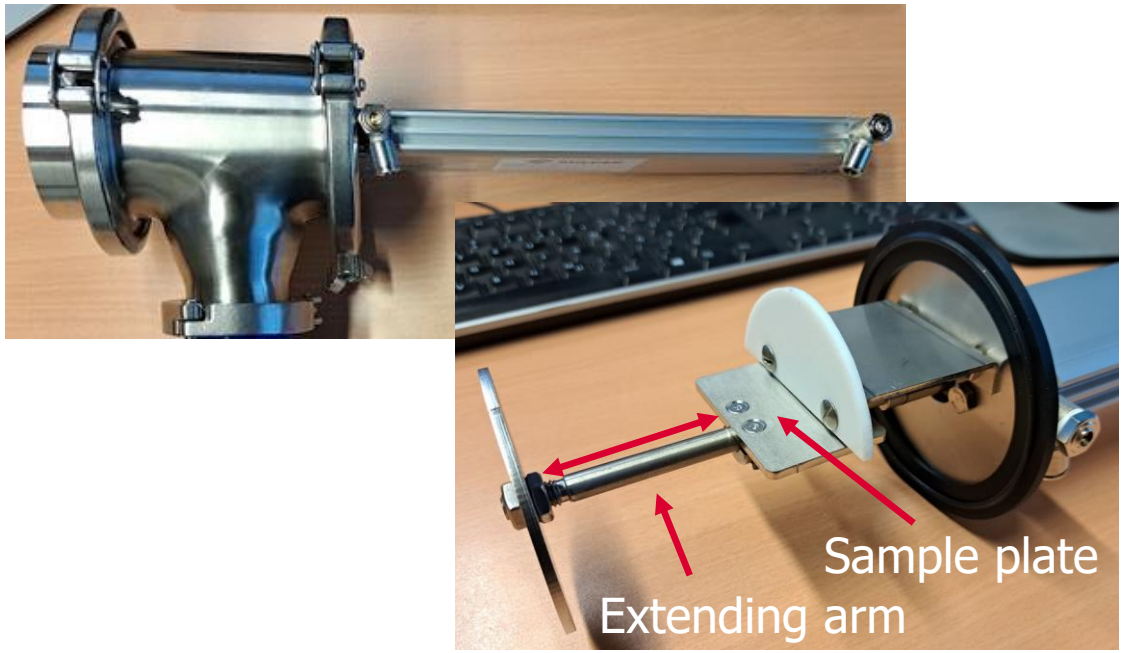
MOEMS … Micro-Opto-Electro-Mechanical Systems

Use Case #1: AGRANA Stärke GmbH

- Austria's only potato starch factory
  - Gmünd, Lower Austria
- Starch is processed into:
  - **Maltodextrin**
  - **Glucose syrups**
- Used in:
  - Mashed potatoes
  - Pudding
  - Carrier in pharma industry
  - Bio-based polymers
  - Adhesives and construction additives
  - Etc.
- Spray drying
  - Gentle drying process
- Product is sampled by an automated plate sampler
- Dropped into sample chamber for subsequent analysis

Automated plate sampler (side view)

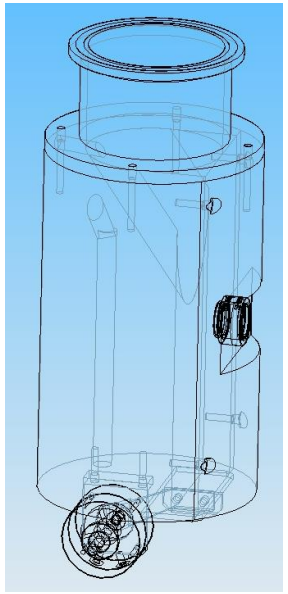


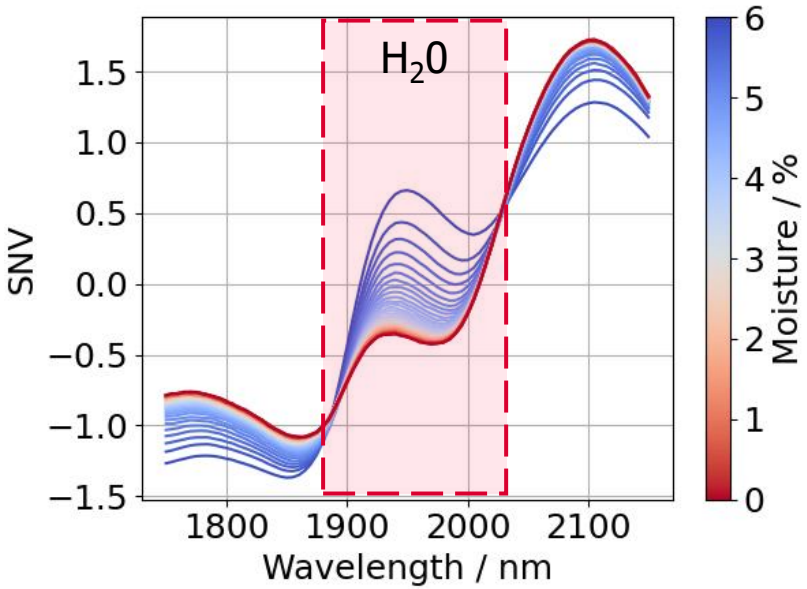


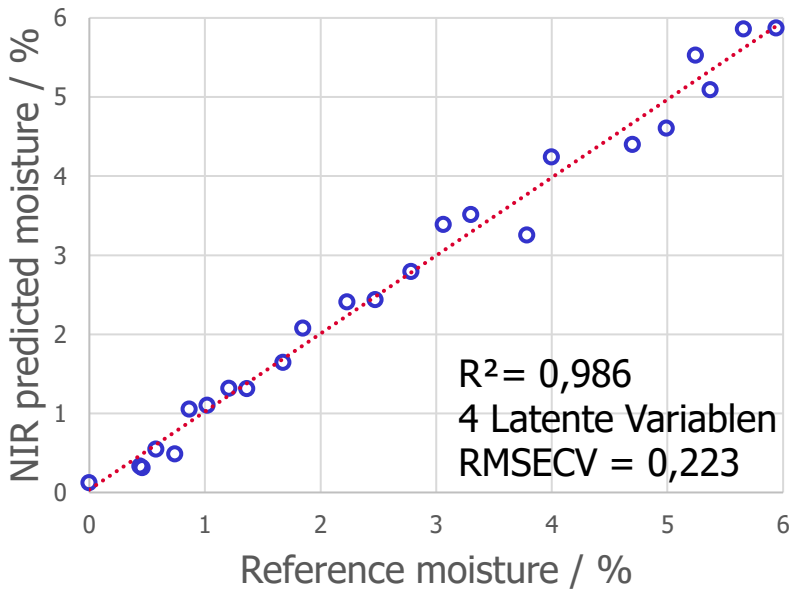
Inside of the automated plate sampler

Sample Chamber

- Sample is dropped into the chamber
- Multi-mode optical fiber
  - Illumination and collection of reflected light
- Ex protection zone
  - Mechanical parts are pneumatic
  - Spectrometer and light source are placed outside
- Sample is sticky
  - Chamber is flushed with pressured air



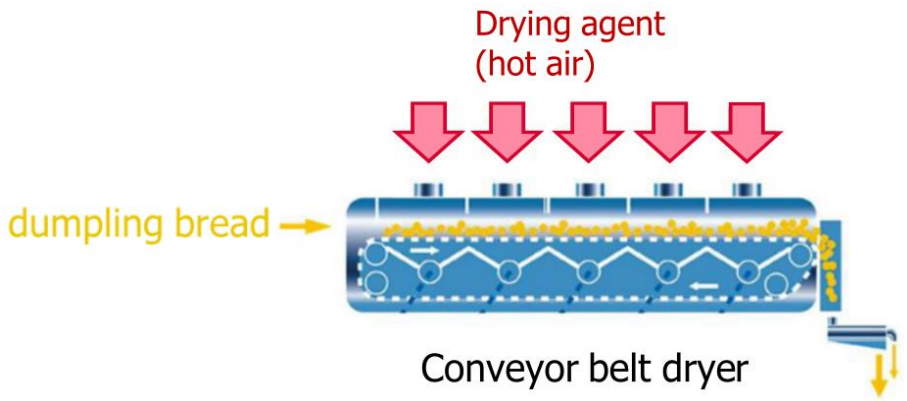




RMSECV…Root Mean Square Error Cross-Validation

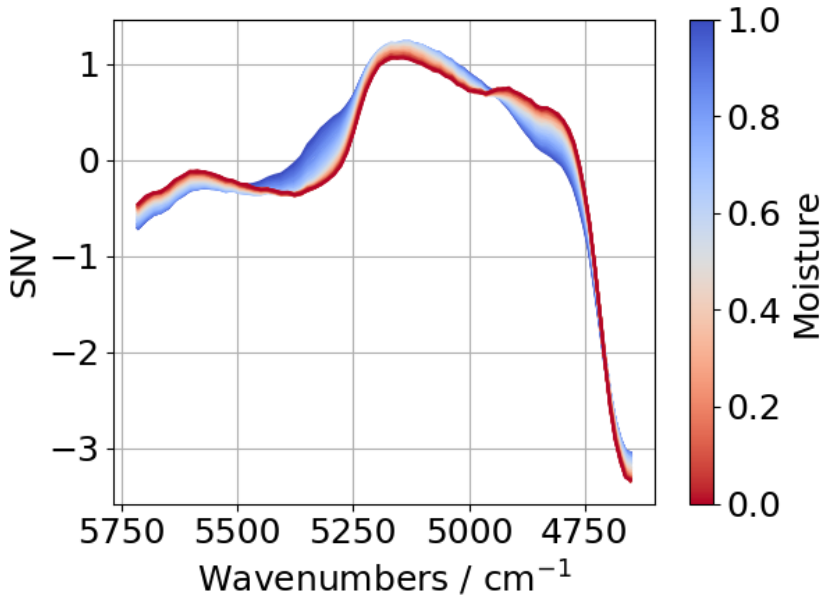
Use Case #2: Fischer Brot GmbH

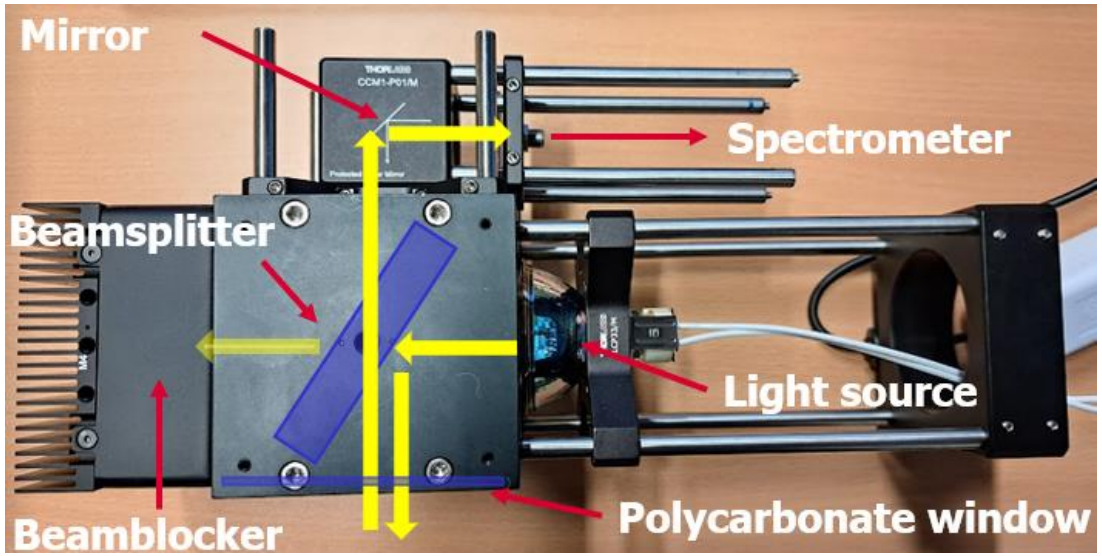
- 14,000 tonnes of bakery products annually
- 100 different products
  - Bread
  - Pastry
  - **Dumplings and breadcrumbs**
- Freshly baked buns are aged and cut into dumplings
- Conveyor belt dryer
  - Energy Source: Natural Gas
- Development of reflection measurement head



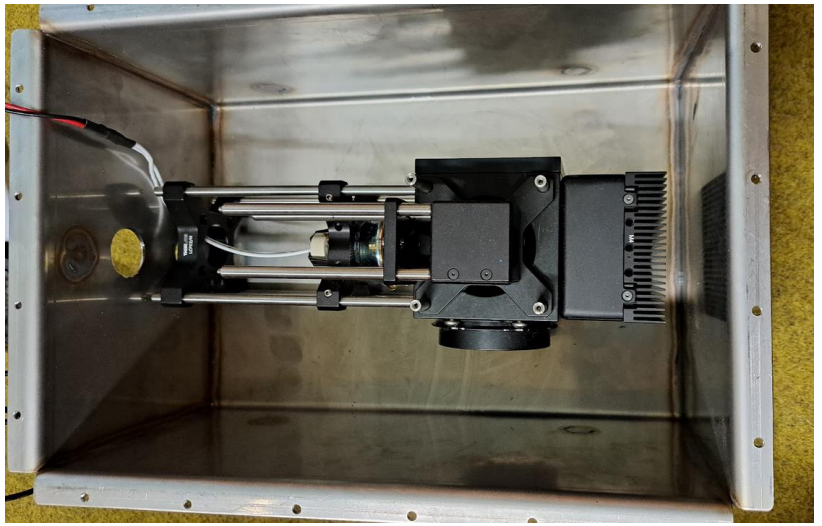
Reflection measurement head

- Conveyor belt is enclosed
  - High temperatures and dust inside the dryer
- Limited Space
  - Several conveyor belts stacked on top of each other
  - Product runs through the dryer in a snake route
- Optical parts out of glas have to be enclosed
  - Reflection measurement head is placed in a stainless steel box
  - Polycarbonate protective window



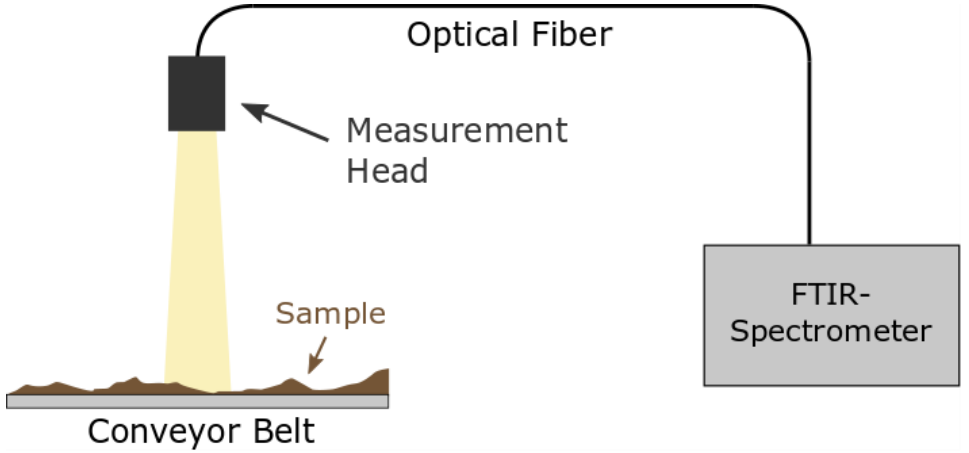


Sample



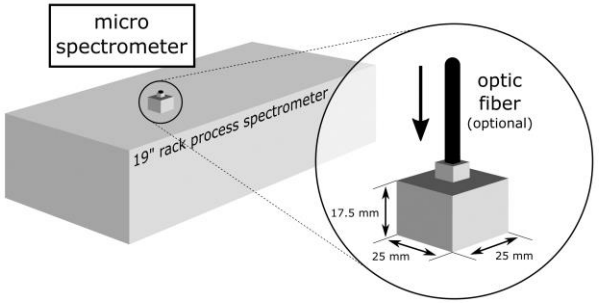
Summary

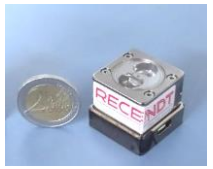
- NIR spectroscopy is a **powerful measurement technique** for moisture measurement
  - → **Inline-capable**
  - → **Automatic and real-time**
  - → **Flexible optical interfaces**
  - → **Non-destructive**



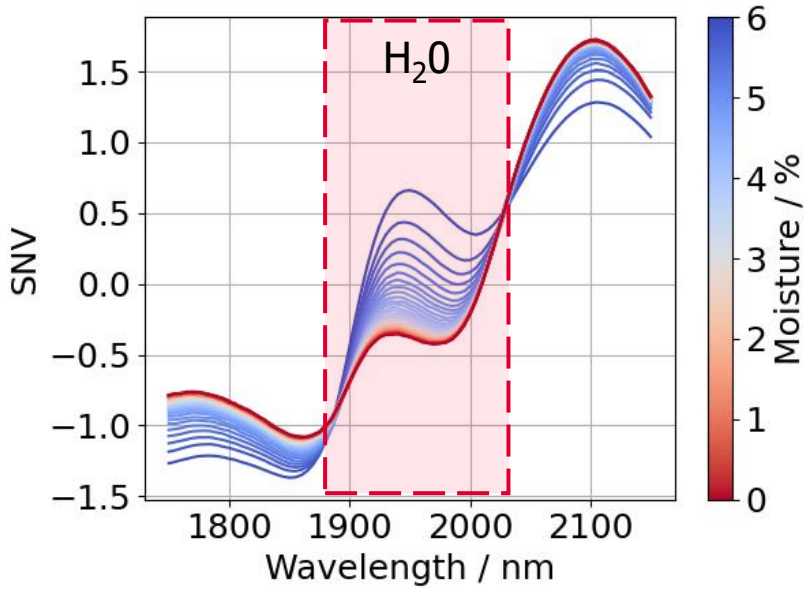
- **Novel MOEMS technology** allows the realization of **cost-efficient** and compact NIR spectrometers

- **Spectral measurement** also allows for **simultaneous determination of additional parameters**
  - Protein, fat, ash content,…





<3 k€



Acknowledgements

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