SensoRein

Technische Universität Braunschweig

Fraunhofer

VDMA Nahrungsmittelmaschinen und Verpackungsmaschinen

Gefördert durch: Bundesministerium für Ernährung und Landwirtschaft aufgrund eines Beschlusses des Deutschen Bundestages

ptble Projektträger Bundesanstalt für Landwirtschaft und Ernährung

Development of sensor systems for cleaning processes

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Background

- Production plants in the food industry are highly automated resulting in oversized cleaning processes since they are not adjusted to the cleaning demand due to the lack of sufficient online validation
- The development of online sensors that allow the validation of the cleaning demand and efficiency is the main objective of the BMEL funded joint project *SensoRein*
- Prototypes based on different sensor methods shall be built up and verified if they are suitable to determine the end of the cleaning process

Sensor systems

Fraunhofer IVV: Quartz Crystal Sensor | Fraunhofer IPM: Fluorescence Spectrometry | Fraunhofer IFAM: Laser-Induced Breakdown Spectroscopy

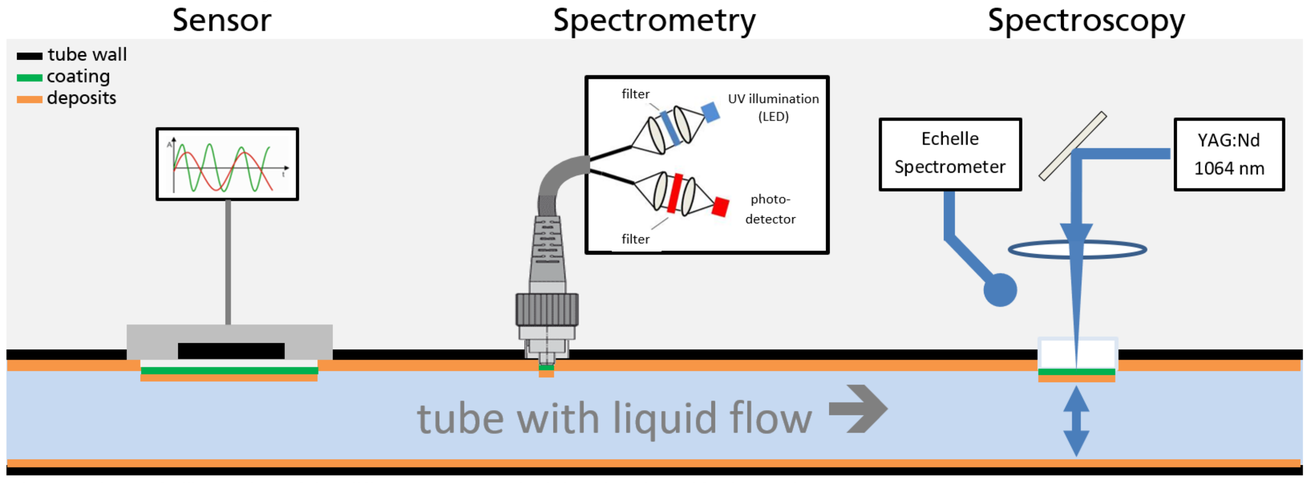

Fig. 1: Schematic illustration of the different sensor principles developed in the project

Quartz Crystal Sensor (QCM)

- Sensor uses the inversed piezoelectric effect
  - ➔ AC voltage generates shear oscillation in a quartz crystal with an AT cut. The measured resonance parameters change when a soil layer is applied to the quartz crystal, what allows conclusions on the soil layer thickness
- Examination of the sensor behavior in cleaning tests with starch in a flow channel test rig
  - ➔ Sensor signal is validated by an established optical contamination sensor which monitors the soil removal on the quartz surface from the opposite side

Fig. 2: Developed prototype

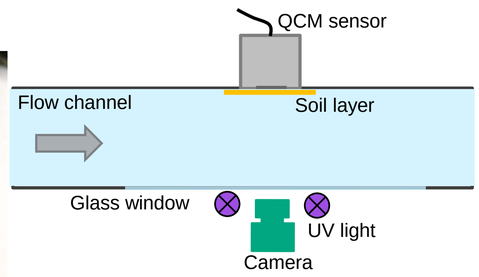

Fig. 3: Integration of the sensor in a flow channel test rig for cleaning tests

Fluorescence Spectrometry

- Optical fibers are integrated into the walls of food processing equipment
- During production (cleaning), a layer of soil will deposit (dissolve) on vessel walls and fiber tip in similar ways
- UV light sent through the fiber gives rise to fluorescence of the soil layer, which is collected by the very same fiber and analyzed together with scattered excitation light
- The signal intensity is related to the amount of soil
- The cleaning process can be monitored and controlled
- The system is:

✓ robust
✓ compact
✓ flexible
✓ affordable

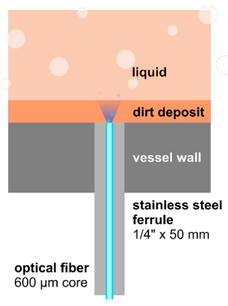

Fig. 6: Integration into the vessel

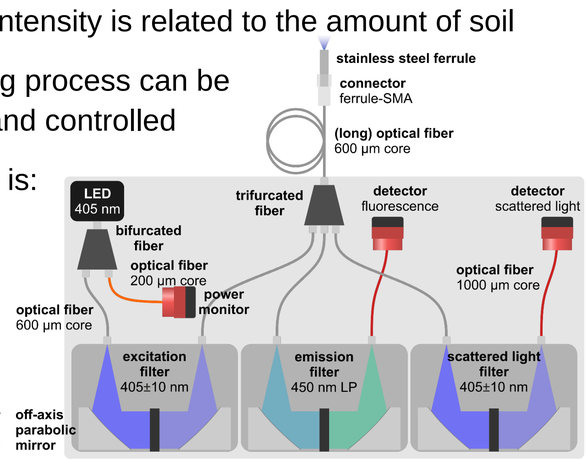

Fig. 7: Advanced filter and detector system

Laser-Induced Breakdown Spectroscopy

- LIBS is well established for elemental analysis on solids, measurements in liquids is a new approach
- Adjusting of laser setup to generate plasma with double pulse and measurement routine to improve detection limit in liquids
- Spectral analysis of plasma yields concentration level of residuals within the tube as shown below for dried tomato paste at air detected via sodium signal

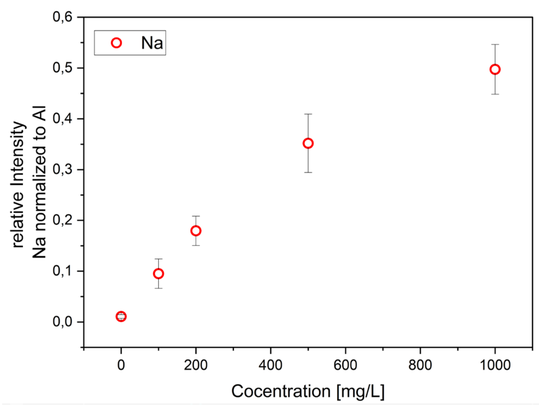

Fig. 9: Correlation of the sodium signal to the concentration of tomato paste

First results

- Cleaning tests show a significant signal shift of the quartz resonance during the soil removal
- Comparison with the optical contamination sensor show a good correlation regarding the detected cleaning progress

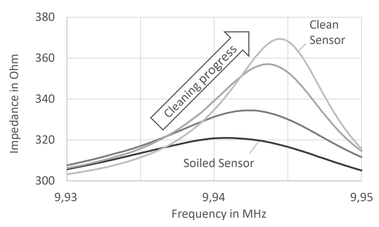

Fig. 4: Measured sensor curves during cleaning

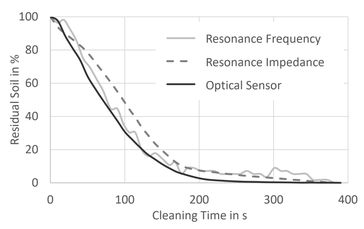

Fig. 5: Comparison of measured residual soil with optical sensor

First results

- Tests with a variety of substances (whey protein, ketchup, mustard …)
- Close to industrial conditions (DIVERSEY test system)
- All substances yield sufficient fluorescence intensity
- No false negative results: A low signal always indicated a clean surface – suitable "stop" indicator for cleaning process
- On going studies: absolute calibration of film thickness, temperature dependence, full automation of sensor operation

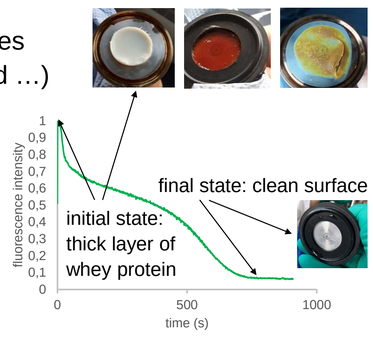

Fig. 8: Measured sensor curves during cleaning

First results

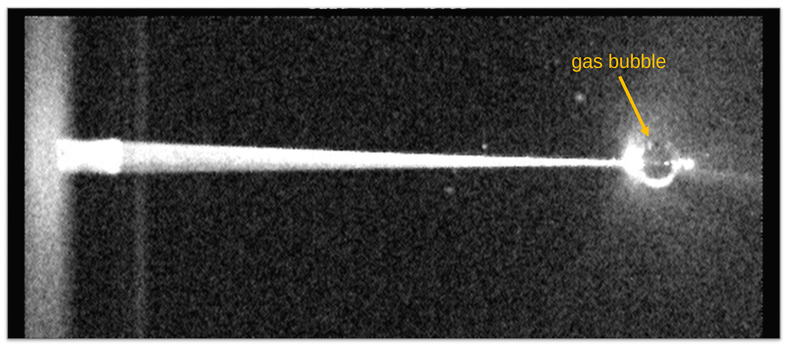

Fig. 10: High speed camera image

High speed camera image of second laser pulse hitting gas bubble to excite plasma for elemental analysis in liquids

Summary

⇨ Prototypes based on different sensor methods have been built up
⇨ First results have shown the functional principle of the different sensor methods

Outlook

⇨ Test runs with the three sensor prototypes in the test rig
⇨ Minimization of the measuring equipment (compact design)
⇨ Examination of further coating candidates regarding their required individual properties

Acknowledgements

Financial support of the Federal Ministry of Food and Agriculture is gratefully acknowledged (grant no. 281A106016).

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Adhesion of a whey protein system on potential sensor coatings

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Background

- Production plants in the food industry are highly automated resulting in oversized cleaning processes since they are not adjusted to the cleaning demand due to the lack of sufficient online validation
- The development of online sensors that allow the validation of the cleaning demand and efficiency is the main objective of the BMEL funded joint project *SensoRein*
- These sensors need coatings that (i) mimic the surface properties of the metal pipe while, (ii) mimic the surface properties and allow the transmission of light or (iii) transmit light and exhibit non-stick behavior

Adhesive force of the model soil

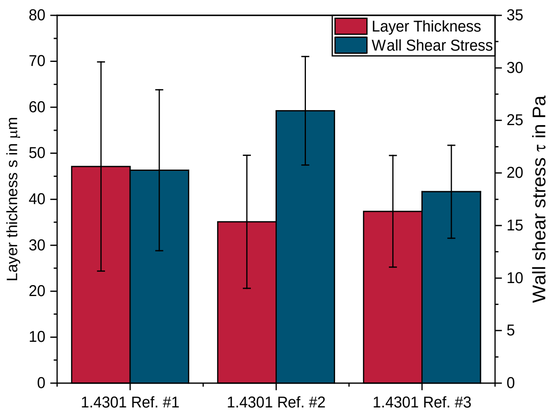


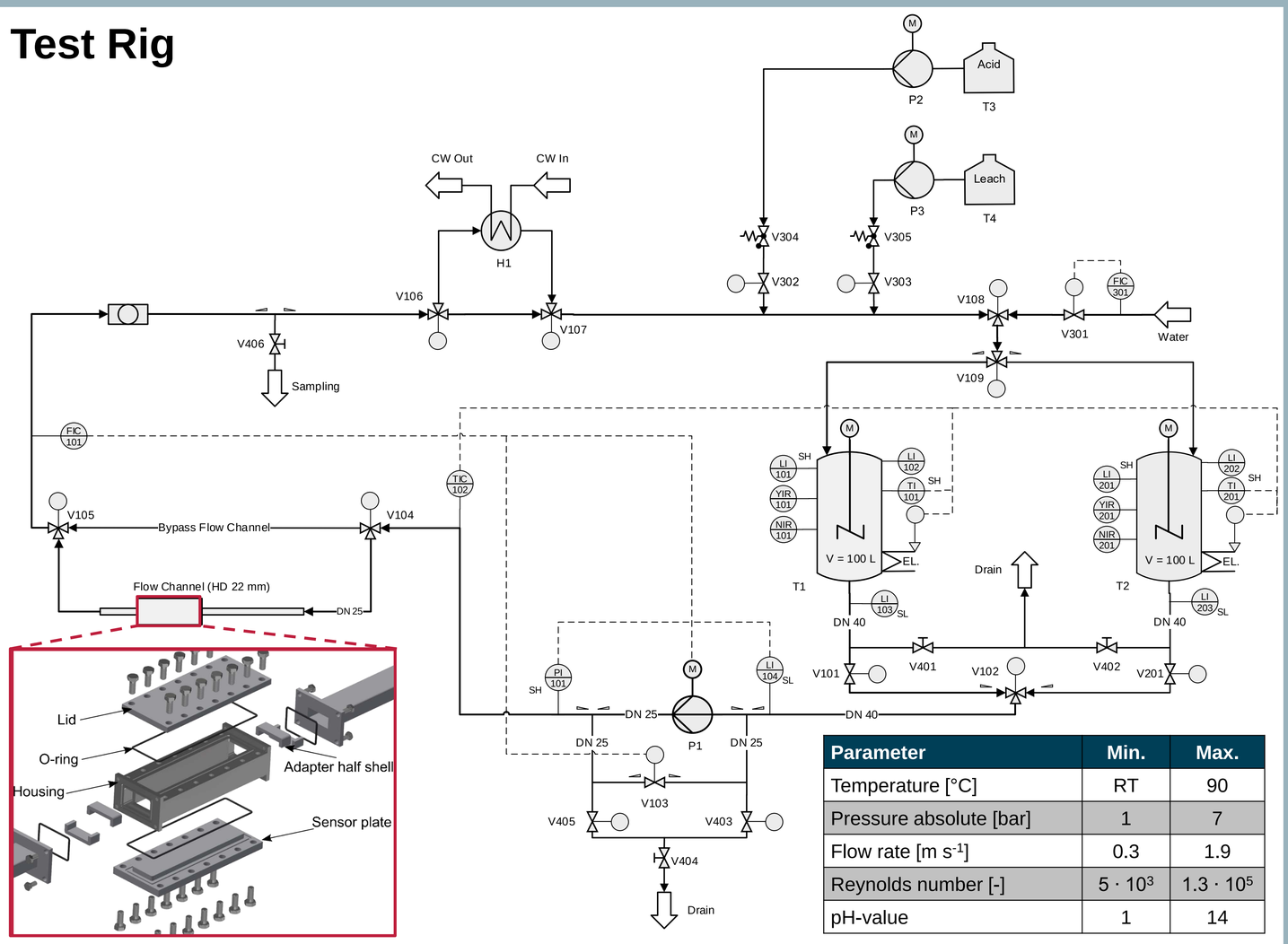
Fig. 1: Layer thickness and wall shear stress of a whey protein system on three 1.4301 stainless steel samples

- Performance of Fluid Dynamic Gauging (FDG) experiments to determine adhesive forces [1]

⇨ Production of very thin layers of a whey protein gel (< 75 µm)

⇨ FDG results reveal a necessary wall shear stress of 21.3 ± 6.7 Pa to pull of the model soil

Test Rig



Parameter	Min.	Max.
Temperature [°C]	RT	90
Pressure absolute [bar]	1	7
Flow rate [m s^{-1}]	0.3	1.9
Reynolds number [-]	$5 \cdot 10^3$	$1.3 \cdot 10^5$
pH-value	1	14

Fig. 4: Process flow diagram of the test rig and exploded view of the flow channel

⇨ The modular flow channel allows the flexible installation of sensor prototypes

⇨ The test rig is suitable for various automatized cleaning experiments including autonomous preparation of the cleaning medium and recording of process parameters (temperature, pH-value, conductivity and flow rate)

Influence of the coating process on the surface roughness

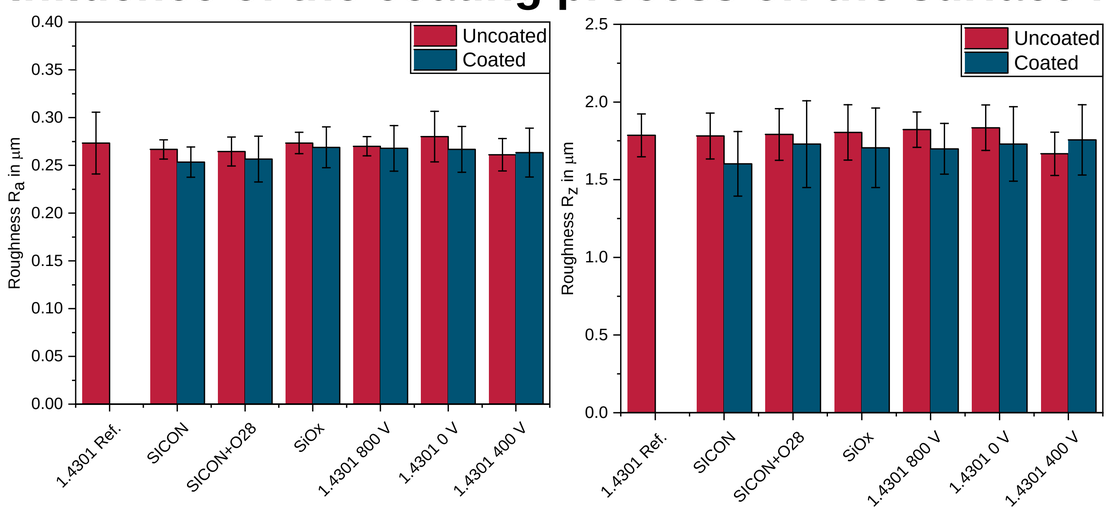


Fig. 2: Surface roughness R_a (left) and R_z (right) for the first examined coatings

- Sample plates were adjusted to a surface roughness of R_a < 0.8 µm
- The samples were prepared with two SICON (iii), one oxide (ii) and three stainless steel sputter (i) coatings
- The surface roughness was determined via digital microscopy

⇨ The surface roughness could be adjusted to R_a = 0.27 ± 0.0017 µm and R_z = 1.79 ± 0.06 µm

⇨ The coating process did not influence the surface roughness

Surface free energy of the potential coatings

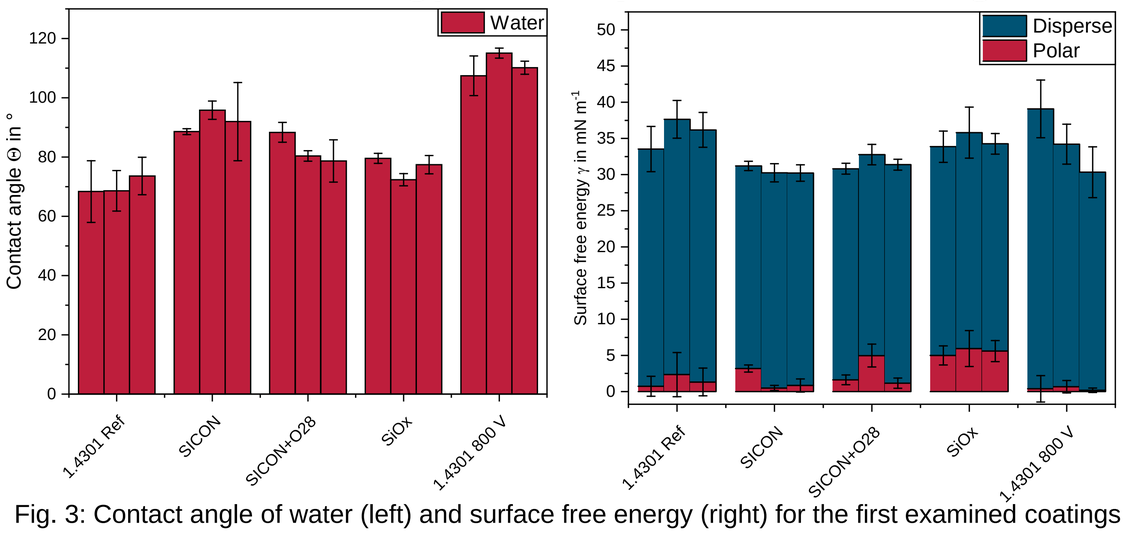


Fig. 3: Contact angle of water (left) and surface free energy (right) for the first examined coatings

- Drop shape analysis to investigate the surface free energy (SFE) appyling the Owens, Wendt, Rabel and Kaelble method (OWRK) [2-4]

⇨ Increased water contact angle for sputtered stainless steel coating

⇨ Relatively high standard deviation of SFE due to the preparation with sandpaper

⇨ Polar part increased for oxide coating

Summary

⇨ Build-up of a test rig for the validation of sensor prototypes under CIP conditions

⇨ Necessary wall shear stress to overcome the adhesive force of whey protein on stainless steel is 21 Pa

⇨ Coating of the sample plates does not affect the surface roughness

⇨ The SFE lies within a narrow range for the investigated coatings

Outlook

⇨ Test runs with the three sensor prototypes in the test rig

⇨ Improvement of the FDG experiments

⇨ Investigation of starch and tomato paste as further model soils regarding the adhesion and contact angle

⇨ Examination of further coating candidates regarding their required individual properties

Acknowledgements

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[2] Owens, D.K. and Wendt, R.C. (1969), Estimation of the surface free energy of polymers. J. Appl. Polym. Sci., 13: 1741-1747.

[3] Rabel, W. (1971). Einige Aspekte der Benetzungstheorie und ihre Anwendung auf die Untersuchung und Veränderung der Oberflächeneigenschaften von Polymeren. Farbe und Lack, 77(10), 997-1005.

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