Real-Time Compositional Analysis of Raw Milk Using Fiber Optic Transflectance Probe and Near-Infrared Spectroscopy

INTRODUCTION

- Digitization of the dairy industry is essential to meet the requirements of Industry 4.0.
- The first step in dairy processing is the compositional analysis of incoming raw milk.
- Conventional laboratory techniques are time-consuming and expensive and often involve hazardous chemicals.
- Vibrational spectroscopic (such as mid-infrared) techniques provide a low-cost and robust alternative.
- NIR spectroscopy sensors can be installed on the process line for real-time compositional analysis.

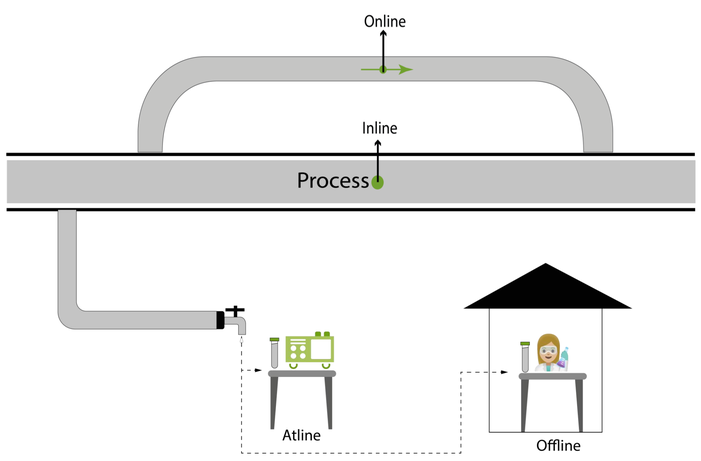

Figure 1 Measurement Approaches In Process Analytics

NEAR INFRARED SPECTROSCOPY

- The principle of NIR spectroscopy is based on the absorption of specific wavelengths due to the vibration of molecules in materials.
- For example, the water molecules will absorb 1350-1450 nm and 1850-2000 nm wavelengths.

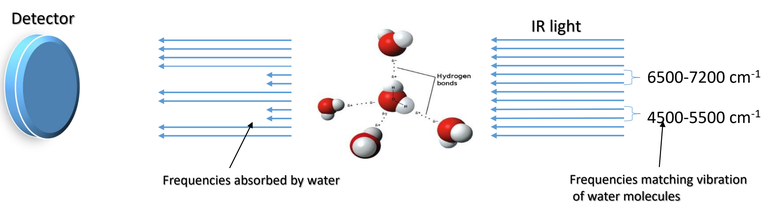

Figure 2 Principle of NIR spectroscopy

- The resultant response is called the NIR spectrum and can provide information about the chemical properties of a sample.

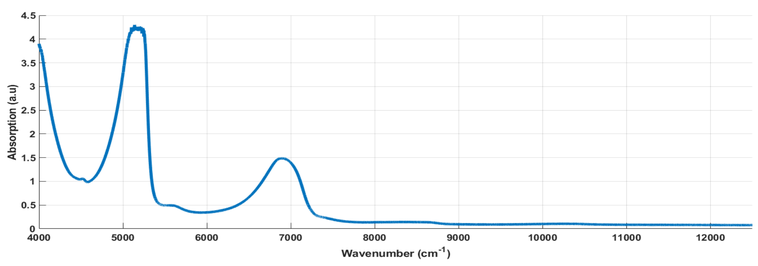

Figure 3: NIR Spectra of Water

RAW MILK

Component	Limits of Variation	Mean Value
Water	85.5-89.5	87.5
Total Solids	10.5 – 14.5	13.0
Fat	2.5-6.5	4.0
Protein	2.5-4.5	3.5
Lactose	4.5-5	4.75
Minerals	0.6-0.9	0.7

Source: (T. Huppertz, Wageningen University & Research)

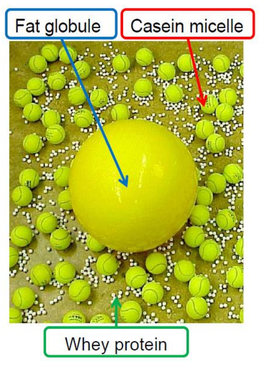

Figure 4 Composition of Raw Milk

Methods & Materials

- No of milk samples: 300 *(Individual Cow samples)*
- Sample temperature: 40 °C
- Agitation speed: 200 RPM
- Instrument Settings
  - *No. of Scans = 256*
  - *Scanning speed = 40 KHz*
  - *Resolution = 32 cm^{-1}*
  - *Repeated measurement = 2*

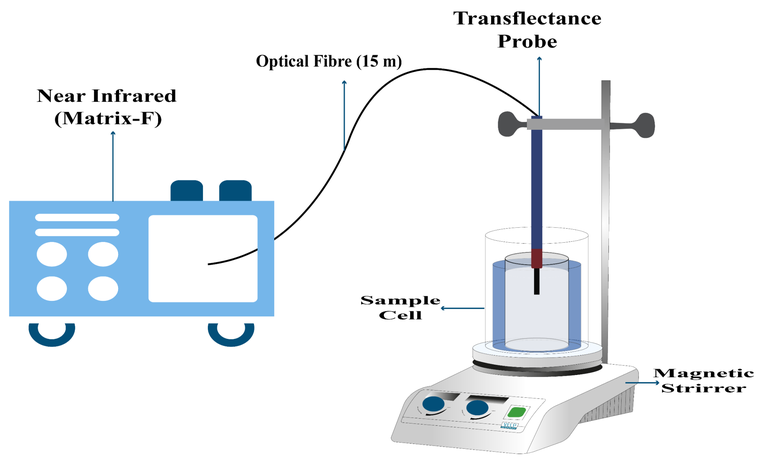

Figure 5 Experimental Setup For Calibration Models

IN-LINE MEASUREMENT

- No. of milk samples: 25 *(Bulk tank samples)*
- Sample temperature: 40 °C
- Flowrate range: 5 to 50 Liter/min
- Repeated measurement = 4

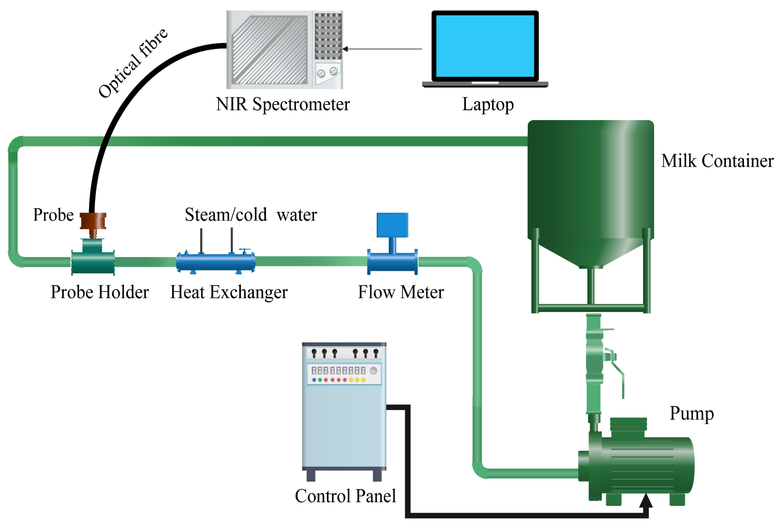

Figure 6 Experimental Setup for In-line Measurement

DATA ANALYSIS

- Software: MATLAB 2019 A
- Pre-processing: Discrete wavelet transform (DWT)
- Feature Selection: Cumulative adaptive reweighted sampling (CARS)
- Multivariate Linear Regression (MLR)

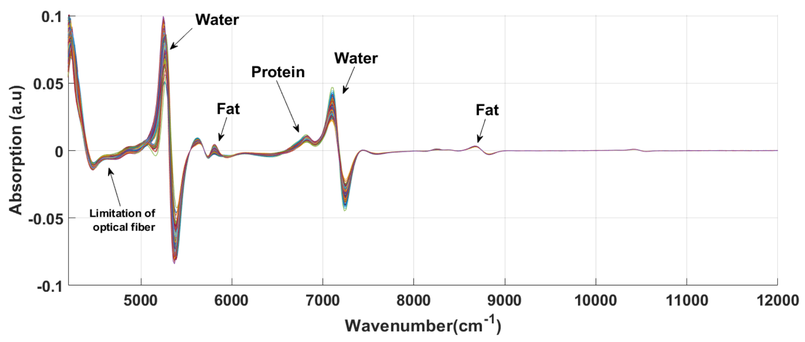

Figure 7 DWT Processed Spectra of Raw Milk

RESULTS

- Regression models were able to quantify fat, crude protein, total solids, and casein with good accuracy ($R^2 > 0.90$)
- The use of feature selection algorithm improved the robustness and prediction performance of calibration models
- The lower prediction performance for lactose can be linked to the limitation of the transflectance probe in acquiring transmittance spectra.

CALIBRATION MODELS

Component	Selected Wavelengths	R^2	RMSE	RPD
Fat	22	0.99	0.10	10.24
Protein	60	0.94	0.08	4.21
Lactose	25	0.59	0.11	1.20
Total Solids	59	0.98	0.17	7.87
Casein	39	0.94	0.06	4.04

Table 1 Prediction performance of Calibration Models

REAL-TIME MEASUREMENT

- Variations in flowrate did not influence the spectra of raw milk or the prediction performance of the model.
- Repeated measurements provide a consistent prediction of component concentration.
- Temperature variations can influence the prediction performance of calibration models.

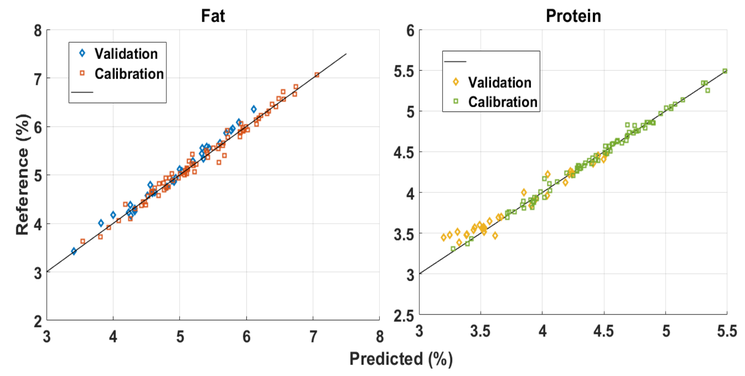

Figure 8 Comparison of actual and predicted concentration

CONCLUSIONS

- NIR sensor with optical fiber transflectance probe can quantify components of raw milk in line.
- The variation in flowrate did not influence the spectra of raw milk.
- The sample's temperature can affect the robustness of calibration model's prediction performance.

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H M Hussain Khan

Supervisors

Dr Norah O'Shea, Dr Ultan McCarthy, Dr Imelda Casey

Teagasc Agriculture and Food Development Authority

SETU Ollscoil Teicneolaíochta an Oirdheiscirt South East Technological University

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