Accurate contactless moisture measurement based on modern ultra-compact NIR spectrometer technology

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NDT4Industry

Member of UAR INNOVATION NETWORK

upper austria

Importance of Inline Moisture Measurement

- **Moisture of products and raw materials** is of **great importance** in many industrial branches
  - e.g. food-, wood-, paper-, polymer-, chemical, pharmaceutical, …

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

→ Despite the importance of moisture measurements, product moisture is often not well monitored in the industry

How to Measure 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

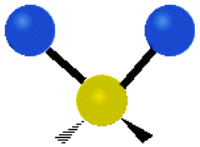
NIR-based Moisture Measurement

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

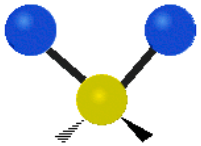
→ Strong **absorption of water in NIR** is exploited to measure water content

Fundamental vibrations of the H_2O-Molecule:

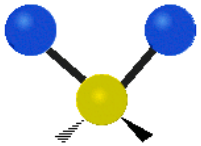
ν_1 O-H symmetric stretching (2734nm)

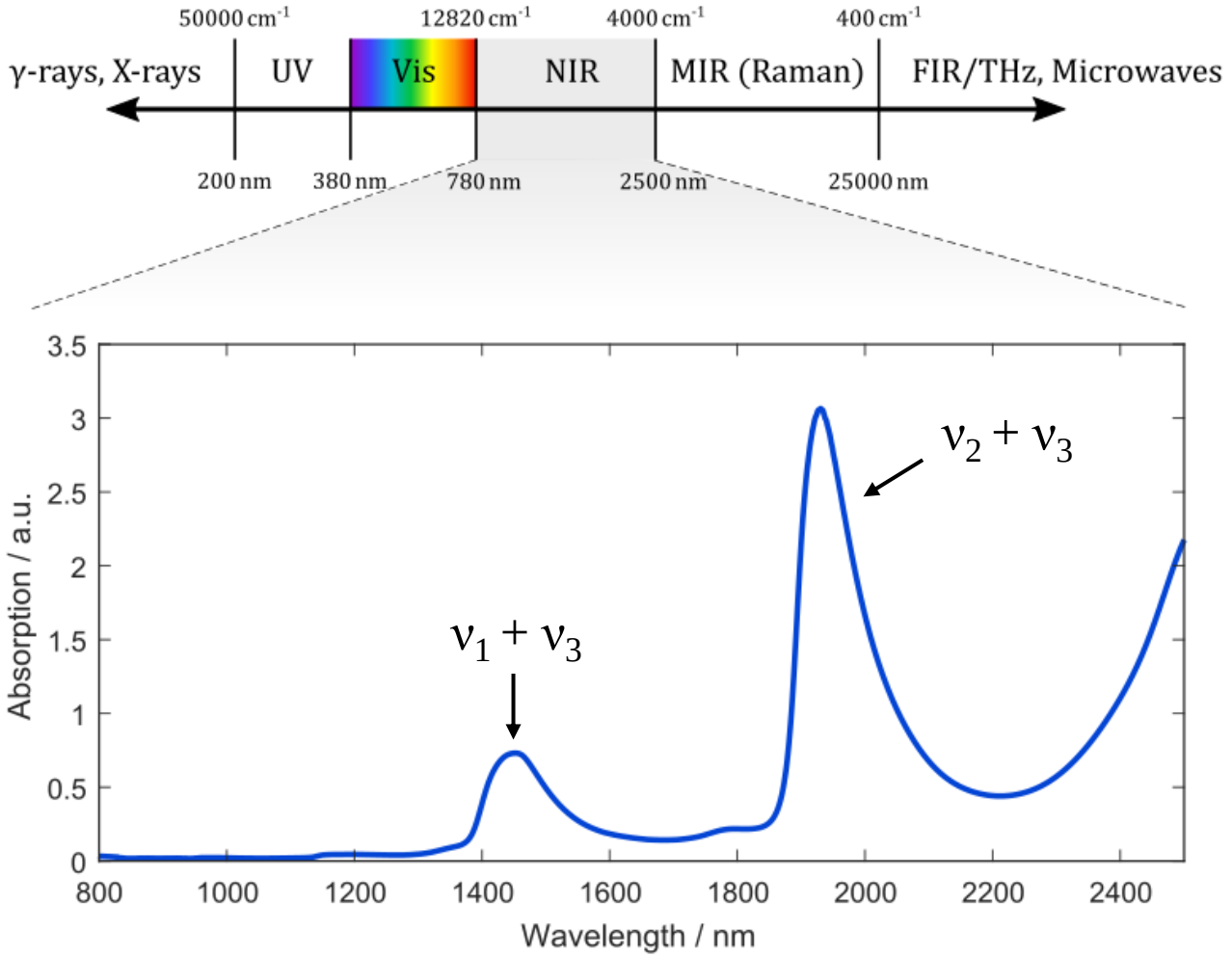


ν_2 H-O-H bending (6269nm)



ν_3 O-H asymmetric stretching (2662nm)

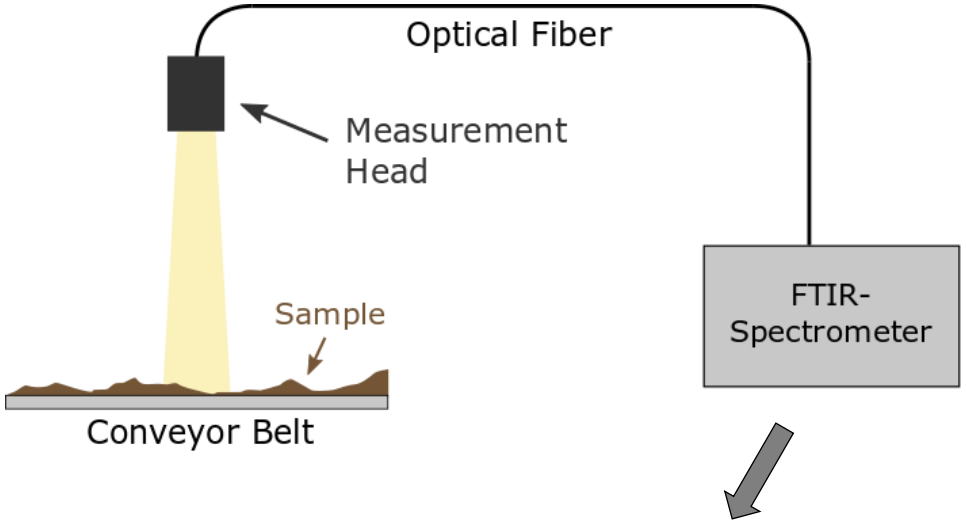




NIR-based Moisture Measurement – Setup

- 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)

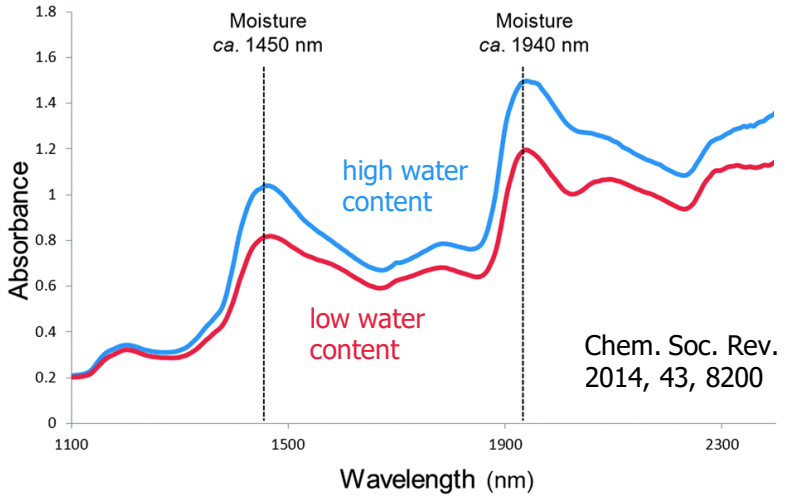


→ **Large measurement distances are possible**

→ **Real-time capable**

→ **Automated measurements**

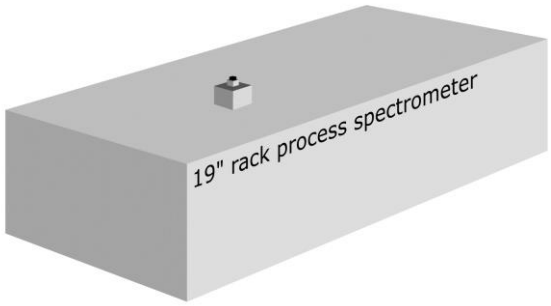
→ **Additional information can also be extracted** from spectra (protein content, fat content, ash content, …)



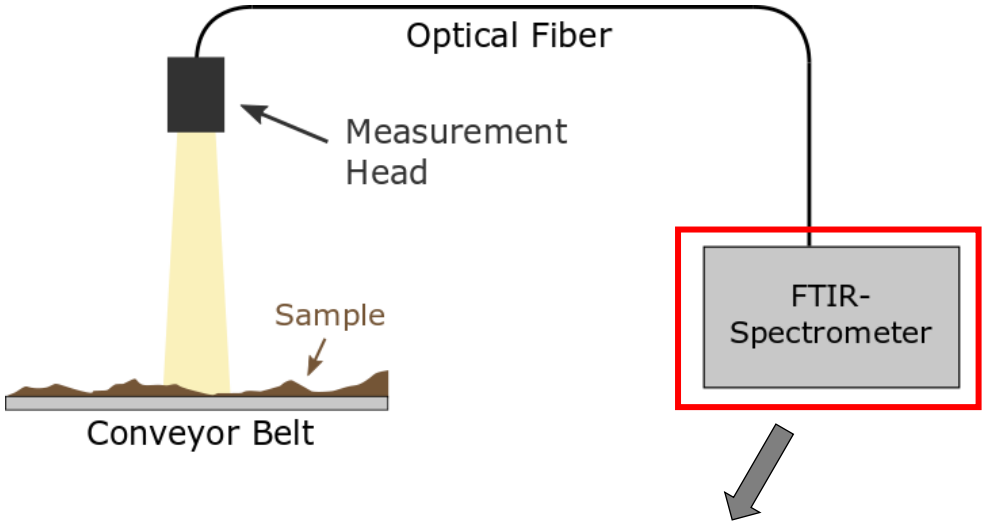
Chem. Soc. Rev. 2014, 43, 8200

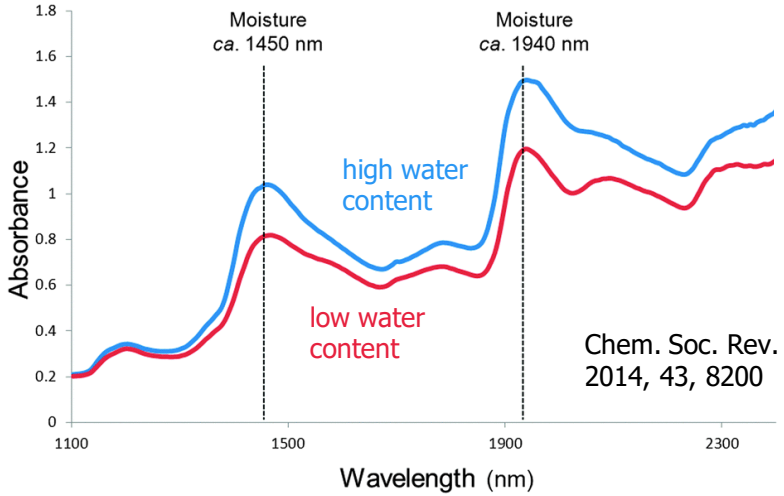
NIR-based Moisture Measurement – Setup

One major downside are the relatively high costs of conventional NIR-spectrometers



>40 k€





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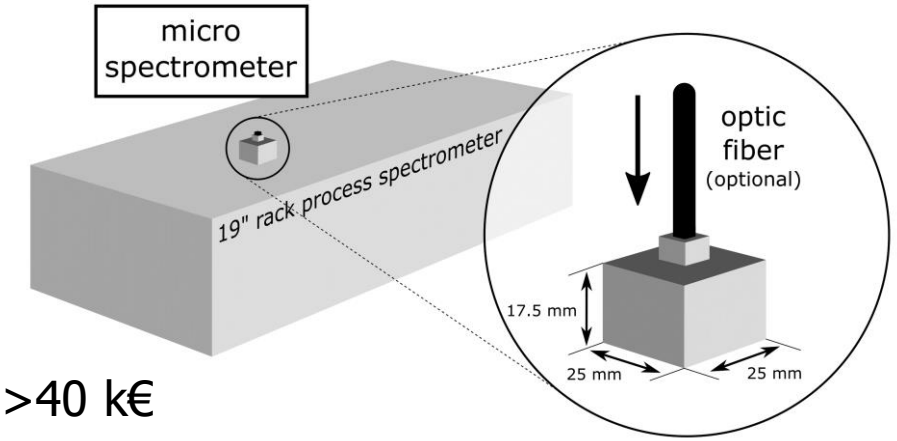

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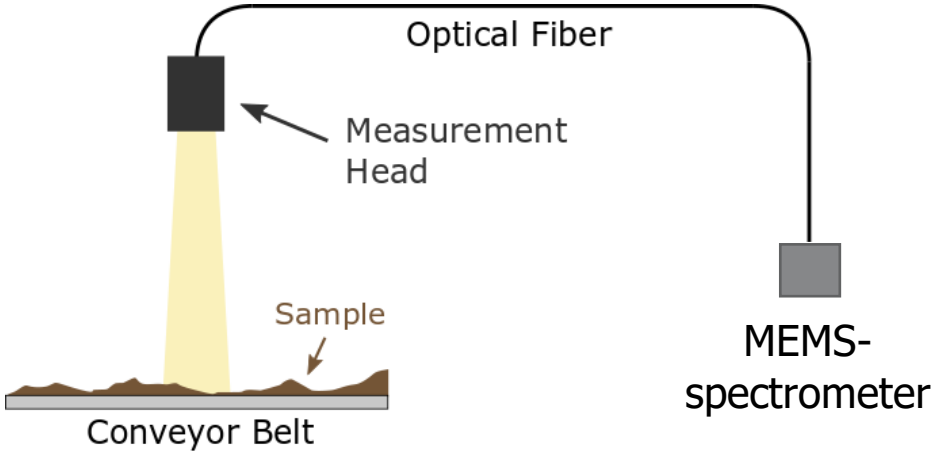
<3 k€



MEMS-based infrared spectrometers

Low Cost - Rugged - Compact

→ Significant **price reduction** for NIR-sensor

→ **Higher ruggedness** (no moving parts)

→ Strongly **reduced space requirements**

→ **Lower power consumption**

→ **Reduced maintenance** efforts

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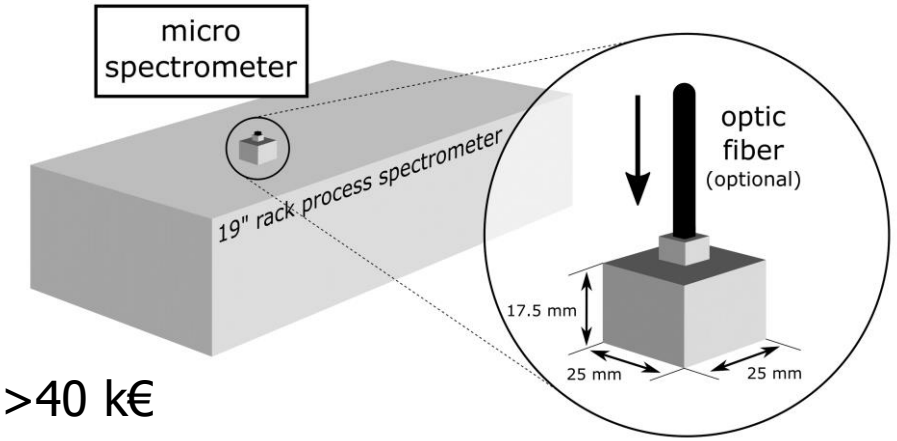

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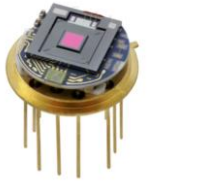
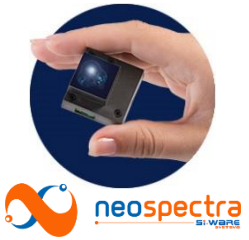
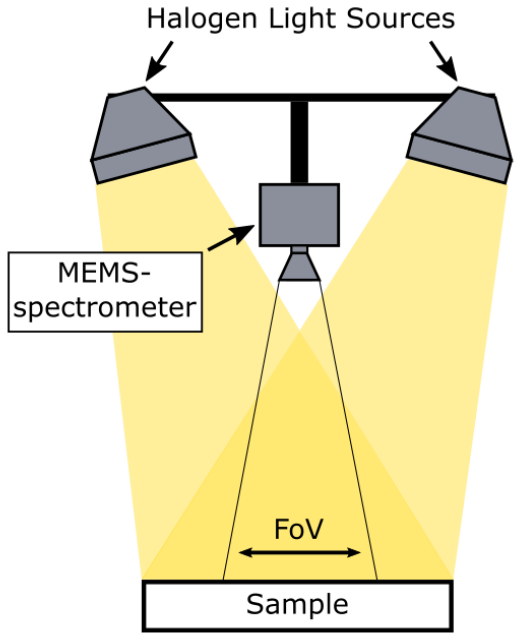


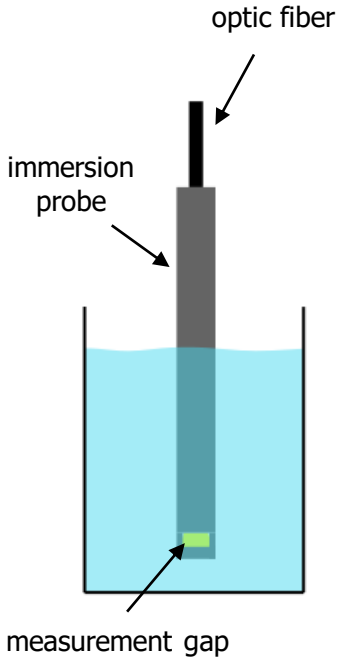


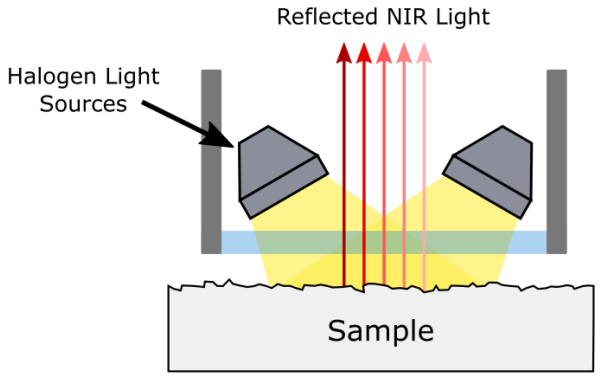
MEMS … Micro-Electro-Mechanical Systems

NIR-based Moisture Measurement – Instrumentation

- MEMS-based spectrometers also allow for **high flexibility** concerning optical interfaces







Spectrometer directly at the measurement position

→ **No need for optical fiber networks**

Measure in liquids using industrial **immersion probes** or **flow cells**

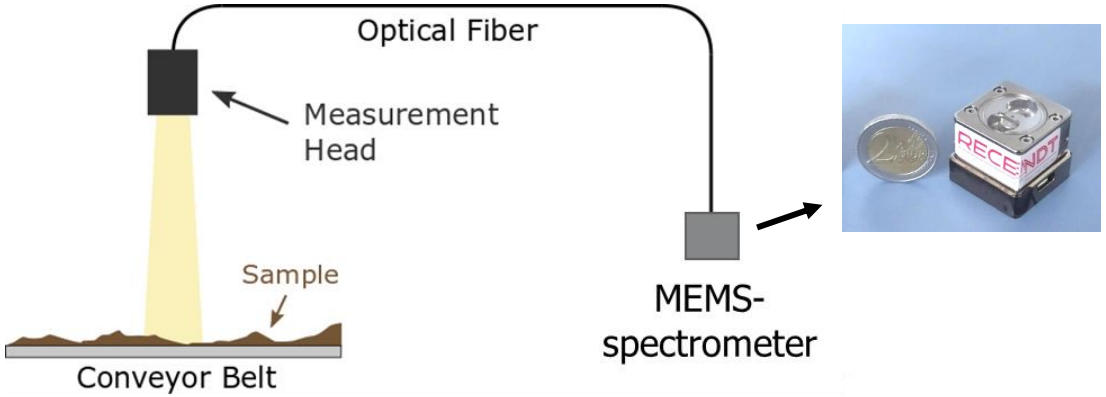
→ also **suitable for very harsh conditions**

Spectrometer **in direct contact** with the sample

→ **built in light sources**

NIR-based Moisture Measurement – Instrumentation

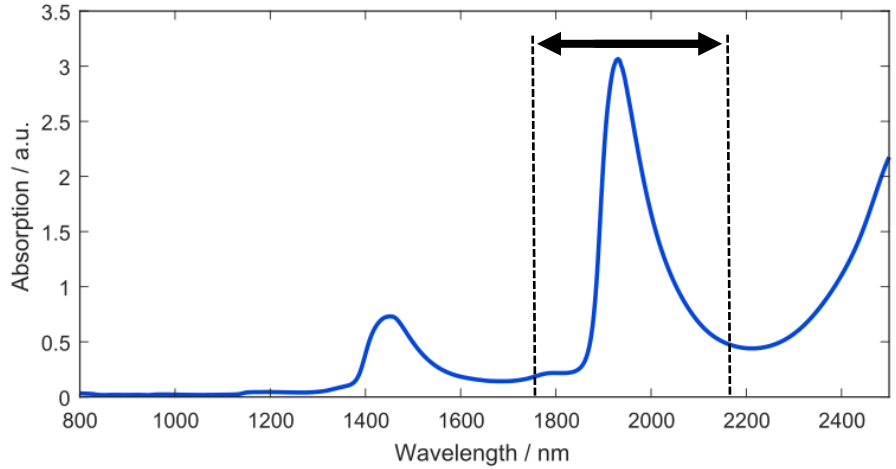
- MEMS-based spectrometers also allow for **high flexibility** concerning optical interfaces

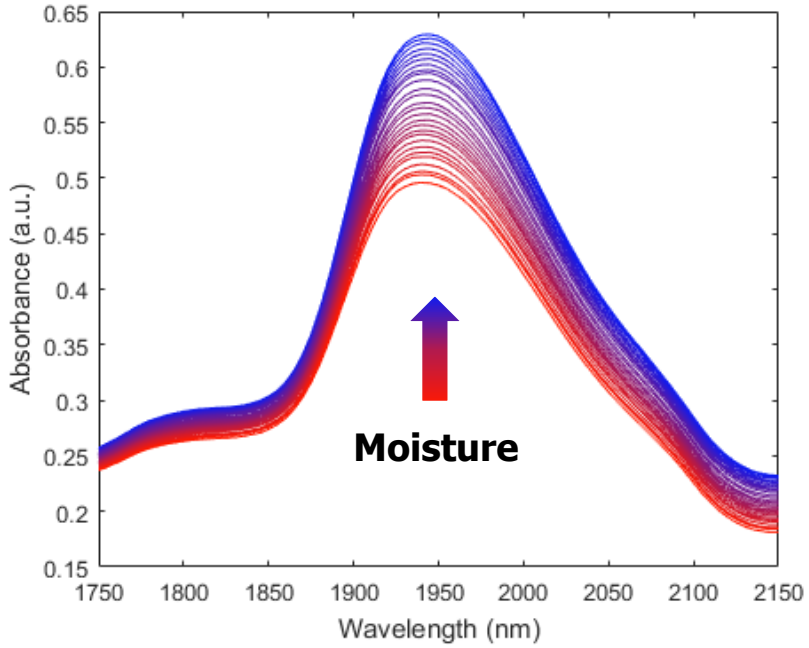


Strongest water absorption band in the NIR-region is measured

→ **Precise moisture measurements are possible**

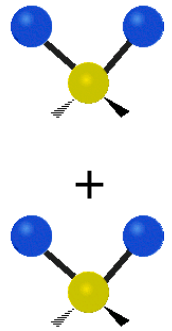
NIR-Absorption of Water





$\nu_2 + \nu_3$

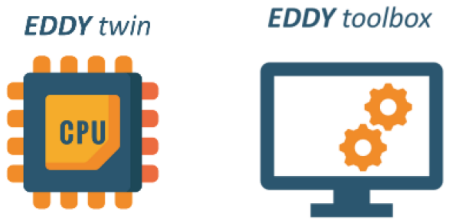
ca. 1940 nm



EDDY – Enhanded Drying

Optimization of industrial drying processes in the food industry using **numerical models** and **monitoring data**

→ **Digital Twin of the drying process**



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NEW ENERGY FOR INDUSTRY

EDDY – Enhanded Drying

AIT AUSTRIAN INSTITUTE OF TECHNOLOGY

FFG Forschung wirkt.

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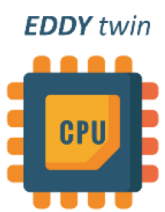
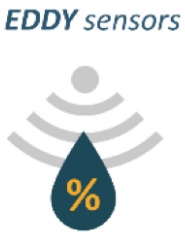
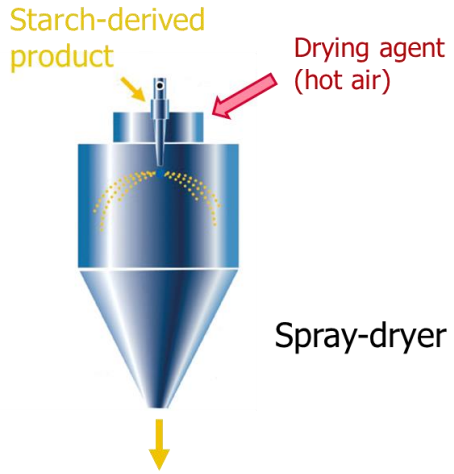


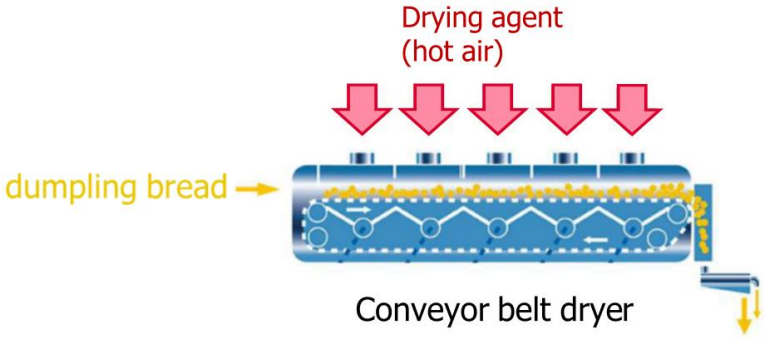




→ Reliable **inline data** of the product moisture is necessary

→ Development of **cost-efficient NIR-based moisture sensors** for:

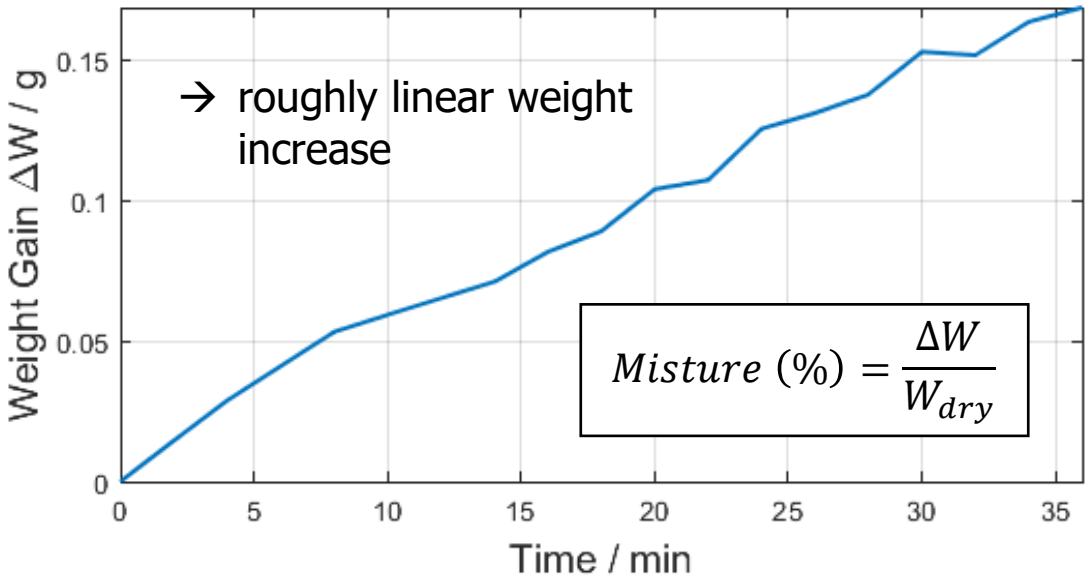
- **starch-derived-products**
- **dumpling bread**

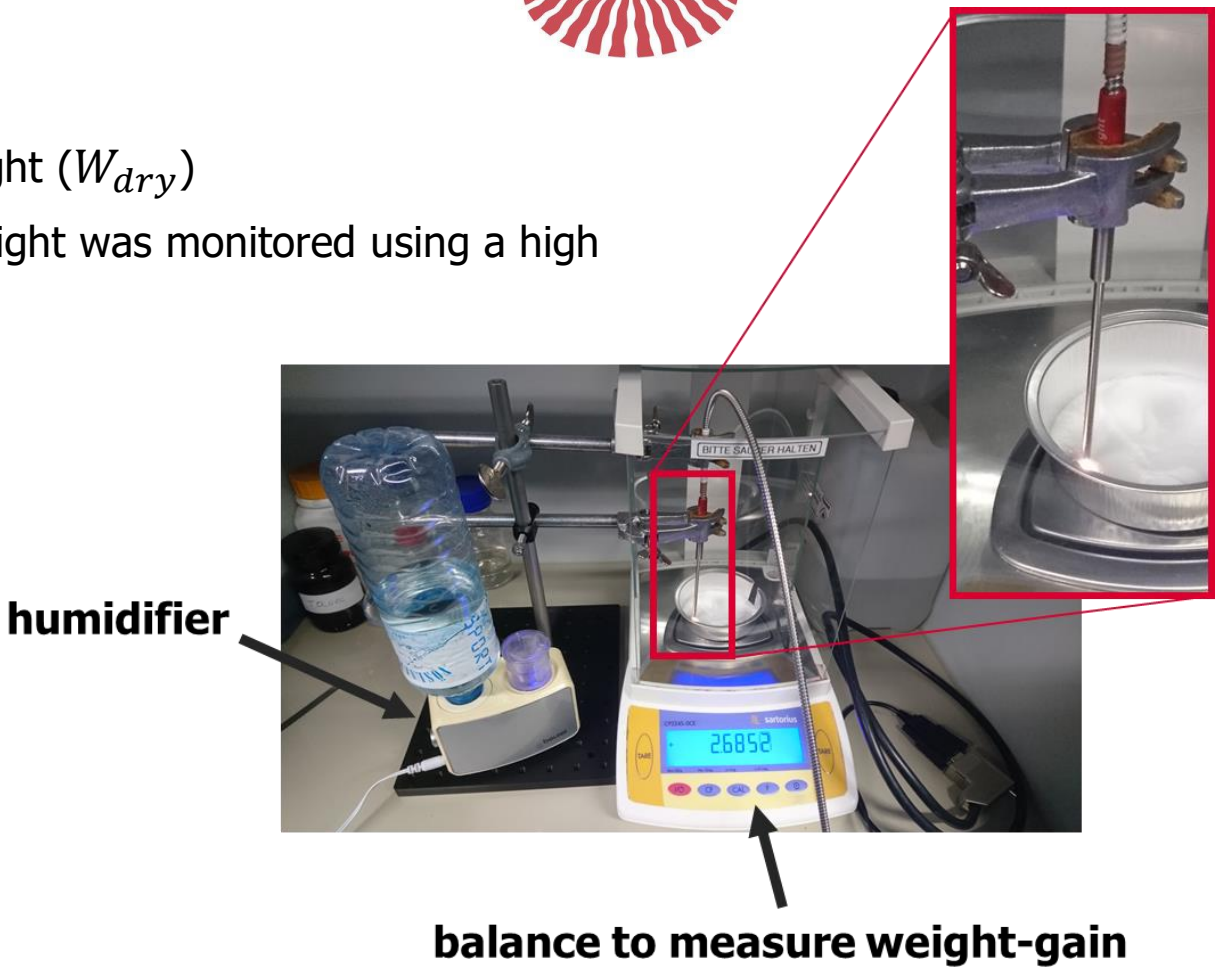


Development of an NIR-based moisture sensor for the inline moisture measurement of **starch-derived-products**

Laboratory measurements

- Sample was completely dried and weighed to get dry weight (W_{dry})
- Humidifier was used to slowly moisturize sample while weight was monitored using a high precision balance

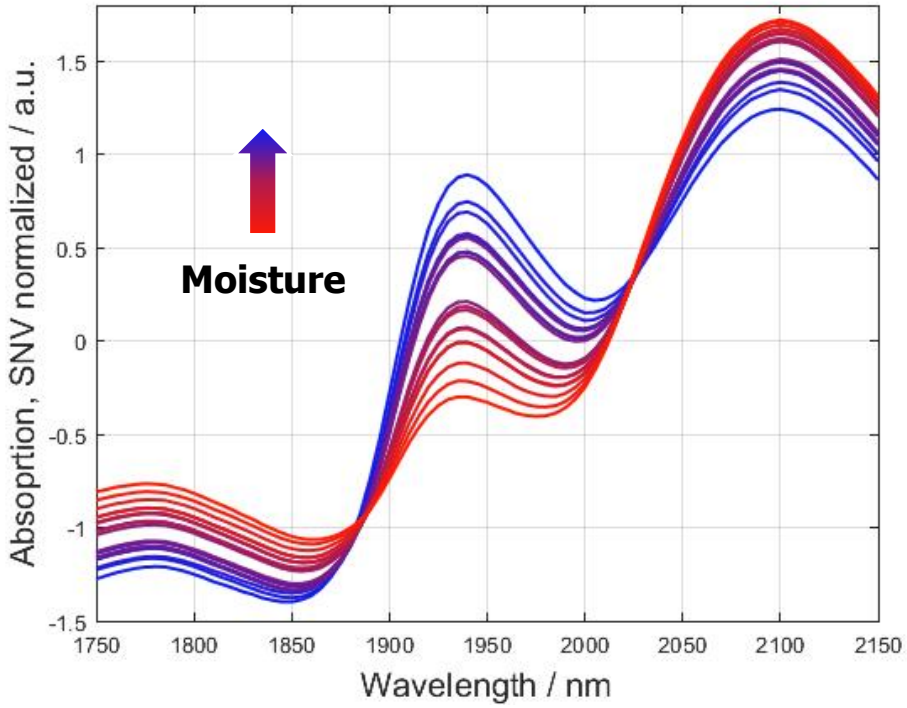


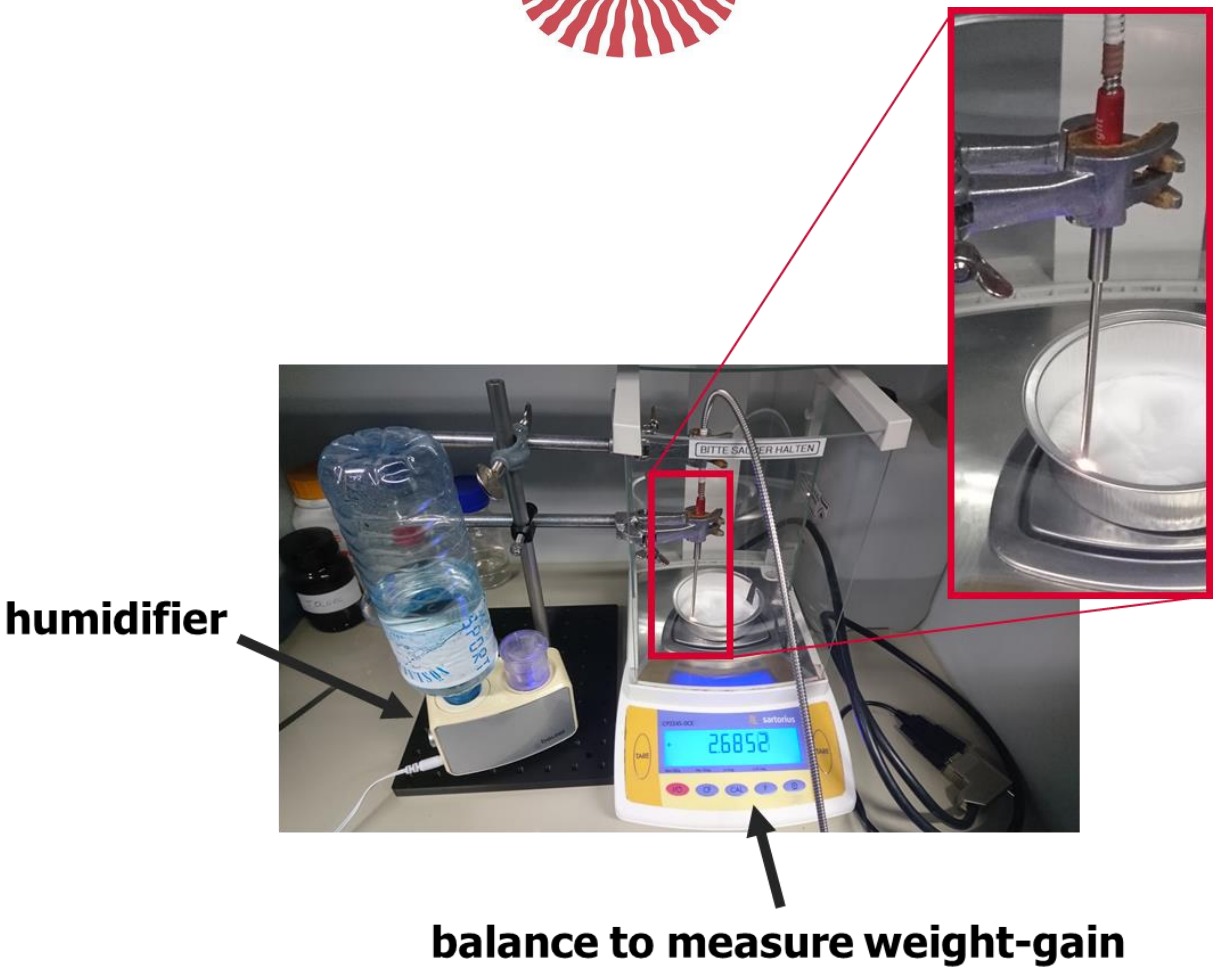


Development of an NIR-based moisture sensor for the inline moisture measurement of **starch-derived-products**

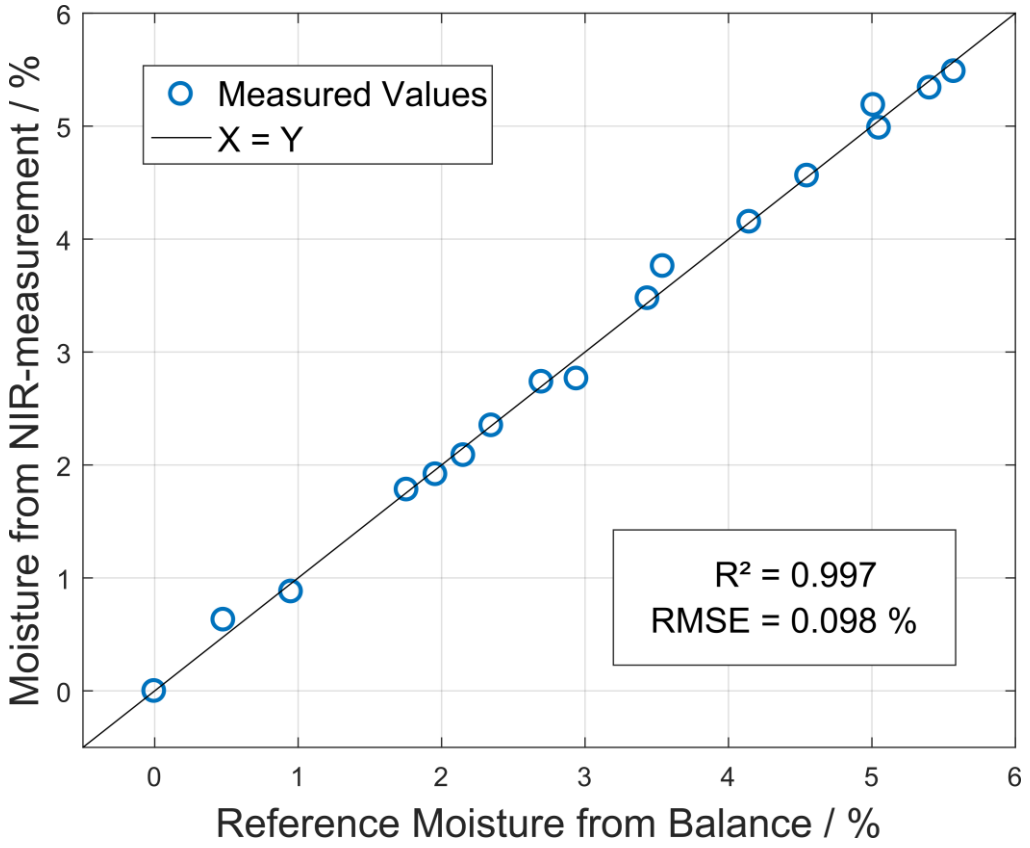
Laboratory measurements

- NIR spectra were collected simultaneously



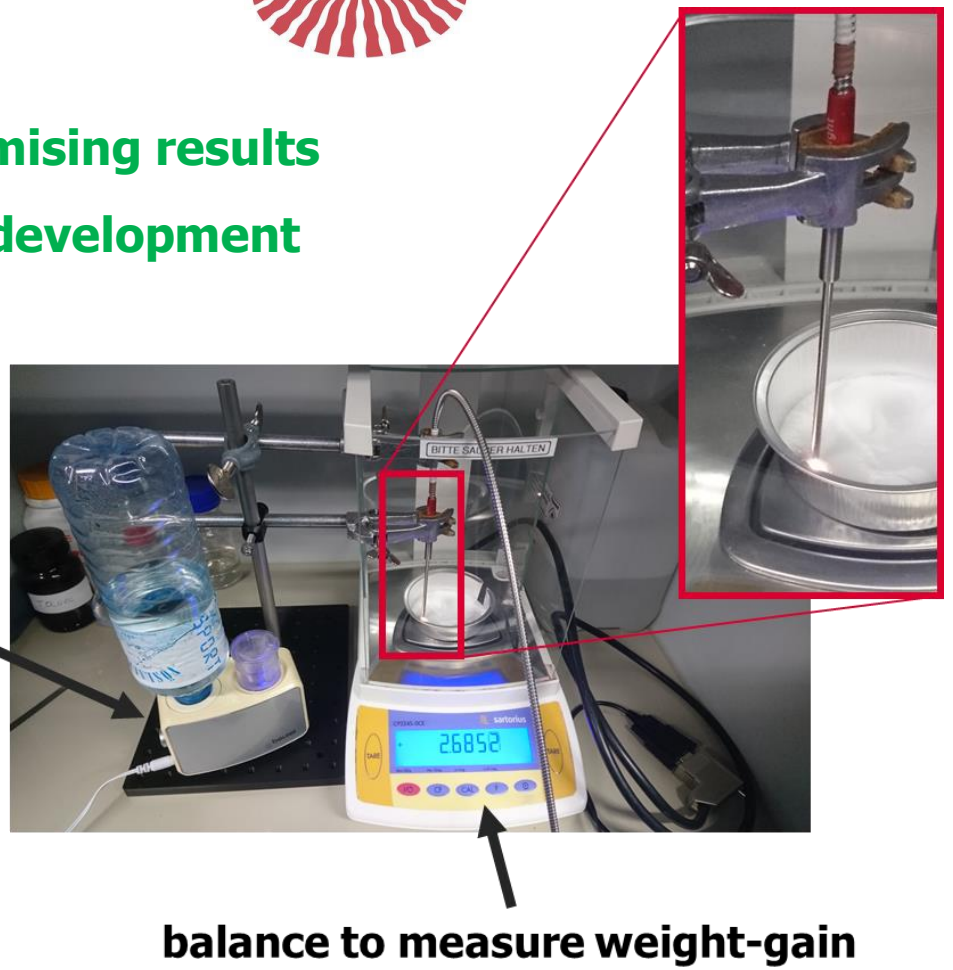


Development of an NIR-based moisture sensor for the inline moisture measurement of **starch-derived-products**



→ **Highly promising results**

→ **Prototype development**



Application Examples

Development of an NIR-based moisture sensor for the inline moisture measurement of **dumpling bread**

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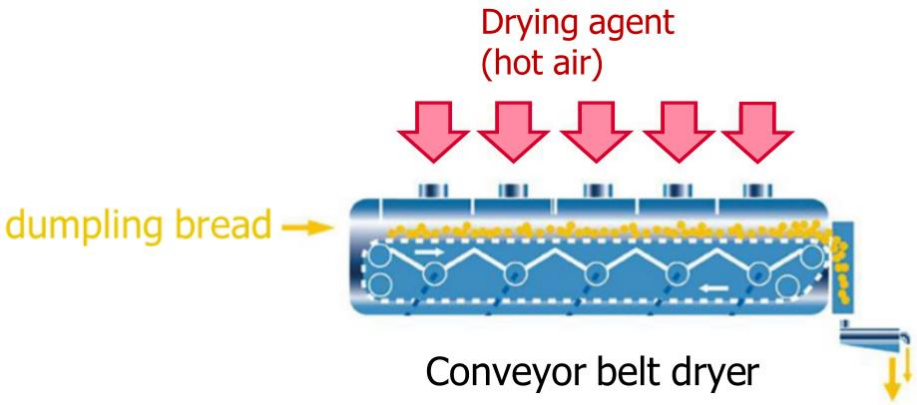
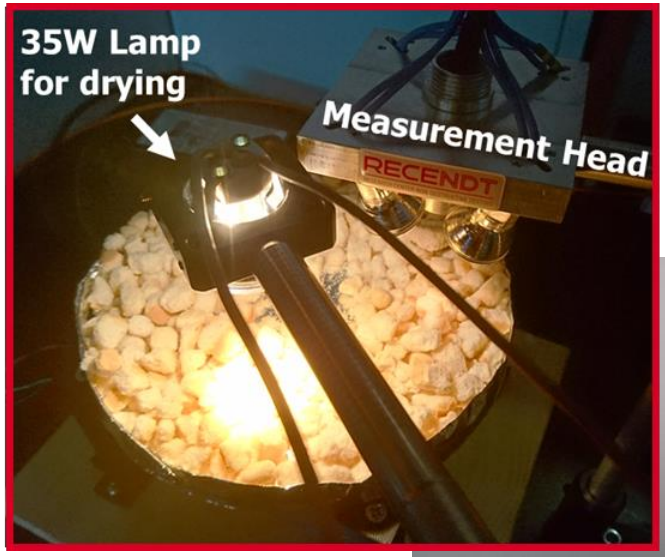
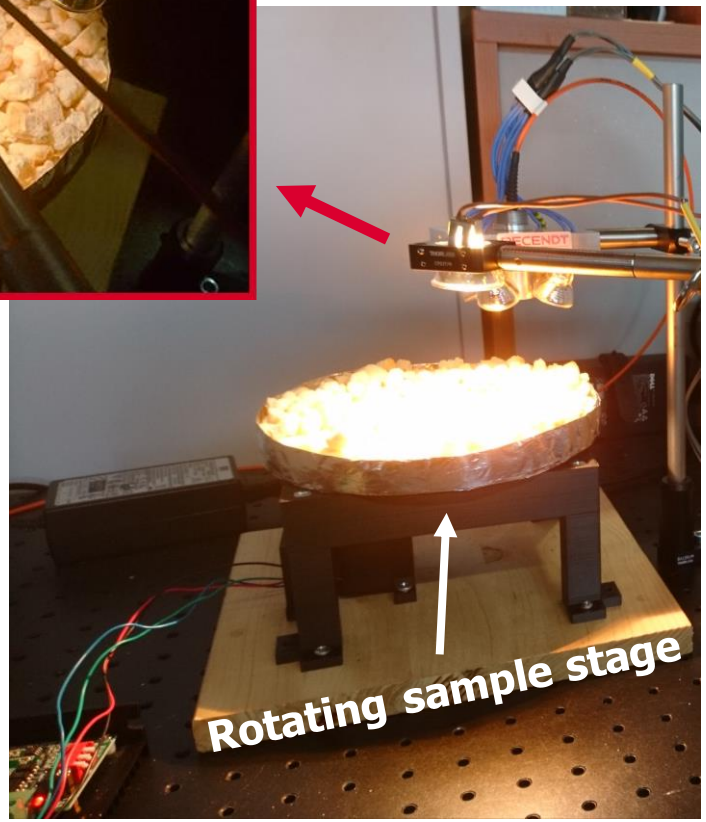
Laboratory measurements

Samples had to be moved during the measurement to simulate conditions in the industrial conveyor belt dryer → **rotation stage**







→ **Weight and NIR spectra can't be measured simultaneously**

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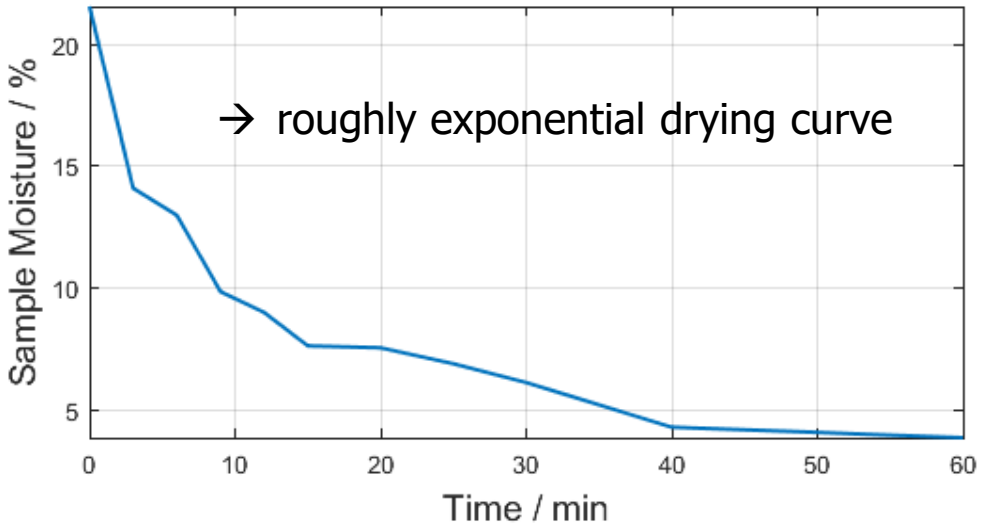
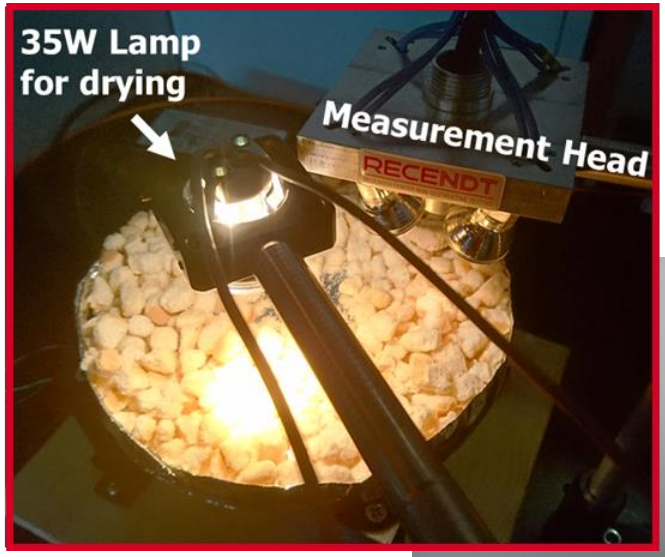
FISCHER BROT

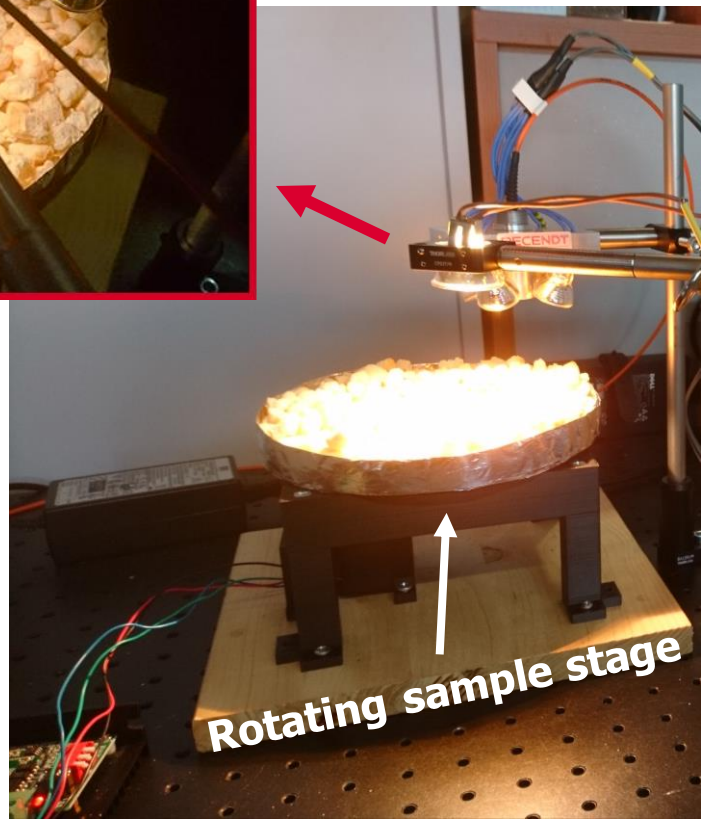
Development of an NIR-based moisture sensor for the inline moisture measurement of **dumpling bread**

Laboratory measurements

- Dumpling bread was moisturized homogeneously
- 35W Halogen lamp was used for drying
- Small samples were taken from the dumpling bread to determine moisture gravimetrically







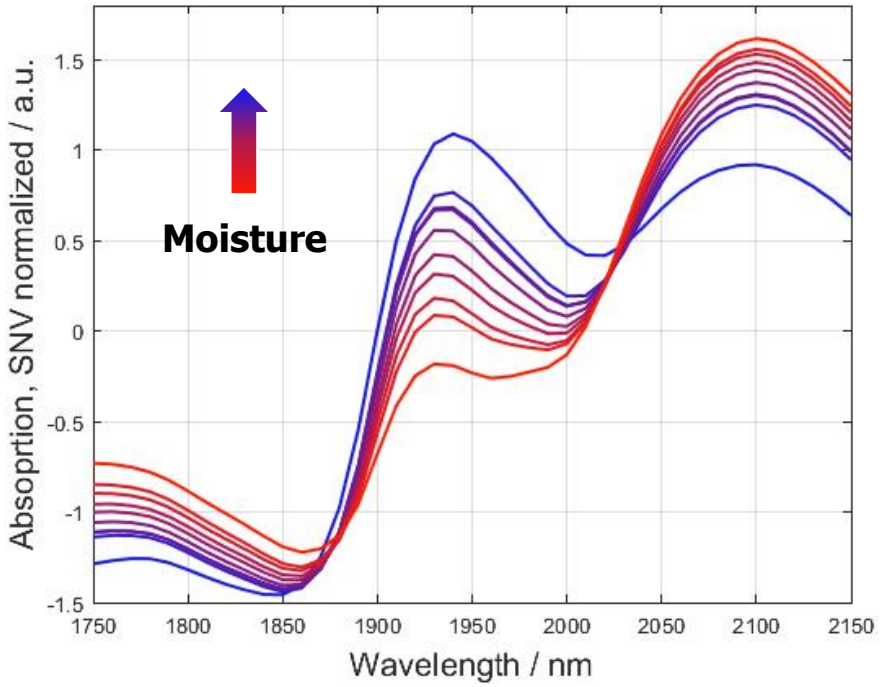
Application Examples

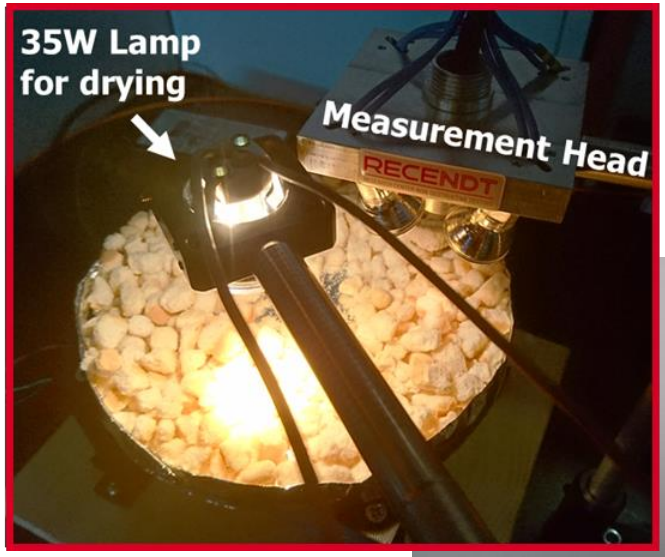
Development of an NIR-based moisture sensor for the inline moisture measurement of **dumpling bread**

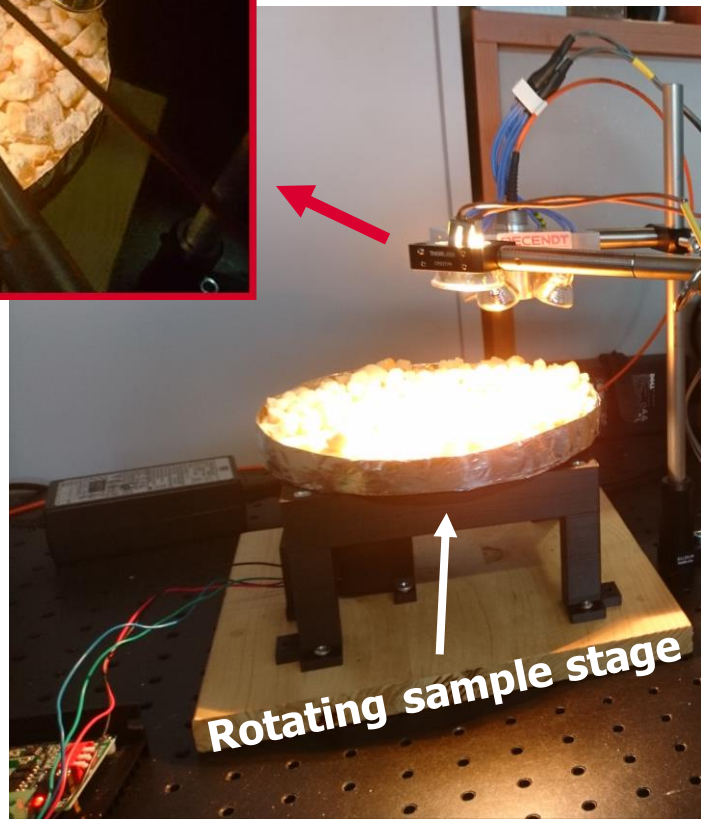
FISCHER BROT

Laboratory measurements

- Measurement head with separate halogen lamps was used to measure NIR-spectra

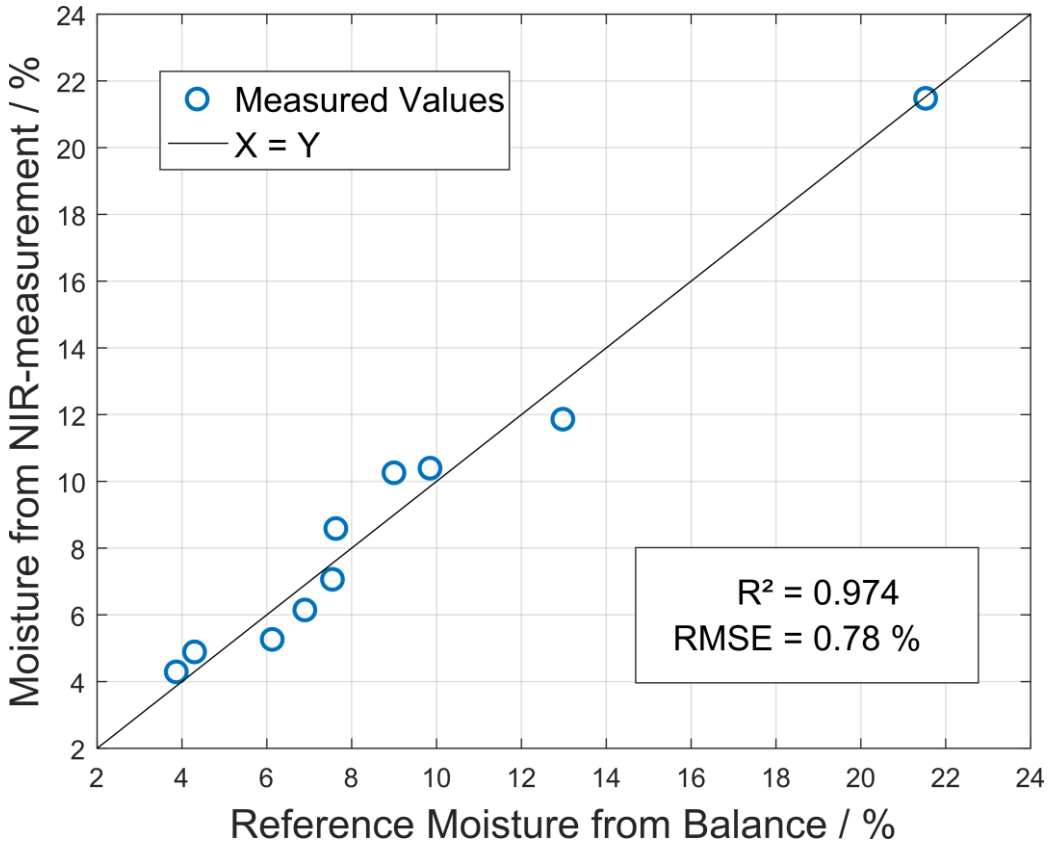


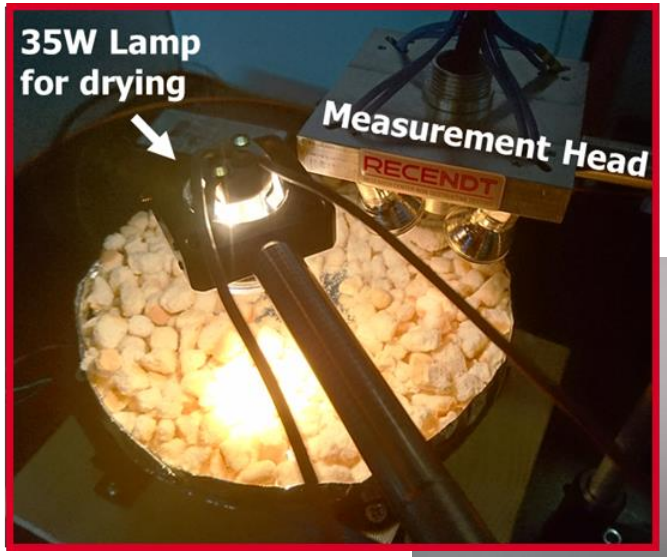


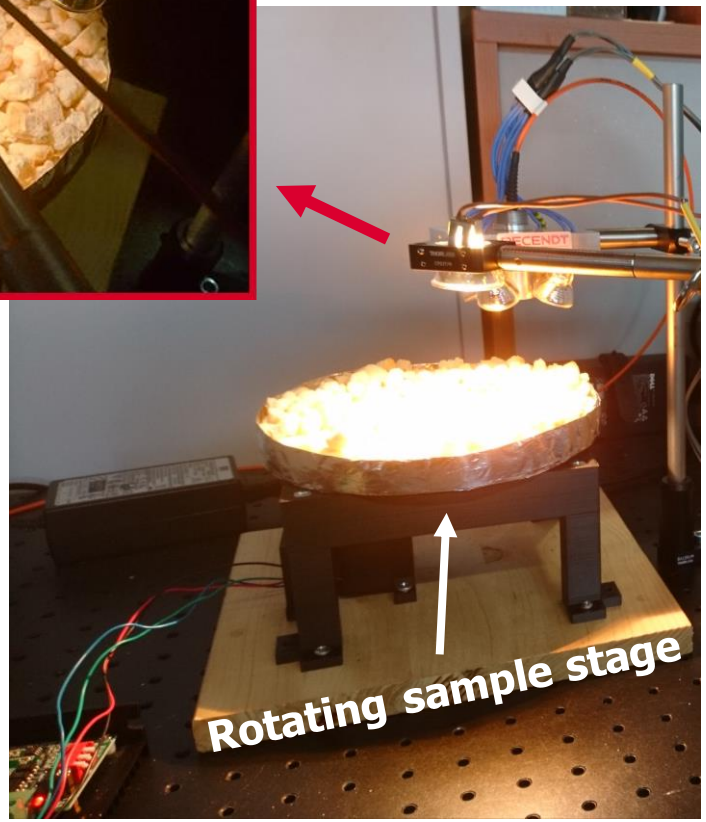


Application Examples

Development of an NIR-based moisture sensor for the inline moisture measurement of **dumpling bread**







→ **Highly promising results**

→ **Prototype development**

Application Examples

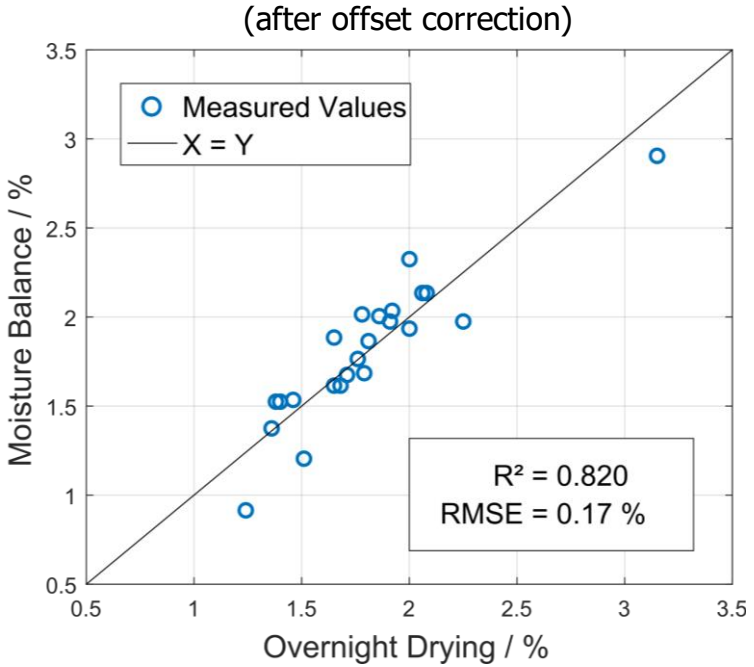
Development of an NIR-based moisture sensor for the inline moisture measurement of **salt**

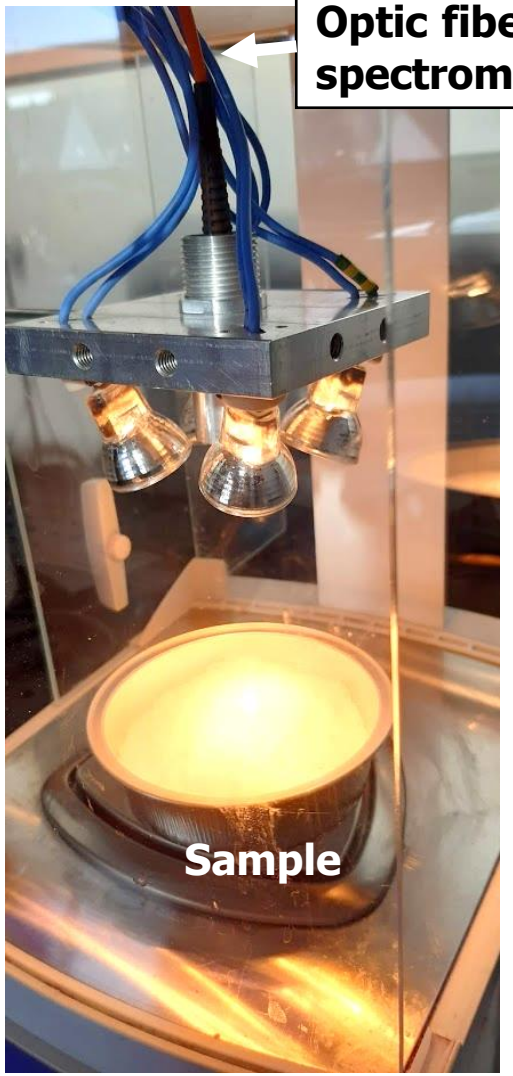
Laboratory measurements

- Samples were sent in **sealed bags** from Salinen Austria AG with (gravimetrically measured) moisture values
- Two moisture values were given:

i) Measured using moisture balance

ii) Dried overnight in drying cabinet, weighed next day



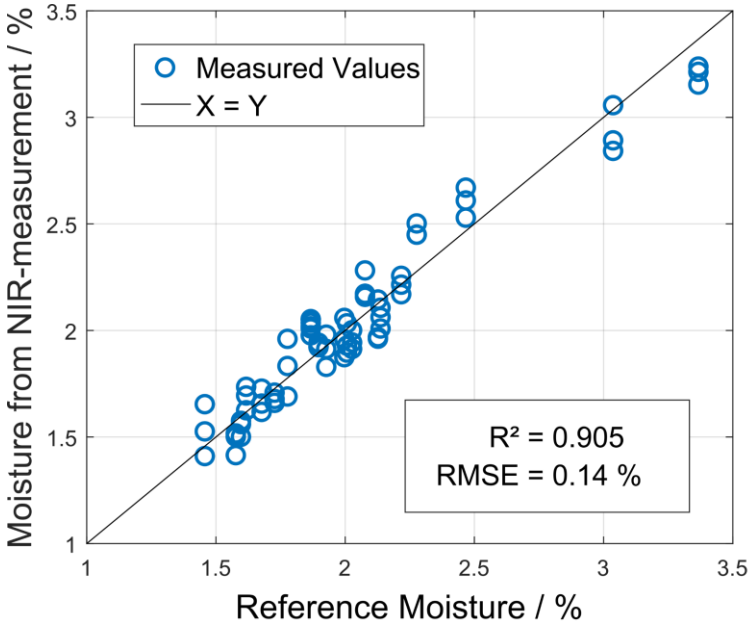


Application Examples

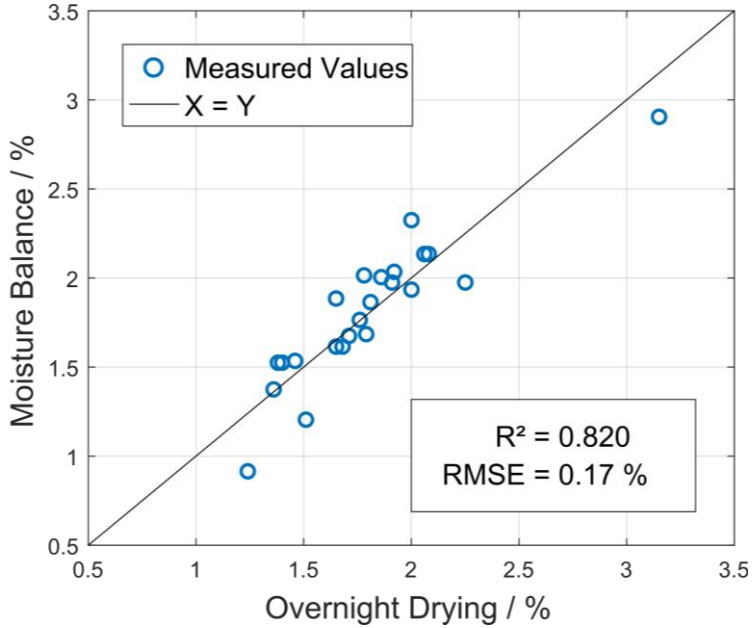
Development of an NIR-based moisture sensor for the inline moisture measurement of **salt**

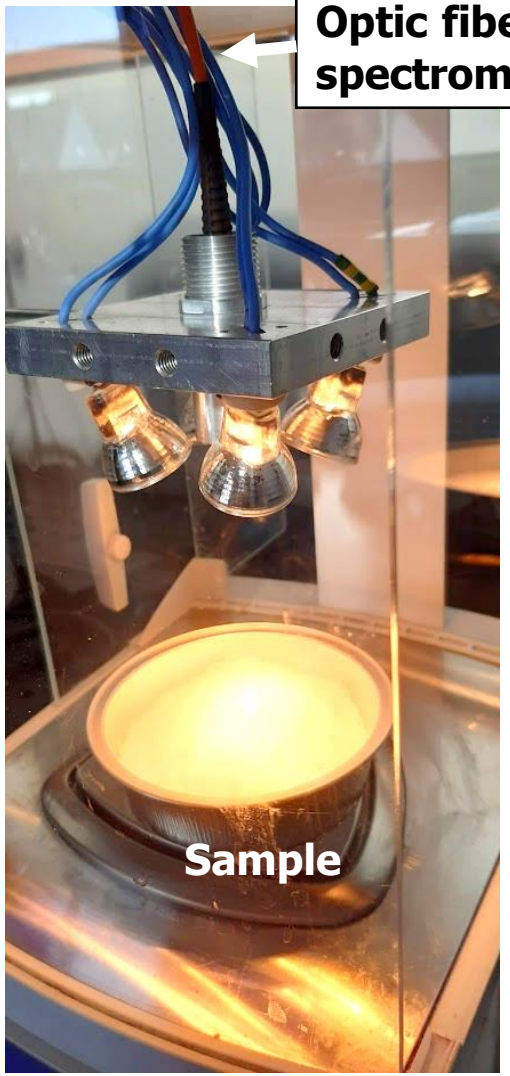
Laboratory measurements

- **NIR measurement shows comparable performance** as reference measurement



(after offset correction)



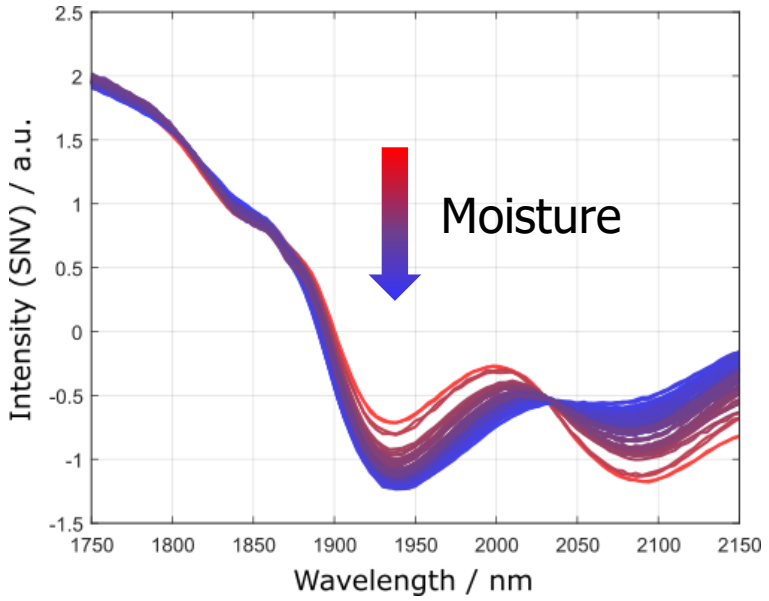


Application Examples

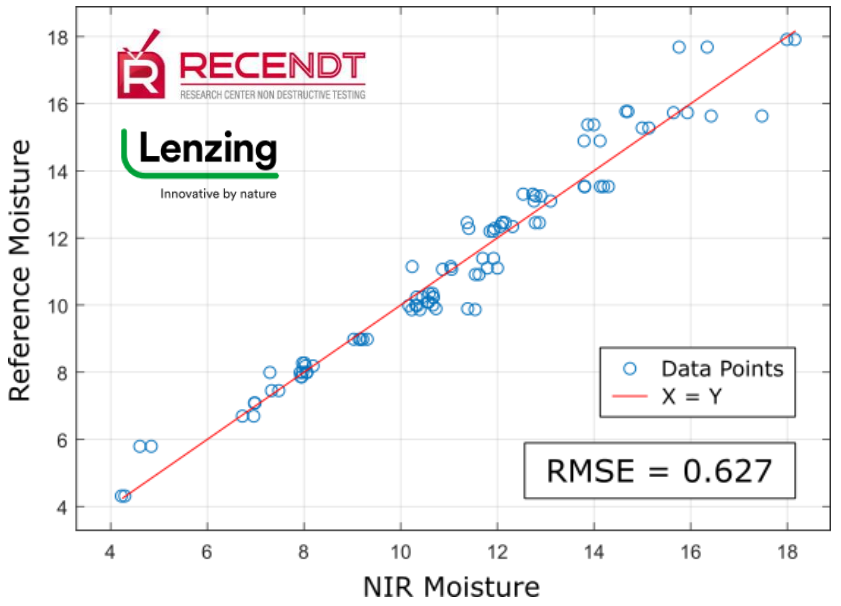
6 NIR-based sensors were successfully integrated into the **production process for contactless moisture measurement**

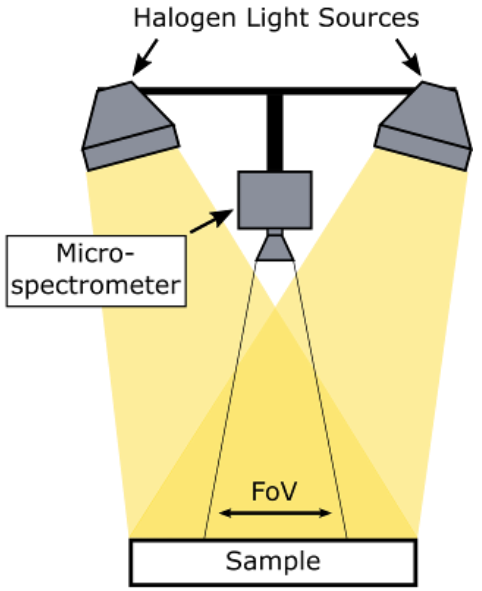
The real-time moisture data allows to **optimize process conditions** in terms of **energy efficiency** and **product quality**

NIR-Spectra



Calibration with Reference





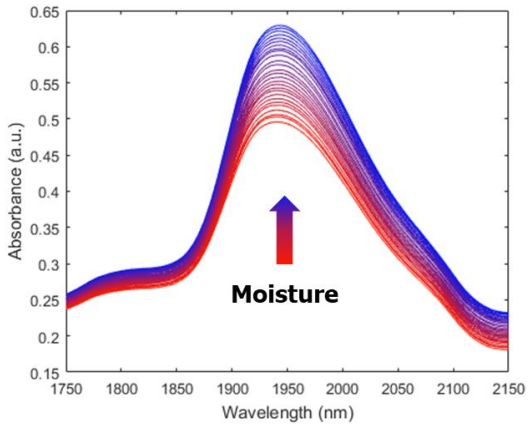
[Success Story – Water Revealed by Light]

Summary

- NIR spectroscopy is a **powerful measurement technique** for moisture measurement

  → **Inline-capable** → **Automatic and real-time**

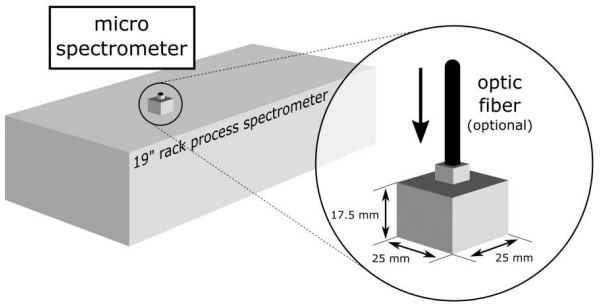
  → **Flexible optical interfaces** → **Non-destructive**

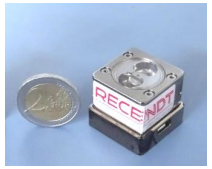


- **Spectral measurement** allows for **higher precision and reliability compared to two point measurements**

- **Spectral measurement** also allows for **simultaneous determination of additional parameters** (e.g. protein content, fat content, ash content, …)

- MEMS-based NIR spectrometer technology allow the realization of **cost-efficient and compact moisture sensors**





<3 k€

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