EHEDG WORLD CONGRESS 2026

"Ensuring Food Safety and Optimising Hygienic Production"

7 & 8 October 2026
Vienna, Austria



+31 610 216 958

www.ehedg.org/congress-2026

A message to our participants



Hein Timmerman

EHEDG President
Global Sector Specialist - F&B
Diversey – A Solenis Company

Dear all,
The EHEDG World Congress 2026 marks an important milestone for our community. This year's edition is our largest World Congress to date, bringing together a record pool of experts, speakers, partners and contributors. But its real value goes beyond the numbers. It lies in bringing together people from across our industry to share knowledge, challenge assumptions and turn science into practice. Hygienic design is fundamental to food safety, operational excellence and sustainable food production. Our ambition is clear: better-designed equipment and factories, more effective cleaning and, ultimately, safer food. Because food safety does not start with cleaning - it starts with design.

Hein Timmerman, EHEDG President



Dr. Gerhard Schleining

Chair Regional Section Austria



Dr. Felix Schottroff

Co-chair Regional Section Austria
Assistant Professor, BOKU University

We are looking forward to meeting you in the modern Vienna International Conference Center, in an international environment next to the United Nations. Thanks to the EHEDG team and members of the Scientific and Organisation Committee, this will be the biggest EHEDG Congress so far with more than 400 participants, 32 posters, 37 sponsors and partners, and an exciting programme. Furthermore you will have the opportunity to experience some Viennese traditions and some historical sights of Vienna. We are looking forward to an insightful event together with you!

EHEDG Austria

EHEDG World Congress 2026
Ensuring Food Safety and Optimising Hygienic Production
Booklet and Book of Abstracts – Vienna, Austria, 7–8 October 2026
Published by European Hygienic Engineering & Design Group (EHEDG)
Amsterdam, The Netherlands
ISBN 978-90-837744-1-1
NUR 946 – Levensmiddelentechnologie
© 2026 European Hygienic Engineering & Design Group (EHEDG)

Sponsors & Partners

Gold Sponsors

Ammeraal Beltech
BIOSCAN LTD
BLÜCHER A WATTS Brand
elesa+Ganter
GEA Engineering for a better world.
ifm
STÄUBLI
Tetra Pak PROTECTS WHAT'S GOOD
VIRAVIX GROUP
WIKA

Silver Sponsors

Endress+Hauser People for Process Automation
KEOFITT World leaders in sterile sampling
SEW EURODRIVE
VIBROFLOORS WORLD GROUP
Vikan ADVANCING HYGIENIC CLEANING
ZAHNA FLIESEN
FREUDENBERG SEALING TECHNOLOGIES
Diversey A SOLENIS COMPANY
SMC
ACO
CSF
Sika
STONHARD
GOUDSMIT MAGNETICS
ECOLAB
TEK SER
UQESH 优契希

Bronze Sponsors

ATT INOX ENGINEERING
POLYSTO strong in hygienic construction
METTLER TOLEDO
habasit
SKF
hillbrush
EiQ industrial

Partners

A3
EFFoST
GLOBAL HARMONIZATION INITIATIVE

Day 1: Wednesday, 7 October

8:00 - 9:00 **Registration** | Name Tags, Welcome Packages, Coffee

Auditorium (Hall C)

9:00 - 9:15 **Opening**
Hein Timmerman *(EHEDG President & Diversey)*

Plenary speeches:

9:15 - 9:55
- **Religion of Food Safety: Prioritising Spending and Investing in Equipment**
  Frank Cervi (Mondelez)

9:55 - 10:30
- **The Importance and Benefits of Diversity & Inclusion: Impact on Creativity and Design**
  Kristen Anderson *(How Women Lead)*

10:30 - 11:00
- **Hygienic Design Is a Decision, Not a Detail – The Message of EHEDG Guideline 8**
  Jürgen Hofmann *(Hygienic Design Weihenstephan)*

11:00 - 11:30 **Coffee break** | Posters, speaker booths, sponsor visits

	Auditorium (Hall C) - Food Safety & Hygienic Building Design	Room II (2.15)- HD of Components	Room III (2.31)- Automation, Data & Food Safety	Main Hall - (Foyer A)
11:30 - 11:50	**GL 44 / Part 2 – Managing of Building Work and Equipment Installation/ Removal During Food Production** Gun Wirtanen *(SEAMK)*	**GL 20 & 14 – Hygienic Design and Safe Use of Mixproof Valves & Requirements for Valves in Hygienic Processes** Uwe Heisswolf *(Kieselmann GmbH)*	**GL 62 – Robotics** Alan Friis *(FORCE Technology)*	Guided Sponsor Visits
11:55 - 12:10	**GL 44 / Part 3 – Hygienic Design Principles for Food Factories** Patrick Wouters *(EHEDG)* & Herwig Nollet *(Volker Aufderhaar)*	**GL 65 – Sampling Systems For Representative Liquid Sampling** Carsten Rosendal *(KEOFITT)*	**Sustainability in Food Factories Through Best Practice Food Safety** Andrew Still *(SMC)*	
12:10 - 12:30	**GL44 / Part 4** Karen-Louise Habermann & Rod Benson *(Sika)*	**The Gauss Illusion: Why Flux Density Does Not Measure Magnetic Separation Performance** *Conré Oostrom (Goudsmit Magnetics)*	**Turning Hidden Risks into Actionable Decisions: A Data-Driven Approach to Food Safety** Brett Ira *(ACO)*	Guided Sponsor Visits

12:30 - 13:30	**Lunch** | Posters, speaker booths, sponsor visits	
	Auditiorium (Hall C)	
13:30 - 14:20	***Round Table*** • **Auditing: The Role Auditing Can Play in Verifying the Effectiveness of Hygienic Design as a HACCP Prerequisite Program** **Moderator:** Marc Cwikowski *(World of Auditing)* **Panel:** Marion Boulay *(IFS),* Elsabe Matthee *(FSSC),* Belen Barber *(SGS)*, Ciaran Conway *(Ferrero)*	
14:20 - 14:45	• **Making Hygienic Design Happen in the Food Factory** Adam Ruskin *(Ecolab)*	
	Auditiorium (Hall C)	Main Hall (Foyer A)
14:45 - 15:15	• **Hygienic Inner Envelope (HIE)** Ahmad Roustom *(BLÜCHER)*	Guided Sponsor Visits
15:15 - 15:40	**Coffee break |** Posters, speaker booths, sponsor visits	
	Auditiorium (Hall C)	
15:40 - 16:10	• **Biofilms in Food Processing: Persistence, Removal, Validation** Felix Schottroff *(BOKU)*	
16:10 - 16:50	• **From Recalls to ROI: Rethinking Hygienic Design & Sanitation Through Risk, Not Zero-Tolerance** Nathan Mirdamadi *(Kerry)*	
16:50 - 17:00	**Closing | Wrap-up** Hein Timmerman *(EHEDG President & Diversey)* & Gerhard Schleining *(BOKU)*	
18:00	**Buses to Dinner Venue**	
19:00 - 19:30	**Arrival & Welcome Cocktail**	
19:30 - 23:00	**Congress Dinner at Orangerie Schönbrunn**	

Day 2: Thursday, 8 October

8:00 - 9:00 **Registration** | Name Tags, Welcome Packages, Coffee

Auditiorium (Hall C)

9:00 - 9:15 **Opening**
Hein Timmerman *(EHEDG President & Diversey)*

- **GL 63 – Chocolate**

9:15 - 9:40 **Speaker:** Matilda Freund (EHEDG)
Co-Speakers: Adam Ruskin (Ecolab), Anett Winkler (Cargill), Chloe Pallister (Nestle), Edyta Margas (Bühler Group), Guiseppe Allais (Ammega Group), Jitendra Rai (Mondelēz International), John Holah (Kersia), Kelly Calixto (Diversey), Matti Heide (TU Dresden), Miomir Niksic (University of Belgrade), Natacha Holmud (FORCE Technology), Nicola Stringer (Barry Callebaut) & Shaun Pitcher (HPS Pigging)

9:40 - 10:05
- **Productivity – The Implementation of Hygienic Design in the Development of a New Site**
  Vicky Van den Bossche *(Agristo)*

10:05 - 10:30

10:05 - 10:30
- **Innovative Flushing Approaches: Experimental Investigations on Complex Components Used in Chocolate-Processing**
  Matti Heide *(TU Dresden)*

10:30 - 11:00
- **From Connected Assets to Business Outcomes: Using Industrial Data to Improve Food Safety, Sustainability and Operational Performance**
  Mohamed Al Kadari *(ifm)*

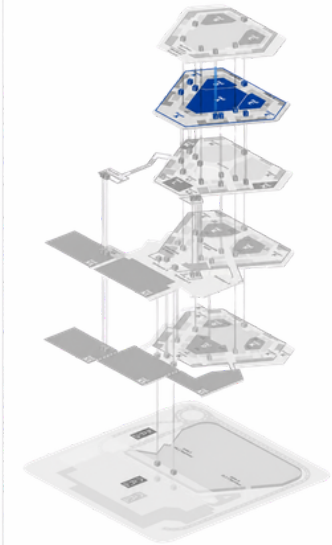
11:00 - 11:30 **Coffee break** | Posters, speaker booths, sponsor visits

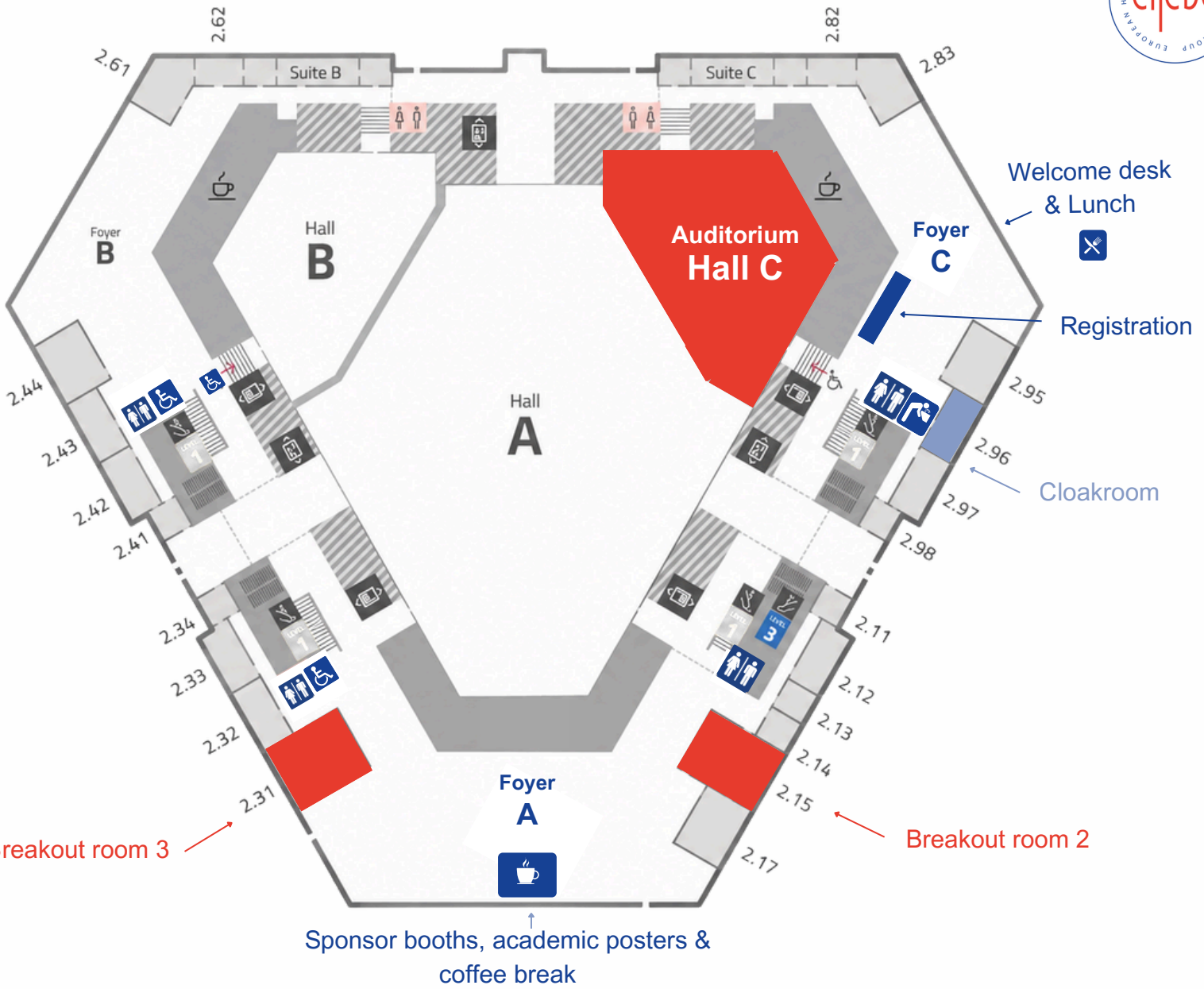
	Auditorium (Hall C) - HD for Dry Materials	Room II (2.15) - CIP: Challenges & Solutions	Room III (2.31) - Equipment, Water & Hygienic Design	Main Hall (Foyer A)
11:30 - 11:50		**GL 50 – Hygienic Design Requirements for CIP Installations** Hein Timmerman & Joe Matthews *(Sycamore Process Engineering)*	**GL42 – Disc Stack Centrifuges - Design and Cleanability** Thomas Kleimann *(GEA Group)*	Guided Sponsor Visits
11:50 - 12:10	**GL 22/41/38/60 – Dry Materials** Gabrie Meesters *(Delft University of Technology)* & Martijn van der Hoeven *(Danone Nutricia Research)*	**Interaction Between Surface Finish and Adhesion Behaviour of Media on Differently Treated Stainless Steel Surfaces** Arnulf Hörtnagl *(THWS)*	**GL28/ Safe and Hygienic Treatment, Storage and Distribution of Water in Food and Beverage Factories** Anett Winkler *(Cargill)*	

12:10 - 12:30	**Sanitation in the Chocolate Industry and the Importance of Hygienic Design** Nicola Stringer *(Barry Callebaut)*	**Digital Assistant is the Future of CIP & COP Processes** Vasyl Mazov *(Viravix)*	**Inside the US Dairy Market: A Regulator's Field Perspective** Meri Beth Wojtaszek *(3-A Sanitary Standards, Inc.)* & Chris Hylkema *(NYS Dept. of Agriculture & Markets)*	Guided Sponsor Visits
12:30 - 13:30	**Lunch** | Posters, speaker booths, sponsor visits			
	Auditorium - Thermal Processing	Room II - Food Packaging & Equipment	Room III - Professional Growth in Hygienic Engineering	
13:30 - 13:50	**GL 39 – Design Principles for Equipment and Process Areas for Aseptic Food Manufacturing** Oliver Martini	**GL 43 – Hygienic Design of Belt Conveyors for the Food Industry** Enrico Visconti *(Habasit)*	**Storytelling in Technical Presentations: How to Keep Your Audience Truly Engaged** Juliane Dias *(Flavor Food Consulting)*	
13:50 - 14:10	**GL 12 – The Continuous or Semi-Continuous Flow Thermal Treatment of Liquid Particulate Foods** Bengt Eliasson *(Tetra Pak)* & Joerg Zacharias *(Krones AG)*	**GL 29 P2 – Hygienic Design of Packaging Systems for Solid Foodstuffs – Part 2: Thermoforming Packaging Machinery** Peter Golz & Tobias Braunegger *(MULTIVAC)*	**Effost & Eye Mentorship Programme** Gabriela Versteeg *(Effost),* Adwy van den Berg *(EHEDG)* & mentors	
14:10 - 14:30	**Insights to Crack and Biofilm Detection** Samuel Peppin *(Bioscan)*	**GL 23 Part 1 & Part 2 - Lubricants** Taco Mets *(Van Meeuwen Lubrication)* & Sofia Öberg	**EHEDG Summer Course** Dirk Nikoleiski & Dr. Gerhard Schleining *(EHEDG)*	
14:30 - 14:50	**Coffe break |** Posters, speaker booths, sponsor visits			
	Auditorium (Hall C)			
14:50 - 15:30	• **Sustainability** **Moderator:** Niamh Burke *(Dairy Processing Technology Centre)* **Panel:** Ludvig Josefsberg *(Tetra Pak),* Georg Kalss *(Bühler Group),* Patrick Wouters *(EHEDG),* Raquel Ezcurra Barcos *(University of Limerick)* & Andrew Still *(SMC)*			
15:30 - 16:10	• **Foreign Bodies** Debra Smith *(Vikan)* & Intisar Khan *(Nestle)*			
16:10 - 16:50	• **Why Do We Dare to Take the Next Bite? Food, Safety and the Strange Act of Putting the Outside World Inside Our Bodies** Marije Vogelzang *(Food Design Playground)*			
16:50 - 17:00	• **Closing | Wrap-up of EHEDG World Congress 2026 & Poster Awards** Hein Timmerman *(EHEDG President & Diversey)* & Gerhard Schleining *(BOKU)*			

Complete floorplan

Entrance 2: Level 2, Foyer C





Foyer A floorplan



Information Desk

Partners

Brand Wall

Poster area

5 SMC

6 ACO

3 BLÜCHER

1 ifm

4 BIO CAN

2 STÄUBLI

23

25 POLYSTO · hillbrush · METTLER TOLEDO 20

26 EHEDG DACH · SKF 21

27 habasit · EIQ industrial · ATT 22

24

18 Jika

16 Vikan

19 STONHARD

17 KEOFITT

14 WIKA

15 AMMEGA GROUP

12 GEA Engineering for a better world.

10 VIRAVIX engineering

13 Tetra Pak PROTECTS WHAT'S GOOD

11 elesa+Ganter

38 GOUDSMIT MAGNETICS

37 TEKSER

36 JOESHO

35 ECOLAB

34 CSF

33 Endress+Hauser

32 Diversey

31 SEW EURODRIVE

30 FREUDENBERG

29 VIPROFLOORS

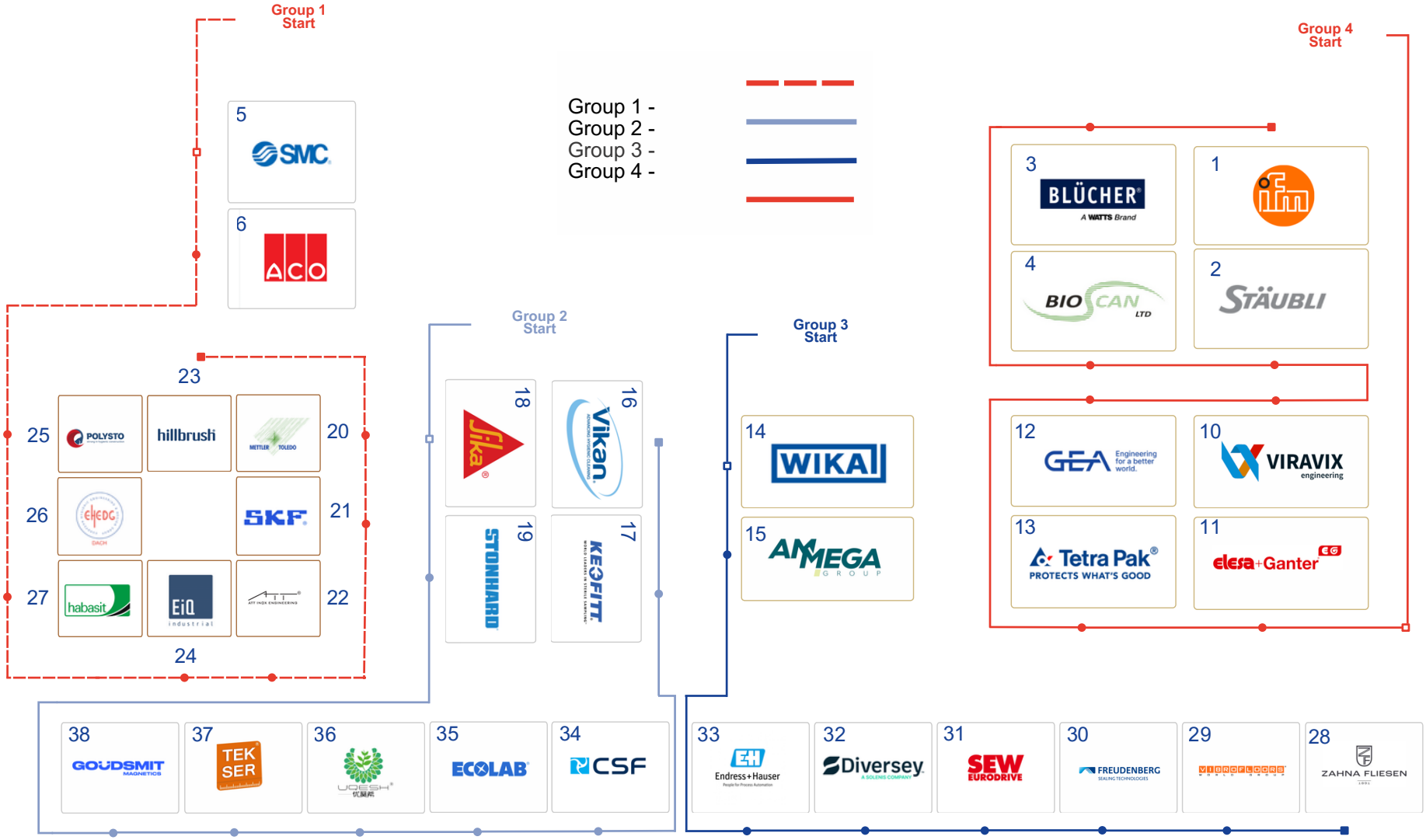
28 ZAHNA FLIESEN

Sponsor Tour Plan

Day 1 - 11:30 -12:30 & 14:45 - 15:15
Day 2 - 11:30 -12:30

Join an exclusive 30-minute sponsor booth tour on Day 1 and Day 2.
Meet exhibitors, explore innovative products and network in a relaxed setting. Each sponsor will have 90 seconds to introduce their company. Participants will be split into four groups of up to 20 people. Spaces are limited, so sign up early! You can join as many tours as you like on Day 1, and one tour on Day 2.

Sign up at the Information desk









Congress Dinner

7 October

Address:
Orangerie, Schönbrunner
Schloßstraße 47, 1130
Wien, Austria

This year's Congress Dinner will take place at the magnificent **Orangerie Schönbrunn**, part of Vienna's historic Schönbrunn Palace complex. With its imperial character and elegant setting, the Orangerie provides a memorable backdrop for an evening of good food, conversation and networking.

Guests* are invited to join us for a **cocktail at 19:00 on Wednesday, 7 October 2026,** followed by **dinner at 19:30.** The dress code for the evening is smart casual.

Transportation

To the Congress Dinner (Orangerie Schönbrunn)
Complimentary bus transportation will be provided **between the Congress venue, Hotel Schani UNO City and Orangerie Schönbrunn**.

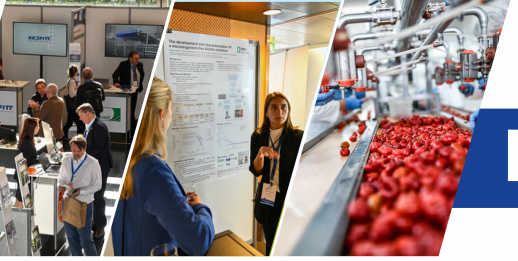
Outbound transfer

- Departure from the ACV / Congress venue: **18:00**
- Stop at **Hotel Schani UNO City**
- Arrival at Schönbrunn: approximately **19:00,** in time for the welcome cocktail

After the Congress Dinner (from Orangerie)

- Buses will depart gradually from Schönbrunn between **22:30 and 23:30.**
- Return stops will include **ACV / Kaisermühlen and Hotel Schani UNO City.**

**Please note: the Congress Dinner is included only for participants whose ticket includes dinner.*



Research posters overview

1.Additive Manufacturing for Hygienic Applications
Simone Paggetti, Andreas Neuberm, Dr. Joerg Zacharias;
Kosme (Innovation HUB); KRONES AG

2.Toward Standardized UV Bioindicators: Comparative Assessment of Microbial Resistance Across UV Technologies
Janyce Franc, Karellen Garcia Mendez, Célia Masson, Matéo Mariotte;
STERIXENE; Applied Microbiology for Food, Biomedical, and Environmental Sciences – Claude Bernard University Lyon

3.Continuous Antimicrobial Blue Light in Food Environments: A Multi-Site Case Study
Bob Meijer, Virpi Sorri, Karin Henricson;
Spectral Blue / LED Tailor Oy

4. Effect of Vaporized Hydrogen Peroxide Decontamination on Structural and Functional Properties of Bio-Based Polymer Materials
Sascha Gans, Yvette Freese, Jörg Zacharias, Felix Schottroff, Victoria Krauter;
BOKU University; KRONES AG

5.Development of a Quantitative Assessment and Compensation Strategy for Shadow Zone Cleanability in Open Plant Cleaning
Zih-Sian Yang, Shu-Li Lin, Shih-Rong Huang, Yu-Ming Chen;
Food Engineering Research and Service Center, Food Industry Research and Development Institute

6.Stability of Elastomers in Emulsified Fat
Matthias D. Eisner;
Yili Innovation Center Europe; Europe Innovation Branch, National Technology Innovation Center for Dairy

7.Risk-Based Diagnosis and a Hygienic Maintenance-Release Framework for Electromagnetic Filling Nozzles Used with Viscous Dairy Products
Amir Mansourian;
Behin Faraz Pouyeh

8.Synthesis and Characterisation of Biomimetic Materials from the Epidermis of Dicentrarchus Labrax for the Development of Antiadhesive Surfaces
Iffat Shahzad, K. Hargreaves & K.A. Whitehead;
Department of Life Sciences, Manchester Metropolitan University

9.Improving the Hygienic Design of the Non-Product-Contact Discharge Area in Dairy Disc-Stack Separators: CIP Nozzle Development and Dead-Leg Elimination
Ömer Oksem, Eray Bozlak;
Haus Centrifuge Technologies

10.Case Study on Mobile Robotic Cleaning in Poultry Processing Using the Exo MC
Karl Schweizer, Chris Henze;
Fraunhofer Institute for Process Engineering and Packaging IVV

11. AI-based Assessment of Cleanability in Processing Facilities – Project Overview

Christian Golla, Ricardo Rebel, Julian Stadie, Enrico Fuchs, Frank Rüdiger, Marc Mauermann;
Fraunhofer Institute for Process Engineering and Packaging IVV, Division Processing Technology; Institute of Fluid Mechanics, Dresden University of Technology

12.From EHEDG Guideline 62 Part 1 to Practice: Development of the New Compact Hygienic Robot

Miha Jevnikar, Dominik Jezeršek;
Research and Development Department, Yaskawa Europe Robotics

13.Non-contact Surface Roughness Classification of Stainless Steel using Active Infrared Thermography and YOLOv11 Deep Learning

Taweepol Suesut, Worapanya Suthanupaphwut;
School of Engineering, King Mongkut's Institute of Technology Ladkrabang; LineMaker Engineering Co., Ltd

14.Microbial Characterization of a Pea-Based Albumin Sidestream and Application of Processing Techniques to Improve Microbial Safety

Thomas Graf, Isabel Kalinke, Prof. Dr.-Ing. Petra Foerst, PD Dr.-Ing. habil. Mathias Hutzler;
TUM Research Center Weihenstephan for Brewing and Food Quality, TUM Associate Professorship of Food Process Engineering

15.Influence of Food-Contact Surface Material on Biofilm Formation by Bacteria Isolated from the Juice-Processing Industry

Ivana Pejanovic, Nemanja Kljajevic, Nada Smigic;
Department of Food Safety and Quality Management, Faculty of Agriculture, University of Belgrade; Molecular Genetics and Genetic Engineering, University of Belgrade

16.Data-driven Identification and Modeling for Cleaning of Surfaces Covered with Film-like Soils

Christian Golla;
Institute of Fluid Mechanics, Dresden University of Technology; now at Fraunhofer Institute for Process Engineering and Packaging IVV, Division Processing Technology

17.Comparison of CIP Cleaning of Statically and Dynamically Grown Biofilms

Julia Löscher, Matthias Joppa, Feliz Schottroff, Enrico Fuchs, Henry Jäger;
BOKU University, Institute of Food Technology; Fraunhofer Institute for Process Engineering and Packaging IVV, Division Process Technology

18.Sustainable Hygienic Design Validation in Food Processing Equipment: Integrating Cleanability and Environmental Sustainability

Raquel Ezcurra Barcos;
University of Limerick





Research posters

19.From Open to Hygienically Enclosed Curd Processing: Risk Reduction and Sustainability Benefits in Cheese Production

Bahar Özyilmaz, Erol Çalışkan, Caner Küpçü;
Department of Food Engineering, Sakarya University; Kromel Makine San. Tic. A.Ş

20.Innovative Surface Decontamination: Using Plasma-processed Air to Decontaminate Dry Plant-based Products such as Oregano and Medical Cannabis to Improve Microbial Safety

Ulrike Spilker, Uta Schnabel, Jörg Stachowiak;
Leibniz Institute for Plasma Science and Technology (INP)

21.Particle Adhesion Due to Different Surface Treatments of Stainless Steel

Thomas Scheidl, Arnulf Hörtnagl;
THWS - Technical University of Applied Sciences Würzburg-Schweinfurt

22.ECOCIP – Optimization of the CIP Cleaning Process for Fermentation Tanks under CO_2 Atmosphere

Aryson Andrade, Kelly Calixto, Willian Vilela;
Diversey, a Solenis Company

23.Microbiological Status of Reused Cleaning-in-Place Liquid in the Dairy Industry

Katrine Thorstensen, Heidi Grønnevik, Marit Smistad, Davide Porcellato;
Faculty of Chemistry, Biotechnology and Food Science, Norwegian University of Life Sciences: TINE SA

24.Cleaning of Surfaces with Water Jets Inspired by the Archerfish

Roman Murcek, Markus Klatte, Andy Spitzenberger, Enrico Fuchs, Marc Mauermann;
Fraunhofer Institute for Process Engineering and Packaging IVV; TU-Bergakademie Freiberg

25.Predicting the Composition of Low Concentration Dairy Side-Streams to Reduce Wastewater Using Machine Learning

Julius Behrens, Christian Zscherpe, Stefanie Schawe, Saskia Schwermann, Corina Jantke;
Hochschule Hannover University of Applied Sciences and Arts

26.CFD-Based Evaluation of Feed Spacer Geometry in Reverse Osmosis Channels Under Constant Porosity: Reducing Pressure Drop While Maintaining Membrane Performance

Mahmoud Saleh, Dominik Ulrich Geier, Thomas Becker;
Technical University of Munich

27.Validation of Ultrasound-Assisted Pasteurisation for Hygienic Processing of Plant-Based Liquid Egg Analogues

Mahsa Farrokhi, Jorge Pinto, Natalia Casanova, Teresa R.S. Brandão, Daniela Machado, Ana M. Gomes, Cristina L.M. Silva;
Universidade Católica Portuguesa, CBQF – Centro de Biotecnologia e Química Fina

28.Industrial Case Study: Improving Crude Palm Oil Quality Preservation Through Temperature Management and Enhanced Magnetic Trap Maintenance

Muhammad Izhar Kairi, Noor Illi Mohamad Puad, Arif Syahmi Alias, Syahril Anuar Md Rejab, Rahmat Ngteni, Mohd Shafril Baharudin, Mohd Shiraz Aris;
Mills Research, Upstream Research

29.Monitoring of Heat-Induced Fouling Using a Clamp-On Ultrasonic System

Yogesh Sharma, Phillip Müter, Dominik Geier, Jörg Hinrichs, Thomas Becker;
Brewing and Beverage Technology, TUM School of Life Sciences;
Department of Soft Matter Science and Dairy Technology, University of Hohenheim

30.Understanding the Fouling Mechanisms in Falling Film Evaporator by Microscopic and Microfluidics Approach

Margot Grostete, Jeehyun Lee, Maude Jimenez, Romain Jeantet, Luca Lanotte;
INRAE, Institut Agro; University of Montpellier

31.Microbiological Assessment of Industrial Washing of Reusable Glass Packaging

Hugo Habert, Nicolas Nguyen Van Long, Pierre Gehannin, Florence Savin, Sonia Le Noc, Delphine Gomez;
ADRIA

32.Design and Industrial Validation of a Hygienic NIR Hyperspectral Inspection System for Foreign Matter Detection in Biscuit Manufacturing

Kübra Yağiz, Başar Bozbiyik, Bora Sağiroğlu, Deniz Algül;
Pladis Global Ülker

Vote for your favourite research poster

Explore the posters and choose your favourite. Select one poster using the online ballot. Voting is anonymous, and you'll find the voting link displayed around the venue.

Hygienic Study Award

Since 2009, the Hygienic Study Award has recognised innovative research that advances hygienic design and safer food production. By connecting academia and industry, the award supports researchers in addressing real-world challenges. The three 2026 winners are honoured at the EHEDG World Congress in Vienna.

1 Poster #16 2 Poster #14 3 Poster #30



Research posters - Abstracts

1

Additive Manufacturing for Hygienic Applications

Simone Paggetti, Andreas Neuberm, Dr. Joerg Zacharias;
Kosme (Innovation HUB); KRONES AG

1) Introduction and background

The design of food-processing machinery poses significant hygienic challenges. In this context, additive manufacturing enables the integration of smooth internal flow paths that reduce sharp edges, stagnation zones, and improve cleanability. Additive Manufacturing is a group of technologies that fabricate three-dimensional objects by joining or consolidating material layer by layer directly from a digital model.

2) Objectives

This study highlights the differences among additive manufacturing technologies after post processing, considering existing hygienic requirements and providing insights toward the development of guidelines for future food-contact applications.

3) Methods

By analyzing components that could benefit from an alternative manufacturing approach, a Design of Experiments was developed based on representative industrial geometries, including three diameters, three curvature radii, and six measurement positions per bend. The resulting artifact was produced using five different additive manufacturing technologies and then processed using five distinct finishing techniques. Porosity, surface roughness, and surface topography were evaluated to assess the effects of both manufacturing and post processing route.

4) Results

Porosity analyses revealed that most technologies achieved relative densities above 99%. Localized porosity was found to play a significant role in the resulting surface roughness, although it appears to be primarily associated with additive manufacturing processes that require further optimization, whereas distributed porosity did not significantly compromise the final surface quality. Although post-processed surfaces did not fully satisfy hygienic guideline requirements over the entire surface, numerous locations exhibited Ra values below 0.8 µm.

5) Conclusions

The results indicate that porosity-related issues can be mitigated through optimized design and post-processing strategies. Surface roughness should be considered from the earliest design stages, as geometry strongly influences the final surface quality. The extent of this effect depends on both the additive manufacturing technology and the finishing process employed.

References

(PDF) Factors Affecting the Surface Roughness of the As-Built Additively Manufactured Metal Parts: A Review

Keywords: Additive manufacturing, Post-processing, Food contact, Guidelines.

Acknowledgements

The authors would like to acknowledge Krones AG for its industrial support, technical expertise, and valuable insights into food-processing applications. The authors also gratefully acknowledge the University of Modena and Reggio Emilia for providing scientific guidance and research support throughout the study.

2 Toward Standardized UV Bioindicators: Comparative Assessment of Microbial Resistance Across UV Technologies

Janyce Franc, Karellen Garcia Mendez, Célia Masson, Matéo Mariotte;
STERIXENE; Applied Microbiology for Food, Biomedical, and Environmental Sciences – Claude Bernard University Lyon

1) Introduction and background

UV technologies are increasingly used in the food industry as chemical-free alternatives; their efficacy depends on microbial species, UV type, fluence, and surface characteristics.

2) Objectives

To compare the efficacy of low-pressure UV, UV LEDs, pulsed light, and medium-pressure UV against Bacillus atrophaeus, Aspergillus brasiliensis, A. carbonarius, Penicillium rubens, and Geobacillus stearothermophilus by modulating energy via treatment time and distance on a patented UV bioindicators (2018), improved under ISO9001 (2024).

3) Methods

Experiments were performed on standardized surfaces and biological indicator supports. UV technologies were applied at varying fluences, distances, durations and culture conditions. Inoculation prevented multilayer formation to avoid false results. Parameters were tested in replicate for robustness. All tests were under controlled conditions; microbial reductions were expressed as $\log_{10}$ decreases.

4) Results

Pulsed light and medium-pressure UV, multi-wavelength technologies, achieved the highest microbial reductions, up to 7 log on Bacillus and Aspergillus in short treatment times. A single pulsed light flash at 10 mm distance produced a 7 log reduction on Aspergillus brasiliensis, demonstrating suitability for aseptic-level decontamination in high-speed packaging. Single-wavelength technologies (UV LEDs, low-pressure UV) achieved moderate reductions (2–5 log) over longer treatment durations, better suited to decontamination chambers or SAS. Statistical analysis confirmed the robustness and significance of the observed microbial reductions across replicates. Inactivation curves showed that fluence, treatment time, distance, and surface type were critical factors. Additionally, the culture medium in which spores were produced influenced UV sensitivity, with certain media yielding more resistant spores. These findings further emphasize the benefits of multi-wavelength technologies for varied microorganisms and surface types.

5) Conclusions

Multi-wavelength UV technologies provide rapid, high-level microbial reductions, offering chemical-free alternatives for high-speed packaging, while single-wavelength UV is suited to lower-throughput applications. Choosing the appropriate technology and parameters ensures reliable microbial control across microorganisms and surfaces, supporting EHEDG hygienic design and aseptic processing.

References

EP 3646890 . Bio-indicator for decontamination by ultraviolet radiation technologies (patent; bio-indicator developed for UV discrete technologies, including pulsed light and continuous/LED UV). Pulsed UV light for bacterial reduction: Impact of physical parameters on Aspergillus brasiliensis (2022), C. Chamontin, B. Nibouche & J. Franc.

Keywords: pulsed light, LED, Low-pressure, Medium-pressure, food-contact surfaces, Bacillus, Aspergillus, UV bioindicator

Acknowledgements

We also thank Hoenle group for providing the low- and medium-pressure UV technologies, which have enabled the establishment of the world's first laboratory equipped with all UV decontamination technologies.

3 Continuous Antimicrobial Blue Light in Food Environments: A Multi-Site Case Study

Bob Meijer, Virpi Sorri, Karin Henricson;
Spectral Blue / LED Tailor Oy

1) Introduction and background

The design of food-processing machinery poses significant hygienic challenges. In this context, additive manufacturing enables the integration of smooth internal flow paths that reduce sharp edges, stagnation zones, and improve cleanability. Additive Manufacturing is a group of technologies that fabricate three-dimensional objects by joining or consolidating material layer by layer directly from a digital model.

2) Objectives

This study highlights the differences among additive manufacturing technologies after post processing, considering existing hygienic requirements and providing insights toward the development of guidelines for future food-contact applications.

3) Methods

By analyzing components that could benefit from an alternative manufacturing approach, a Design of Experiments was developed based on representative industrial geometries, including three diameters, three curvature radii, and six measurement positions per bend. The resulting artifact was produced using five different additive manufacturing technologies and then processed using five distinct finishing techniques. Porosity, surface roughness, and surface topography were evaluated to assess the effects of both manufacturing and post processing route.

4) Results

Porosity analyses revealed that most technologies achieved relative densities above 99%. Localized porosity was found to play a significant role in the resulting surface roughness, although it appears to be primarily associated with additive manufacturing processes that require further optimization, whereas distributed porosity did not significantly compromise the final surface quality. Although post-processed surfaces did not fully satisfy hygienic guideline requirements over the entire surface, numerous locations exhibited Ra values below 0.8 µm.

5) Conclusions

The results indicate that porosity-related issues can be mitigated through optimized design and post-processing strategies. Surface roughness should be considered from the earliest design stages, as geometry strongly influences the final surface quality. The extent of this effect depends on both the additive manufacturing technology and the finishing process employed.

References

(PDF) Factors Affecting the Surface Roughness of the As-Built Additively Manufactured Metal Parts: A Review

Keywords: Additive manufacturing, Post-processing, Food contact, Guidelines.

Acknowledgements

The authors would like to acknowledge Krones AG for its industrial support, technical expertise, and valuable insights into food-processing applications. The authors also gratefully acknowledge the University of Modena and Reggio Emilia for providing scientific guidance and research support throughout the study.

4 Effect of Vaporized Hydrogen Peroxide Decontamination on Structural and Functional Properties of Bio-Based Polymer Materials

Sascha Gans, Yvette Freese, Jörg Zacharias, Felix Schottroff, Victoria Krauter;
BOKU University; KRONES AG

1) Introduction and background

Alternative bio-based and biodegradable materials are gaining importance in food packaging due to increasing sustainability demands. However, their compatibility with established hydrogen peroxide (H2O2)-based decontamination processes used before aseptic filling for food and beverage applications remainsinsufficiently understood. Since similar processes are applied across various packaging applications, their effects on the functional properties of emerging materials require evaluation.

2) Objectives

This study evaluates the effects of H2O2-based decontamination on the structural and functional properties of three bio-polymers: Poly(lactic acid) (PLA), Poly(lactic acid)/ poly(hydroxyalkanoate) blend (PLA/PHA), and Poly(ethylene 2,5-furandicarboxylate) (PEF). Poly(ethylene terephthalate) (PET) served as a conventional reference.

3) Methods

Materials were exposed to vaporized H2O2 under industrially relevant conditions (70 °C, 5000 ppm H2O2, 12 s). Decontamination efficiency was verified using Bacillus atrophaeus spores. Material changes were assessed by Fourier transform infrared spectroscopy (FTIR), contact angle measurements, surface roughness analysis and residual H2O2 determination.

4) Results

All materials exhibited measurable chemical and surface-related changes after oxidative decontamination. Compared with PET, the bio-based polymers showed greater susceptibility to surface modification, reflected by changes in wettability, surface free energy, and roughness characteristics. Nevertheless, the effects remained moderate and were largely confined to the surface. No evidence of severe degradation or loss of functionality was observed, indicating suitability for H2O2-based decontamination under the investigated conditions.

5) Conclusions

The results demonstrate that the investigated bio-based materials are compatible with industrial vaporized H2O2-based decontamination processes under the conditions applied in this study and may support the integration of more sustainable materials into aseptic packaging applications.

References

Andrady, A. L., Barnes, P. W., Bornman, J. F., Gouin, T., Madronich, S., White, C. C., Zepp, R. G., & Jansen, M. A. K. (2022). Oxidation and fragmentation of plastics in a changing environment; from UV-radiation to biological degradation. Science of The Total Environment, 851, 158022. https://doi.org/10.1016/j.scitotenv.2022.158022 Niaounakis, M. (2015). Biopolymers: Applications and trends. Elsevier WA. Siracusa, V., Rocculi, P., Romani, S., & Rosa, M. D. (2008). Biodegradable polymers for food packaging: A review. Trends in Food Science & Technology, 19(12), 634–643. https://doi.org/10.1016/j.tifs.2008.07.003

Keywords: Bio-based materials, Decontamination, Hydrogen Peroxide, Polymer degradation

Acknowledgements

The author would like to express sincere gratitude to Yvette Freese and Dr. Jörg Zacharias at Krones AG for their valuable support and guidance throughout this study. Special thanks are also extended to Dr. Felix Schottroff and Dr. Victoria Krauter from BOKU University for their academic supervision and insightful feedback.

5 Development of a Quantitative Assessment and Compensation Strategy for Shadow Zone Cleanability in Open Plant Cleaning

Zih-Sian Yang, Shu-Li Lin, Shih-Rong Huang, Yu-Ming Chen;
Food Engineering Research and Service Center, Food Industry Research and Development Institute

1) Introduction and background

In open plant cleaning (OPC), shadow zones caused by components such as leveling feet, support structures, sensors, and pipe connections increase contamination risk, yet current hygienic guidelines lack a standardized method for quantitatively assessing their impact on cleaning performance.

2) Objectives

This study aims to establish a quantitative methodology for shadow zone cleanability and a compensation strategy for inaccessible cleaning areas, providing design guidance for hygienic equipment and OPC systems.

3) Methods

A laboratory-scale platform used a six-axis robotic arm (payload: 10 kg; reach: 1300 mm; repeatability: ±0.03 mm), sized for real-world deployment, with a flat fan nozzle. A 1.5% hydroxyethyl cellulose solution with riboflavin (2 g/L) served as fluorescent model soil on leveling feet (GN 20, Ganter). Shadow zones were first identified by evaluating cleaning performance across nozzle-to-sample angles (90°-45°) along a fixed linear path. Then, compensation strategies were implemented by adjusting flow rate (3-6 L/min) and spray distance (50-300 mm), evaluated using a newly developed shadow zone cleanability index (SZCI).

4) **Results**

Results indicated that cleaning efficiency improved as the angle shifted from 90° to 45° (k rising from 0.03 to 0.06, R^2>0.93), yet residue converged to an asymptote of around 28%, reflecting shadow regions unresolved by angle alone. To compensate, distance reduction outperformed flow rate adjustment, raising SZCI to 98% as distance decreased from 300 to 100 mm at 4.5 L/min. Furthermore, increasing flow rate extended the critical distance for SZCI ≥ 95% from around 130 mm (3 L/min) to 250 mm (6 L/min). This suggests automated cleaning systems with robotic arms that freely adjusting nozzle-to-target distance hold greater practical applicability.

5) Conclusions

This work establishes a quantitative framework for evaluating shadow zone cleanability and provides a basis for adaptive spray parameter control in intelligent cleaning systems.

Keywords: open plant cleaning, shadow zone cleaning, cleaning compensation strategy, adaptive spray system

Acknowledgements

The funding provided by the government to the Food Industry Research and Development Institute for this project is gratefully acknowledged.

Ammeraal Beltech
Powered by AMMEGA Group

ONE STOP BELT SHOP



No Compromise
on Food Safety





ammeraalbeltech.com

BIO SCAN LTD

'Detecting the Unseen
in Real Time'

bioscanltd.com

BLÜCHER®

A WATTS Brand

'Keeping up the flow'

www.blucher.com

elesa+Ganter EG

'Two companies.
One world of standard parts.'

elesa-ganter.com

6 Stability of Elastomers in Emulsified Fat

Matthias D. Eisner;
Yili Innovation Center Europe; Europe Innovation Branch, National Technology Innovation Center for Dairy

1) Introduction and background

Elastomers like EPDM are known to not be compatible with fats/oils, however little is known on the limits of fat content when the fat is in an emulsified state as for instance in cream.

2) Objectives

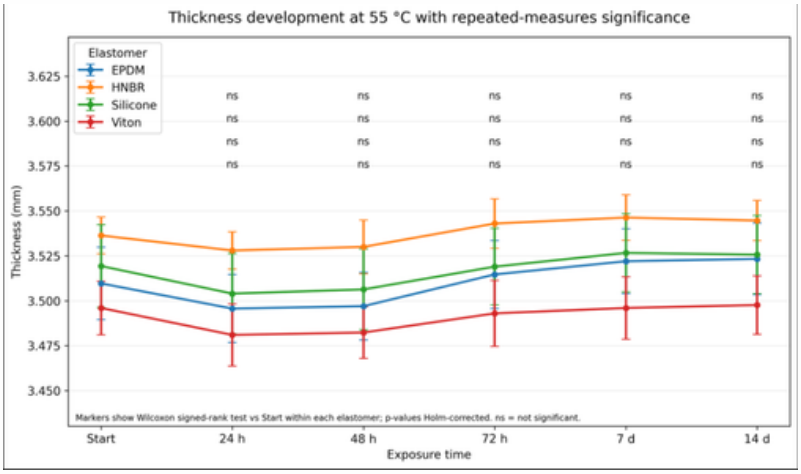
To set up a testing method for elastomer compatibility in emulsified foods and to assess the compatibility of four elastomers with 35 % fat cream.

3) Methods

Compatibility with 35 % fat UHT cream was tested at 20 °C, 55 °C, 85 °C and 100 °C on O-Rings in four different materials (EPDM, HNBR, VMQ and Viton; FDA and EC1935/2004 certified) by immersion of disinfected specimen for up to 14 days (based on ISO 1817:2011). Thickness, weight change and hardness were measured on three indepent specimen per treatment.

4)Results

At 85 °C and 100 °C excessive browning and creaming of the UHT cream occurred leading to concerns on the relevance of the immersion tests for in process conditions. Especially creaming of fat is a potential issue as the elastomer specimens sink to the bottom of the pots where the fat content is lower (or even close to zero) if strong creaming occurs. At 20 °C some samples showed gelling due to microbial contaminations. The test condition at 55 °C appeared the most suitable condition and will be used for future experiments with varying fat content and degree of homogenisation.



None of the elastomers shows significant changes in thickness over time. Even though 35 % fat is beyond the range commonly recommended for EPDM, it does not show excessive swelling. This is attributed to the finely emulsified state of the fat in homogenised UHT cream limiting direct interaction of the elastomer surface with the fat.

5) Conclusions

Stability of elastomers can be significantly higher than expected from specifications if the fat is in an emulsified state. Standard testing conditions needs to be adjusted to be suitable and practical for the food matrix used in the test.

Keywords: elastomer, seal, compatibility, emulsion, oil

Acknowledgements

The author thanks Pauline van Leusden for support in the experimental design.

7 Risk-Based Diagnosis and a Hygienic Maintenance-Release Framework for Electromagnetic Filling Nozzles Used with Viscous Dairy Products

Amir Mansourian;
Behin Faraz Pouyeh

1) Introduction and background

Electromagnetic filling nozzles used with viscous dairy products may develop intermittent performance faults. Repeated, uncontrolled disassembly during troubleshooting can also increase hygienic risk.

2) Objectives

This bench case study aimed to identify electrical condition indicators and to propose a traceable, risk based framework for diagnosis and hygienic maintenance release.

3) Methods

A healthy OEM reference nozzle, a locally manufactured nozzle and one faulty OEM nozzle were assessed. The reported field symptom was increasing fill weight after approximately five production hours, with temporary recovery after cleaning-in-place and recalibration. Bench checks included assembly and seal inspection, DC resistance, insulation to the body, free movement and actuation threshold. Series inductance (Ls), quality factor (Q) and equivalent series resistance (ESR) were measured at 1 kHz in two shaft positions on the local and faulty OEM nozzles; the faulty OEM nozzle was retested after one hour of energisation.

4) Results

DC resistance was similar for the healthy OEM reference and locally manufactured coils (16.5 and 16.8 ohm), but initial movement occurred at approximately 9 and 24 V, respectively. At 1 kHz, the local nozzle showed Ls 48.2-49.0 mH, Q 0.794-0.944 and ESR 0.326-0.381 kohm; the faulty OEM nozzle showed Ls 75.9-77.7 mH, Q 1.144-1.354 and ESR 0.352-0.426 kohm. After one hour of energisation, its Ls increased to 78.3-79.8 mH and ESR to 0.363-0.437 kohm. No short to the body or mechanical seizure was detected, demonstrating that continuity and free movement alone did not identify the observed condition differences.

5) Conclusions

Actuation threshold and dynamic electromagnetic measurements differentiated the tested conditions more clearly than DC resistance alone. The proposed maintenance-release framework combines these indicators with documented seal and packing inspection, leakage testing, functional cycling and assembly verification. Correlation with long-term in-line performance and hygienic validation remains necessary before the framework can be claimed as a validated requalification procedure.

References

EHEDG Guideline 8, Hygienic Design Principles, Fourth Edition, 2025; EHEDG Guideline 48, Elastomeric Seals, 2023.

Keywords: Hygienic filling nozzle; Electromagnetic actuator; Condition-based maintenance; Maintenance release

Acknowledgements

The author acknowledges Dr. Vafa Hemati for his technical contribution to the original magnetic circuit design

8

Synthesis and Characterisation of Biomimetic Materials from the Epidermis of Dicentrarchus Labrax for the Development of Antiadhesive Surfaces

Iffat Shahzad, K. Hargreaves & K.A. Whitehead;
Department of Life Sciences, Manchester Metropolitan University

1) Introduction and background

The use of surfaces found in nature to provide templates for self-cleaning biomimetic modal templates has attracted significant attention in recent times. One such surface is that of the Dicentrarchus labrax (European sea bass). Of particular interest is how the surface properties maintain the hygienic status of the surfaces with particular focus centered around their unique topographically structured surfaces. However, such surfaces have a mucus layer, and the incorporation of sustainable conditioning films to achieve anti-adhesive properties have been largely overlooked.

2) Objectives

This study provides a fundamental insight into the development of a novel sustainable anti-adhesive surface that have the potential to reduce the need for cleaning, through detailed biomimicry.

3) Methods

This research aimed to determine the surface properties of D. labrax using chemical analyses (Fourier Transform Infrared and Raman spectroscopy), topographical imaging (Scanning Electron Microscopy, Optical profilometry), and hydrophobicity (Dynamic contact angle measurements). The antiadhesive efficacy of the surfaces assessed using attachment and retention assays in the presence and absence of conditioning films, against food borne pathogens.

4) Results

The results demonstrated distinct macro- and micro-topographical features were successfully reproduced onto fabricated biomimetic surfaces. The physical properties and modified chemical characteristics were shown to reduce biofouling when compared to the non-topographical controls. The D. labrax biomimetic replicates showed distinct changes in attachment and retention of microbes in the presence and absence of fish mucus.

5) Conclusions

The impact of this work demonstrated that these surfaces have the potential to reduce biofouling in the longer term, providing a template for the design of antifouling surfaces in the future.

Keywords: antiadhesive surfaces, hygiene, sustainable solutions

9 Improving the Hygienic Design of the Non-Product-Contact Discharge Area in Dairy Disc-Stack Separators: CIP Nozzle Development and Dead-Leg Elimination

Ömer Oksem, Eray Bozlak;
Haus Centrifuge Technologies

1) Introduction and background

In disc-stack separators, particularly in dairy applications, prolonged operation and intermittent running without product raise internal surface temperatures and promote the adhesion of expelled organic milk residues both in dead zones that lie outside the reach of the existing CIP system and in dead legs within the sludge collector, where they cause contamination.

2) Objectives

This study aimed to improve cleaning efficiency in these non-product-contact areas by developing a nozzle that directs cleaning fluid to the dead zone outside the bowl group and by eliminating the dead leg in the sludge collector that caused contamination.

3) Methods

Deposits in the non-product-contact areas were documented photographically before both improvements. In the first, the bowl group design was modified to add a nozzle directing cleaning fluid to the dead zones outside the bowl group, which previously received no cleaning fluid. In the second, the dead leg in the bowl-independent sludge collector — where cleaning fluid could not reach and contamination formed — was eliminated. Cleaning effectiveness was evaluated by the riboflavin fluorescence method in accordance with the VDMA riboflavin test: target surfaces were coated with riboflavin, the CIP cycle was run, and residual fluorescence was inspected under UV light. As a case study, cleaning performance was documented qualitatively through photographic and video evidence.

4) Results

This work is presented as a qualitative case study. With the added nozzle, cleaning fluid was confirmed to reach the dead zones outside the bowl group, and eliminating the dead leg removed the contamination risk in the sludge collector. For both improvements, the riboflavin fluorescence method showed no residual fluorescence on the inspected target surfaces after the CIP cycle. These qualitative outcomes were further supported by photographic and video documentation confirming that cleaning fluid reached the previously uncleaned target areas throughout the cycle.

5) Conclusions

These two improvements enhanced the cleaning efficiency of an already compliant CIP system in the non-product-contact areas and reduced contamination risk, advancing the hygienic design of dairy separators.

References

1. EHEDG Guideline Doc. 8 (4th ed., 2025): Hygienic Design Principles.
2. EHEDG Guideline Doc. 42 (2nd ed., June 2025): Disc Stack Centrifuges - Design and Cleanability.
3. VDMA Process Plant and Equipment Association: Riboflavin test for low-germ or sterile process technologies - Fluorescence test for examination of cleanability. Information Sheet, English edition, March 2008.

Keywords: disc-stack separator; cleaning-in-place (CIP); dead zone; dead leg; hygienic design.

Acknowledgements

The authors would like to thank HAUS Centrifuge Technologies for providing the experimental facilities, testing resources at the Science and Innovation Centre, and continuous support throughout this study.

10 Case Study on Mobile Robotic Cleaning in Poultry Processing Using the Exo MC

Karl Schweizer, Chris Henze;
Fraunhofer Institute for Process Engineering and Packaging IVV

1) Introduction and background

Manual cleaning of open food production environments is labour-intensive, physically demanding and difficult to standardise, while hygienic production requires reproducible cleaning, efficient resource use and safe working conditions.

2) Objectives

This industrial case study assessed whether the Exo-MCD, a mobile cleaning robot for open production environments, can reduce water consumption while meeting defined hygiene targets in a poultry processing station.

3) Methods

The Exo-MCD was evaluated at a poultry “grill station” including drainage channels, a conveyor belt, stainless-steel collection trays and overhead structures. After production, one manual reference cleaning and two robot-assisted cleaning trials were documented over three production days. Cleaning comprised pre-rinsing, alkaline foaming, rinsing, disinfection and final rinsing with approx. 50 °C water and site specific cleaning media. Water consumption was measured using a clamp-on ultrasonic flow sensor, cleaning time was recorded for each step, and hygiene performance was assessed at five predefined sampling points using LuciPac A3 Surface swabs for ATP/ADP/AMP.

4) Results

Both Exo-MCD trials achieved ATP values below the 500 RLU pass threshold at all five sampling points, with trial 1 ranging from 32 to 442 RLU and trial 2 from 116 to 427 RLU. The manual reference required 58.0 min and 960.0 L of water. Including the manual pre-rinse reference, the first robot-assisted run required 92.3 min and 555.3 L; after one optimisation of paths, motion sequences and nozzle configuration, the second run required 72.4 min and 475.3 L. Thus, water consumption was reduced by 42.2% and 50.5% versus manual cleaning, while cleaning time was reduced by 19.9 min between the robot-assisted trials. Manual support remained necessary for plant preparation, protection of sensitive components, media changeover and isolated hard-to-reach areas.

5) Conclusions

These industrial trials demonstrate that mobile robotic cleaning can meet defined ATP-based hygiene targets in a real poultry processing environment and substantially reduce water consumption. Further optimisation of accessibility, process parameters and human-robot task allocation may increase automation and improve industrial applicability.

References

[1] L. A. L. Giske, E. Bjørlykhaug, T. Løvdal, O. J. Mork, Experimental study of effectiveness of robotic cleaning for fish-processing plants, Food Control 100, 269–277, 2019.
[2] M. Bakke, A Comprehensive Analysis of ATP Tests: Practical Use and Recent Progress in the Total Adenylate Test for the Effective Monitoring of Hygiene, Journal of Food Protection 85(7), 1079–1095, 2022.

Keywords: mobile cleaning robotics; food hygiene; ATP verification; poultry processing; resource efficiency

GEA

Engineering for a better world.

'Engineering for a better world'

www.gea.com/en/



FAST MOVING TECHNOLOGY

STÄUBLI



ROBOTICS

Food specialists in Hygienic design

Tetra Pak®

PROTECTS WHAT'S GOOD

'Tetra Pak: Protects What's Good'

www.tetrapak.com

11 AI-based Assessment of Cleanability in Processing Facilities – Project Overview

Christian Golla, Ricardo Rebel, Julian Stadie, Enrico Fuchs, Frank Rüdiger, Marc Mauermann;
Fraunhofer Institute for Process Engineering and Packaging IVV, Division Processing Technology; Institute of Fluid Mechanics, Dresden University of Technology

1) Introduction and background

Designing components and systems in compliance with hygiene standards is essential for product safety and makes cleaning significantly more efficient, but requires a high level of expertise to implement.

2) Objectives

The goal of the project is to use AI to develop a simple, intuitive method to be used as early as the development phase to verify whether the components are designed to meet hygiene standards.

3) Methods

The assessment is based on the machinery directive 2006/46/EC, general design recommendations, the EHEDG guidelines [1, 2], and 3A sanitary standards [3]. The guidelines must be translated into criteria that can be verified algorithmically. An AI segmentation model is being developed to identify hygiene-critical areas in CAD models or plant layouts and evaluate them according to specific criteria. In addition, flow-induced cleaning is quantified using a cleaning index [4]. Reduced-order models will be developed and used to calculate the flow and the cleanability index in the plant so that computations can be performed on industrial practicable time scales.

4) Results

This contribution provides an overview of the project; a diagram illustrating the proposed methodology is shown in Fig. 1. In addition, initial work on the following topics is presented: a) the development of reduced-order models for determining the cleanability index, b) concepts for corresponding validation experiments, c) the formulation of quantitative criteria for evaluating cleanability, d) the development of an AI-based segmentation model. Pipe elbows serve as a first example.

5) Conclusions

These results greatly facilitate the conduct of virtual hygienic design assessments and make them more accessible for widespread use. Overall, this contributes to the sustainable development of machinery and systems.

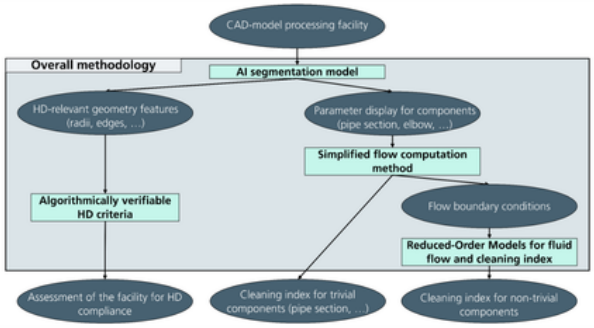


Figure 1 Diagram of the methodology to be developed in this project. Input: CAD model of the processing facility; Output: Evaluation of the system for HD compliance and cleaning index

References

[1] EHEDG, „EHEDG Guidelines Doc. 2: A method for assessing the in-place cleanability of food processing equipment (3. Aufl.)“. 2007.
[2] European Hygienic Engineering Design Group, *EHEDG Guidelines Doc. 8: Hygienic Design Principles*, 3. Aufl. 2018.
[3] „3A Sanitary Standards - General Requirments“. 3A, Januar 2028.
[4] M. Joppa, T. Hanisch, und M. Mauermann, „Methodology for the assessment of cleanability and geometry optimization using flow simulation on the example of dimple-structured pipe surfaces“, *Food and Bioproducts Processing*, Bd. 132, S. 141–154, März 2022, doi: 10.1016/j.fbp.2021.12.004.

Keywords: AI, Cleaning, Hygienic Design, Reduced-order Models

Acknowledgements

The project (11-38725) of the IVLV is supported within the programme for promoting the Industrial Collective Research (IGF) of the German Federal Ministry of Economic Affairs and Energy (BMWE), based on a decision by the German Bundestag.

12

From EHEDG Guideline 62 Part 1 to Practice: Development of the New Compact Hygienic Robot

Miha Jevnikar, Dominik Jezeršek;
Research and Development Department, Yaskawa Europe Robotics

1) Introduction and background

Robots used in open food-processing environments combine complex moving joints, hollow bodies and utility interfaces, creating specific risks of contaminant ingress, residue accumulation and insufficient cleanability.

2) Objectives

This industrial case study evaluates how the fundamental hygienic design criteria of EHEDG Guideline 62 Part 1 were translated into the design of the new compact six-axis robot.

3) Methods

The development team converted the guideline topics into a design-input checklist covering hygienic risk assessment, materials, foreign-body prevention, auxiliary media, accessibility, cleanability, seals and documentation. The robot's design was reviewed against this checklist together with EHEDG GL 8 and GL13. Attention was given to external geometry, rotating joints, sealing interfaces, exposed fasteners, connectors, internal routing of signal and fluid lines, coating and lubricant selection, and maintenance access. Cleanability validation testing through an EHEDG ATL is planned as the next step in the product verification process.

4) Results

The review resulted in a robot with smooth transitions, reduced external recesses, sealed interfaces, internally routed utilities and an external axial-sealing concept at rotating joints. The HD variant includes targets for IP69 protection, chemical resistance, food-contact compliant material systems, ISO Class 5 cleanroom suitability and GMP Grade A suitability.

5) Conclusions

EHEDG GL 62 Part 1 provided a practical framework for converting hygienic-design principles into concrete robot-body design decisions.

References

1. EHEDG GL 62-1, Hygienic Design Criteria for Robotic Systems, 2026.
2. EHEDG GL 8, Hygienic Design Principles, 2025.
3. EHEDG GL 13, Hygienic Design Criteria for Wet-Cleaned Open Food Equipment, 2024.

Keywords: Hygienic Design, 6-Axis Robot, Cleanability, Axial Sealing, EHEDG GL 62

Acknowledgements

The authors acknowledge the EHEDG Robotics Working Group for their contributions to the development of hygienic design criteria for robotics

13 Non-contact Surface Roughness Classification of Stainless Steel using Active Infrared Thermography and YOLOv11 Deep Learning

Taweepol Suesut, Worapanya Suthanupaphwut;
School of Engineering, King Mongkut's Institute of Technology Ladkrabang; LineMaker Engineering Co., Ltd

1) Introduction and background

Surface finish quality is one of the critical parameters in hygienic equipment design, especially in food, beverage, pharmaceutical, and biotechnology industries. Stainless steel surfaces with improper roughness can promote product residue accumulation, bacterial adhesion, and biofilm formation, which directly affect cleanability and food safety. Therefore, hygienic standards such as EHEDG and 3-A Sanitary Standards emphasize the importance of surface smoothness and proper material finishing for hygienic process equipment.

Conventionally, surface roughness is measured using contact profilometers. Although highly accurate, these methods are time-consuming, require direct contact with the equipment surface, and are difficult to implement for in-line inspection during manufacturing or maintenance operations. In hygienic production environments, non-contact and rapid inspection methods are increasingly desirable to support preventive quality control and hygienic verification processes.

2) Objective

The proposed system aims to evaluate stainless steel surface conditions without physical contact, supporting future applications in hygienic equipment inspection and smart manufacturing environments.

3) Materials and Methods

Stainless Steel Surface Preparation: AISI 304 stainless steel specimens were selected because this material is widely used in hygienic processing equipment due to its corrosion resistance, cleanability, and compliance with hygienic design requirements.

Different surface roughness conditions were prepared using mechanical polishing with abrasive papers of various grit sizes including 40, 80, 180, and 400 mesh. Additional samples were treated using Scotch-Brite finishing to simulate industrial hygienic finishing conditions commonly used in food processing equipment fabrication.

Surface roughness values (Ra) were measured using a contact profilometer as reference data. The measured Ra values ranged from approximately 0.25 μm to 1.98 μm depending on the polishing condition.

Active Infrared Thermography System: Thermal images were captured using a FLIR A315 infrared camera equipped with an uncooled microbolometer sensor operating within the wavelength range of 7.5–13 μm. The thermal excitation source was generated using a calibrated infrared blackbody source to produce controlled thermal reflection patterns on the stainless-steel surfaces.

The experimental setup was designed to simulate a non-contact inspection environment. The thermal camera was positioned approximately 60 cm from the specimen surface under controlled ambient conditions at approximately 27°C.

Differences in roughness influenced the emissivity and thermal reflection characteristics of the stainless-steel surfaces. Rougher surfaces generated more irregular thermal distribution patterns, while smoother surfaces exhibited more uniform thermal responses.

Deep Learning-Based Surface Classification: The acquired thermal images were processed and annotated using the Roboflow platform. A total of 622 thermal images were collected and resized to 512 × 512 pixels for deep learning training.

The dataset was divided into: 560 images for training (90%); 62 images for validation (10%)

YOLOv11 deep learning architecture was employed to classify stainless steel surface roughness conditions from thermal images. The model was trained for 100 epochs to learn thermal distribution features associated with different surface finishing conditions.

4) Results

The experimental results demonstrated that thermal imaging combined with AI could effectively distinguish stainless steel surfaces with different roughness levels.

The YOLOv11 model achieved: mAP@0.5 ≈ 0.995; mAP@0.5:0.95 ≈ 0.89

Classification accuracy for different surface conditions was: 40 mesh: 90%; 80 mesh: 85%; 400 mesh: 90%; Scotch-Brite finished surfaces: 100%

The results indicate that thermal image characteristics strongly correlate with surface finishing conditions. Smoother hygienic finishing surfaces showed more homogeneous thermal distributions due to more consistent infrared reflection behavior.

One limitation was observed for the 180 mesh condition, which showed lower classification performance because its thermal characteristics were similar to the 80 mesh surface. This suggests that future work should include larger datasets and regression-based roughness estimation approaches for improved sensitivity.

From a hygienic design perspective, the proposed system demonstrates strong potential as a rapid screening and verification tool for hygienic surface finishing inspection. The technology may support:

- Hygienic fabrication quality control
- Surface finishing verification
- Preventive maintenance programs
- Smart hygienic manufacturing systems

The proposed approach also aligns with Industry 4.0 concepts by integrating AI and non-destructive sensing technologies into hygienic process equipment monitoring.

5) Conclusions

This study demonstrated the feasibility of AI-based non-destructive stainless steel surface roughness detection using Active Infrared Thermography and YOLOv11 deep learning.

The proposed method successfully classified different stainless-steel surface finishing conditions using non-contact thermal imaging techniques. The system achieved high classification accuracy and showed strong potential for hygienic design applications, particularly in food and pharmaceutical manufacturing industries where surface cleanliness and cleanability are critical requirements.

The integration of thermal imaging and artificial intelligence may provide a future pathway toward rapid hygienic inspection systems for industrial manufacturing and hygienic equipment verification.

References

[1] EHEDG document No.32 Material of Construction for Equipment in Contact with Food, 2005.
[2] C. A. Brown, Surface Texture Analysis: The Handbook. London, UK: Springer, 2013.
[3] T. R. Thomas, Rough Surfaces. London, UK: Imperial College Press, 1999.
[4] International Organization for Standardization, Geometrical Product Specifications (GPS) — Surface Texture: Profile Method — Terms, Definitions and Surface Texture Parameters (ISO 4287). Geneva, Switzerland: ISO, 1997.

Keywords: Stainless Steel Surface Roughness, Active Infrared Thermography, Deep Learning, YOLOv11, Non-destructive Testing, Hygienic Design

Acknowledgements

The authors gratefully acknowledge the School of Engineering, King Mongkut's Institute of Technology Ladkrabang, for supporting this research.

14

14.Microbial Characterization of a Pea-Based Albumin Sidestream and Application of Processing Techniques to Improve Microbial Safety

Thomas Graf, Isabel Kalinke, Carolin Wolf, Petra Foerst
TUM Research Center Weihenstephan for Brewing and Food Quality, TUM Associate Professorship of Food Process Engineering

The demand for plant-based foods for a growing world population is increasing. Pea proteins are gaining interest in food technology due to the increasing problem of supplying humanity with protein. Currently untapped potential for human nutrition lies in the utilization of a pea-based albumin sidestream obtained after alkaline wet-extraction and isoelectric precipitation of pea flour. Therefore, the present study aims to present important findings for the transformation of the often-discarded albumin sidestream into a valuable food ingredient.

When it comes to minimizing the environmental impact of food production, it is also essential to reduce losses and inefficiencies throughout the value chain. Postharvest losses and waste in the supply chain, particularly from industrial-like sidestreams of protein processing, are of special interest. Utilizing pulse protein side-stream fractions can significantly reduce waste, thereby enhancing the concept of a circular economy. Moreover, upgrading sidestreams from waste or animal feed to higher-quality food can provide economic benefits.

However, reformulating traditional products with new plant-based ingredients requires careful attention to microbiological safety and the stability of the final product. Understanding the presence of microbial contaminants in plant-based ingredients, along with their key characteristics related to growth and inactivation, is necessary to assess microbial risk. This knowledge would further enable the effective design of processing conditions and reformulations for plant-based foods, ensuring food safety and preventing spoilage.

Currently, significant knowledge gaps remain regarding the microbial composition of various sources of plant proteins, where the initial levels of microbial contaminants remain inconsistent. Additionally, established standard heat treatments to remove microorganisms, as used for milk products, may not be suitable for plant-based alternatives, as their chemical and physical properties differ from those of milk. The present study aims to reduce these knowledge gaps for a pea-based albumin sidestream. The thesis investigates changes in microbial load during the production of the albumin sidestream out of pea flour. In addition, the microbial composition of the albumin sidestream is analyzed, along with storage tests to assess microbial stability. Heating processes and microfiltration are performed to explore methods for reducing the microbial load. Results that have not been previously described, regarding microbial stability and the removal and inactivation of microorganisms in the albumin sidestream, are presented. The findings of this study help in assessing the microbial risk management of a pea-based albumin sidestream.

At first, in the present study, the alkaline wet-extraction and isoelectric-precipitation, used to extract an albumin sidestream (2S) from pea flour, was transformed from a laboratory-scale extraction process into an extraction process that mimics industrial-like processes. The extraction procedure is outlined in Figure 1. For the transformation, the concentration of pea flour was increased in a first step from 6.3 % w/w to 20.0 % w/w, and the centrifugation time and applied g-force during centrifugation were reduced in a second step from 4500 xg for 20 min to 3000 xg for 1 min. In this regard, hypothesis 1 (H1) was proposed: increasing the concentration of pea flour and adjusting centrifuge settings would result in changes in the microbial loads of the product streams.

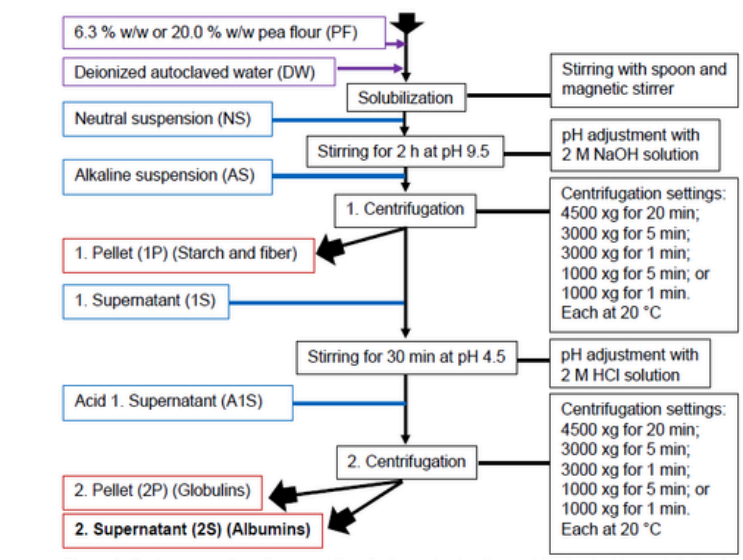


Figure 1: Basic process flow diagram of the alkaline wet-extraction and the isoelectric-precipitation for the production of an albumin sidestream (2S) out of pea flour. Raw materials are shown with a purple frame, process intermediates with a blue frame, and end products with the desired main components in brackets in a red frame. Process steps are shown in the middle with their corresponding parameters on the right side.

The microorganisms in the samples were quantified using a standard pour-plating method with 10-fold serial dilutions. The procedures were carried out following the established guideline DIN EN ISO 4833-1:2013. To determine the total viable count of aerobic mesophilic bacteria (VMC), 1 mL of the homogenized samples and their 10-fold serial dilutions were transferred to sterile Petri dishes (90 mm) and pour-plated with 18 – 20 mL of sterile liquid Plate Count Agar (PCA). Each sample and its corresponding dilution series were plated in duplicate. After the culture medium had solidified in the plates, they were incubated at 30 ± 0.5 °C for 48 ± 2 hours.
The microbial load of the end products and intermediates during production of albumin sidestream is shown in Figure 2.

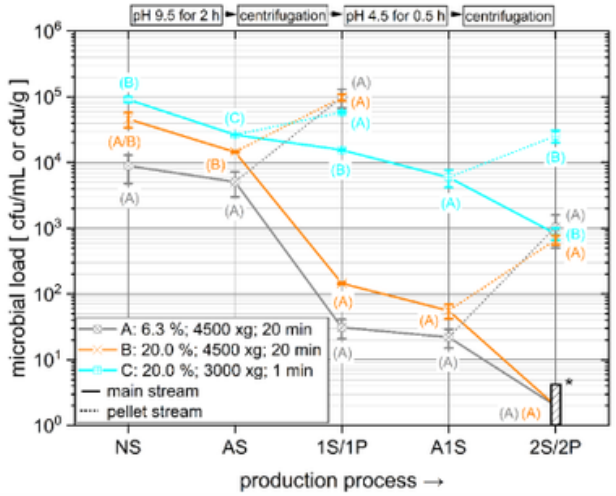


Figure 2: Microbial load as viable mesophilic count (VMC) at end products and intermediates during production of albumin sidestream (2S). The x-axis shows the process intermediates and final products obtained during the extraction process. VMC of the supernatants is shown in the main streams. VMC of the pellets is shown in the pellet streams. The following abbreviations are used in the figure: NS = neutral suspension of pea flour and water; AS = alkaline suspension at pH 9.5; 1S = first supernatant; 1P = first pellet; A1S = acidic first supernatant at pH 4.5; 2S = second supernatant; 2P = second pellet. The results are based on 2 biological replicates for each setting. Capital letters in parentheses indicate the significance of the differences between one product, such as AS, across settings A, B, and C (ANOVA, post hoc Bonferroni test, $p < 0.05$).
* VMC was below the limit of precise quantification of 4 cfu/mL.

14 The selection of centrifugation conditions impacted the microbial loads of the product streams. This opens up opportunities for producers of albumin sidestream to manage the flow of microorganisms through adjustment of centrifuge settings. The selection of the centrifugation parameters proved to be the most important factor for managing the flow of the microorganisms during the extraction process. Out of this knowledge, guidelines can be derived: To achieve a low microbial load in pea protein extracts, producers should perform intensive centrifugation during the alkaline extraction. The disadvantage, however, is that the starch and fibercontaining pellet after the first centrifugation then has a higher microbial load. It must therefore 4 be weighed up in each individual case what further uses the respective products have and what effects microbial contamination in the respective intended uses has. The increase in the pea flour concentration did not influence the microbial load in the end products. In summary, hypothesis 1 can therefore only be partially agreed with. As a further objective, the microbial status during storage of the albumin sidestream produced with industrial-like production settings was evaluated. The results are shown in Figure 3.

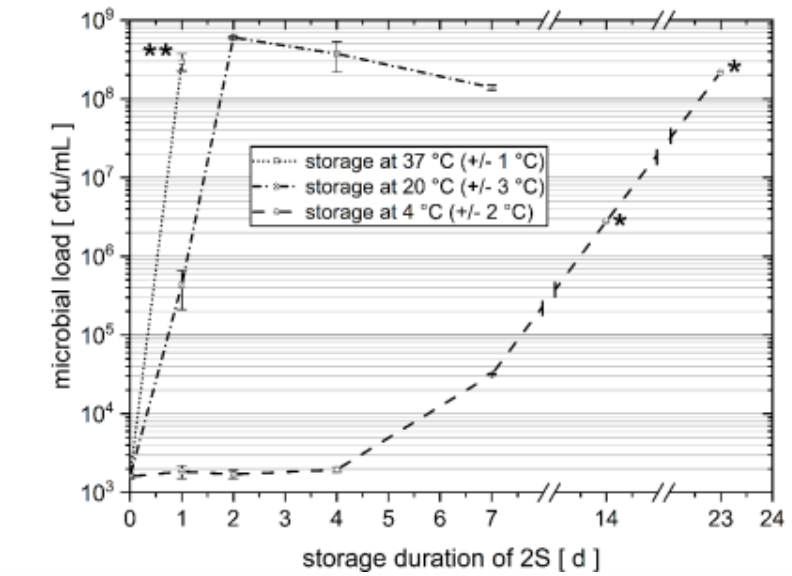


Figure 3: Microbial load of albumin sidestream (2S) during storage at 4 °C, 20 °C, and 37 °C. The data points were created from 2 biological replicates, if not otherwise stated. The data points were connected with dashed lines to improve readability. It is important to note that the dashed lines do not represent the time-dependent changes in viable mesophilic count (VMC) between data points. * The microbial load after 14 d was measured only in the second run; the microbial load after 23 d was measured only in the first run. ** Microbial load of 6 biological replicates of 2S after storage at 37 °C for 1 day; initial VMC was assumed to be the same as at the initial VMC of the storage tests at 4 °C and 20 °C. Microorganism growth in 2S occurred at 37 °C, 20 °C, and even at 4 °C, indicating microbiological instability and showing that 2S is a supportive medium for the reproducing microorganisms. Cold storage of albumin sidestream at around 4 °C after production is recommended, as 2S remained microbially stable at a storage temperature of 4 °C for approximately 4 days. The storage tests with the albumin sidestream have led to the recommendation of a cold storage around 4 °C for a maximum of 4 days after production in order to keep microbial stability. During this time period, producers of albumin sidestream can either transport the albumin sidestream for further processing or store the product until measures are taken to reduce or inactivate microorganisms. Furthermore, the microbial community was analyzed from freshly produced albumin sidestream (2S) and its fermented form (2SF), obtained after 24 h storage at 37 °C, by sequencing the V3-V4 region of 16S rRNA. Additionally, a primer targeting at chloroplast 16S rRNA gene sequence was used during PCR to selectively inhibit the amplification of plant chloroplast 16S rRNA, resulting in a higher relative yield of bacterial amplicons.

Analysis of the microbial composition of the albumin sidestream showed that the unfermented albumin sidestream (2S) was dominated by Latilactobacillus curvatus and Erwinia or Pantoea species. Possible changes in the microbial composition from pea flour to 2S might have been caused by the extraction process. To test this assumption, further analysis of the microbial composition of all process intermediates and end products of the extraction process is necessary. The fermented albumin sidestream (2SF),

obtained after storage of 2S at 37 °C for 24 hours, was dominated by Lactococcus taiwanensis with a smaller proportion of Escherichia or Shigella species. The comparison with 2S shows that fermentation caused a shift in the microbial community. Apart from Escherichia and Shigella species, the dominating microorganism groups in 2S and 2SF do not pose a threat to food safety. Further analyses are recommended to obtain a more quantitative and precise result about the microbial community of 2S and 2SF in order to draw final conclusions regarding food safety.

To reduce microbial load and ensure food safety in the albumin sidestream, heat treatment with several temperature-time combinations and filtration with one representative setting were performed. Fermented albumin sidestream (2SF), obtained after storage of 2S at 37 °C for 24 hours, was used for the microbial reduction tests. In this regard, hypothesis 2 (H2) was proposed: heat treatment and filtration (microfiltration, 0.1 µm, 10 °C) effectively reduce or inactivate microorganisms in the albumin sidestream.

Through microfiltration with a membrane with a pore size of 0.1 µm, an average reduction in microbial load of 6.1 ± 0.6 log10 cfu/mL was obtained. There were no significant differences in dry matter, protein content, and globulin-to-albumin ratio observed between the 2SF feed, the permeate, and the retentate, suggesting that no significant concentration occurred during microfiltration. Therefore, microfiltration might be a promising method for ensuring the food safety of the albumin sidestream. Regarding filtration, H2 was therefore accepted. Unlike thermal treatment, microfiltration does not lead to thermally induced particle agglomeration, which is important for preserving natural protein structure and functionality. Furthermore, in contrast to thermal treatment, the removal of microorganisms with microfiltration does not depend on the D-values of the microorganisms and the initial microbial load. In comparison, for thermal treatment in industrial applications, to ensure food safety, the realistic worst-case microbial load must be assumed, and an appropriate temperature-time combination must be selected. Then, even in cases of low microbial contamination, the product is processed using the worst-case heating setting, which leads to product damage due to excessive heat treatment.

However, one disadvantage of the filtration is that the microorganisms-enriched retentate must also be used to fulfill the overall product use. For the retentate, thermal treatment could be used to inactivate the microorganisms. Heating temperatures of 126 °C or 140 °C are recommended in order to inactivate bacterial spores. The necessary holding times depend on the initial microbial load and must be determined with further tests. Due to the resulting thermal damage, the retentate may then, depending on the intended use, have to be used for a different purpose than the permeate. It must also be noted and further investigated that microfiltration does not separate out any valuable ingredients apart from the microorganisms.

For the reduction of microbial load with heat treatment, the samples were heated at 64 °C (± 1 °C) for holding times of around 0 min – 120 min, at 78 °C (± 2 °C) for holding times of 0 s - 87 s, and 126 °C (± 0.5 °C) and 140 °C (± 0.5 °C) for holding times between 2 s and 15 s. With these temperature-time combinations, the established heat treatments pasteurization, extended shelf-life processing with high-heat-treatment, and ultra-high temperature processing should be imitated.

At 64 °C, a D-value of D64 °C ≈ 20.8 s ± 3.0 s was analyzed, and at a heating temperature of 78 °C, a D-value of D78 °C ≈ 11.9 s ± 0.9 s was determined. To accurately determine the Dvalues, additional tests with different temperature-time combinations and with selected bacterial strains are recommended. As it was assumed that bacterial spores survived the heat treatment at 64 °C and 78 °C, hypothesis 2 (H2) was rejected for the heat treatment at these temperatures.

At heating temperatures of 126 °C and 140 °C for holding times of 3 s (± 0.5 s), microbial loads of < 1 cfu/mL with 8.45 ± 0.09 log10 reduction were found. These heating conditions are likely to effectively inactivate spore formers in 2S, ensuring food safety and potentially extending storability, provided recontamination is avoided. Therefore, regarding the heat treatments at 126 °C and 140 °C, H2 was accepted. However, further research with additional heating conditions is needed to determine the optimal process window for conclusive results. To sum up, the present study presents valuable insights for producers of albumin sidestream. However, further research is necessary to close the knowledge gap regarding microorganism behavior in the albumin sidestream and to determine the best practices for achieving microbial food safety. With this knowledge industry might be able to turn the albumin sidestream into a valuable product stream used for human nutrition. For further research, the current study offers important starting points, such as the effective approach to achieving microbial food safety in the albumin sidestream through microfiltration without causing thermal damage to the product. This research could unlock the potential for widespread use of albumin sidestream in human nutrition.

VIRAVIX engineering

'Taking care of what's precious'

viravix.com



INSTRUMENTATION FOR FOOD AND BEVERAGE PROCESSING

Pressure
Temperature
Level
Weighing
Force
Calibration

WIKA
Smart in sensing

www.wika.com

EHEDG UNIVERSITY MEMBERSHIP

The Next Generation of Hygienic Design Professionals

The food industry is facing a major generational shift. As experienced professionals retire, there is a growing need to prepare a new generation of experts in hygienic design and food safety.
Through our new academic membership model, EHEDG is helping universities connect students and lecturers with industry knowledge, practical expertise and internationally recognised educational resources supporting future careers and stronger collaboration.

WHAT ARE THE BENEFITS FOR UNIVERSITIES?

Up to 5 lecturers or professors from each participating university gain access to a wide range of exclusive academic and professional resources, including:

ACADEMIC INTEGRATION

Access to EHEDG's extensive knowledge base, including:

- **60+ Guidelines**
- **White Papers**
- **Position Papers**

Resources that can be integrated directly into:
Food Safety curricula, Hygienic Design & Engineering courses and Food Processing programmes

E-LEARNING ACCESS

Access to the EHEDG e-learning platform for relevant student cohorts, featuring:

- Industry-focused learning modules
- Flexible online training
- International best practices in Hygienic Engineering & Design

STUDENT CERTIFICATION

Students receive:

- Individual certificates upon successful module completion
- Credentials ready to showcase on LinkedIn and professional portfolios

INDUSTRY-RELEVANT EDUCATION

Support students with:

- Real-world hygienic design knowledge
- Exposure to industry standards
- Enhanced employability within the food and process industries

15 Influence of Food-Contact Surface Material on Biofilm Formation by Bacteria Isolated from the Juice-Processing Industry

Ivana Pejanovic, Nemanja Kljajevic, Nada Smigic;
Department of Food Safety and Quality Management, Faculty of Agriculture, University of Belgrade; Molecular Genetics and Genetic Engineering, University of Belgrade

1) Introduction and background

Biofilm formation on food-contact surfaces is influenced by both material properties and environmental conditions, making their evaluation essential for hygienic equipment design.

2) Objectives

The objective of this study was to evaluate the influence of food-contact surface material on biofilm formation by bacterial isolates from the juice-processing industry.

3) Methods

A total of 63 bacterial isolates recovered from the juice-processing environment were screened for growth in LB medium, and seven isolates showing robust growth were selected for biofilm formation. As LB medium did not support sufficient biofilm formation, subsequent experiments on stainless steel, PET, glass, and silicone coupons were performed in TSB supplemented with 0.5% glucose. Following incubation at 30 °C for 72 h, biofilm biomass was quantified using the crystal violet assay by measuring absorbance at 584 nm. Data were analysed by two-way ANOVA followed by Bonferroni post hoc multiple comparisons, with statistical significance set at $p < 0.05$. Biofilm-forming ability was classified according to the method of Stepanović et al. (2000) based on optical density values relative to negative controls.

4) Results

Biofilm biomass differed significantly among coupon materials and bacterial strains, with a significant interaction between these factors ($p < 0.05$). Glass supported significantly greater biofilm biomass than stainless steel, PET, and silicone (Table 1), and all isolates were weakly adherent on stainless steel and PET and non-adherent on silicone, whereas Thermus scotoductus and Leuconostoc mesenteroides (5/25) were moderately adherent on glass.

Table 1 Biofilm biomass (mean OD_{584} ± SD) and adherence classification of bacterial isolates on different food-contact surface materials after 72 h incubation.

Bacterial strain	Stainless steel	Glass	Silicone	PET
Thermus scotoductus	0.67 ± 0.05 (W)	1.16 ± 0.04(M)	0.44 ± 0.02 (N)	0.40 ± 0.04 (W)
Burkholderia sp.	0.49 ± 0.08 (W)	0.69 ± 0.17 (W)	0.38 ± 0.12 (N)	0.35 ± 0.05 (W)
Bacillus licheniformis	0.44 ± 0.08 (W)	0.70 ± 0.17 (W)	0.25 ± 0.04 (N)	0.37 ± 0.08 (W)
Asaia lannensis	0.40 ± 0.05 (W)	0.61 ± 0.05 (W)	0.19 ± 0.03 (N)	0.37 ± 0.15 (W)
Asaia bogorensis	0.39 ± 0.02 (W)	0.69 ± 0.08 (W)	0.38 ± 0.07 (N)	0.35 ± 0.12 (W)
Leuconostoc mesenteroides (5/25)	0.45 ± 0.05 (W)	0.69 ± 0.14 (W)	0.40 ± 0.15 (N)	0.33 ± 0.10 (W)
Leuconostoc mesenteroides (6/25)	0.65 ± 0.21 (W)	1.24 ± 0.08 (M)	0.26 ± 0.03 (N)	0.38 ± 0.18 (W)

Classification: N = non-adherent; W = weakly adherent; M = moderately adherent.

5) Conclusions

The results demonstrate that food-contact material influences biofilm formation by bacterial isolates from the juice-processing environment. The isolate exhibiting the greatest biofilm-forming ability will be selected for further evaluation in juice-supplemented medium to better simulate industrial conditions and subsequently used to validate biofilm development on hygienic and non-hygienic prototype equipment.

References

Stepanović S., Vuković D., Dakić I., Savić B., Švabić-Vlahović M. (2000). A modified microtiter-plate test for quantification of staphylococcal biofilm formation. Journal of Microbiological Methods, 40, 175–179.

Keywords: biofilm; food-contact materials; juice-processing environment

16

Data-driven identification and modeling for cleaning of surfaces covered with film-like soils

Christian Golla
Institute of Fluid Mechanics, Dresden University of Technology, Dresden, Germany
Now at Fraunhofer Institute for Process Engineering and Packaging IVV, Division Processing Technology, Dresden, Germany

Motivation Cleaning is omnipresent in all human activities. Especially in the food processing and pharmaceutical industry, deposits introduce the risk of compromising product quality by cross-contamination or microbial growth [1]. Due to high hygiene standards, cleaning comes with high economic and ecological costs, e.g., reported in [2– 4]. These costs are accepted to prevent health risks. Experts [5–8], however, stated that cleaning procedures consume more resources than necessary, since their design is mostly done empirically. The optimization potential can be exploited if cleaning procedures are better understood and the knowledge is transferred into suitable computational models [9–11].
Modeling fundament The approach used in the present thesis to exploit optimization potential is the so-called Boundary Condition Cleaning Modeling (BCCM) approach, first introduced by [12]. Applying a BCCM involves two steps: First, the flow in the component of interest is investigated. Typically, a Computational Fluid Dynamics (CFD) simulation is performed to obtain the mean flow field. The investigation of the flow is carried out without consideration of the soil. Therefore, the soil layer must be sufficiently thin so that its presence does not alter the cleaning fluid flow. Second, the soil removal itself is calculated using a suitable model, whereby the flow velocity is not changed. This decoupling step significantly reduces the computational effort of the simulation and makes this modeling approach suitable for industrial application. To avoid developing an individual model for each type of soil, the soils are classified beforehand according to their behavior during removal, termed cleaning mechanism. The cleaning mechanisms distinguished here, shown in Fig. 1, are diffusive dissolution, cohesive separation, adhesive detachment and viscous shifting. In the case of diffusive dissolution, the soil is dissolved in the cleaning fluid. The transport of soil molecules into the cleaning fluid is driven by diffusion. Cohesive separation occurs when the applied hydrodynamic loads overcome the cohesive binding strength of the soil, thus, removing it in chunks. For small soil chunks detaching close to the surface, cohesive separation appears similar to diffusive dissolution from a macroscopic viewpoint. The counterpart, adhesive detachment happens, when the hydrodynamic load overcomes the soil-substrate adhesion. In the case of viscous shifting, the soil itself flows or becomes flowable.

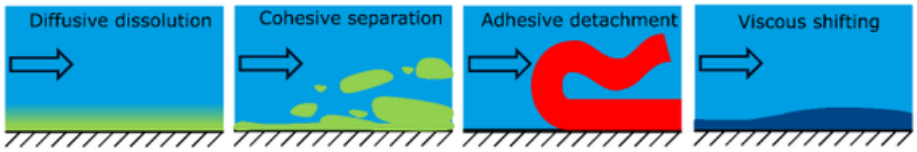


Figure 1. Overview of the cleaning mechanisms defined in [13] and addressed in this thesis. Optimization strategy for industrial cleaning problems With the cleaning mechanisms as a foundation, a possible strategy toward optimization of cleaning procedures of filmlike soils is as follows: In the first step, the cleaning problem is analyzed and classified according to the cleaning mechanism. In principle, two outcomes can result from the classification: a) There is a single dominant cleaning mechanism. b) Several cleaning mechanisms are relevant, or a transition between the mechanisms occurs. Once the classification is carried out, a suitable cleaning model for the problem can be selected. In the next step, the model is parameterized for the present soil. If the model is parameterized correctly, the cleaning simulation leads to quantitative predictions of the cleaning time. Saving resources is achieved by systematic variation of operating conditions and application of optimization strategies.
Research objectives Three necessary conditions must be met to follow this strategy, which are represented by the research objectives of this thesis. First, a classification tool for the cleaning mechanism is required. Second, baseline models for each cleaning mechanism must be available within the BCCM framework. A BCCM for diffusive dissolution is already available [12]. Third, a more complex model that allows the transition between cleaning mechanisms must also be available in case no single cleaning mechanism can be assigned to the problem.

Data-driven identification of cleaning mechanisms The task of identifying the cleaning mechanism can be interpreted as a machine learning (ML) problem. More precisely, it is a classification task, belonging to the field of supervised learning. Such an algorithm requires data for training. To this end, cleaning experiments performed with model soils were considered. In the present context, the term model soils refers to soils that are representative of one of the cleaning mechanisms. No experiments were performed by the author of the thesis, but the evaluation and extraction of model parameters. As discussed in the introduction, diffusive dissolution and cohesive separation might be similar in appearance and can hardly be distinguished from a macroscopic point of view. Hence, these mechanisms were summarized for the classification task as cohesive separation. Cohesive separation was investigated using dried starch 12410 as model soil, adhesive detachment using dried ketchup and viscous shifting using petroleum jelly. During the studies, ML algorithms were trained and evaluated using videos from cleaning experiments with the model soils and water as cleaning fluid. Later, these algorithms were applied to videos of cleaning experiments with more complex soils. Two different solution strategies, illustrated in Fig. 2, were developed. In the first strategy, sub-regions of the videos, consisting of a few pixels, were analyzed. Feature extraction and labeling were performed manually. Features and labels assigned to each sub-region constituted the input-output pairs for simple neural networks (NNs). In the second strategy, the videos were interpreted as 3D images, and an advanced image segmentation algorithm, the fully convolutional network (FCN), was applied. No manual pre-processing of features was performed. The ML models were evaluated in terms of several metrics. One is the accuracy, representing the ratio of pixels being classified correctly to the total number of pixels. When tested on unseen model soil data, the first strategy yielded accuracies up to 80% and the second strategy accuracies up to 90%. While the second strategy provided better results for the task at hand, the first strategy constitutes a general methodology for time-series clustering and is not limited to the application of video data. For example, the technique was later successfully applied in [14] for the classification of particle jumps in the context of sediment transport.

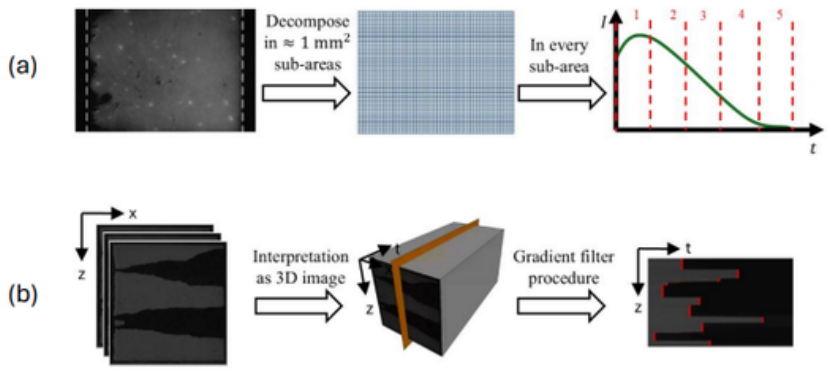


Figure 2. Illustration of the two strategies used to build a machine learning model. (a) Time-series analysis, (b) interpretation as 3D-images. After training, the ML models were applied to cleaning experiments with egg yolk, gelatin, starch 12616 and vanilla pudding. The accuracies obtained vary in a range of 45 – 90%. From qualitative comparison it was found that the models were able to predict the cleaning mechanisms of unknown soils correctly with minor flaws. Hence, the models can make reasonable suggestions on which cleaning model should be used. The metrics evaluated leave some room for improvement, which can, for example, be achieved if a few samples of the new soil data are included in the training data. This is especially true when combined with active learning, since a small number of samples could be sufficient in that case. As a use-case demonstration for the technology, around 50 additional cleaning experiments with ketchup were investigated, with temperature and sodium hydroxide concentration of the cleaning fluid systematically varied, as these factors have a significant influence on the cleaning mechanism in question. From the evaluation, a regime map for the cleaning mechanism was derived. This representation makes it immediately apparent how temperature, sodium hydroxide concentration, and mechanical stress influence the cleaning mechanism. The evaluation of new cleaning experiments takes only a few seconds with the developed technology.

Modeling of adhesive detachment The cleaning mechanism was first analyzed systematically using cleaning experiments with ketchup as a model soil and water as a cleaning fluid. In the experiments, a turbulent flow develops after just a few seconds. However, the first regions appear to be cleaned after about

two minutes. Since the load imposed by the flow remains constant during this time, apart from turbulent fluctuations, the adhesion between the soil and the substrate must therefore decrease over time. This decrease in binding forces is attributed to the ingress of the cleaning fluid into the soil. The model thus consists of calculating the load from the flow, describing the swelling behavior and the effect of swelling on the adhesive binding forces, and formulating a suitable removal criterion. An overview of the model is provided in Fig. 3a. To obtain a measure for the load, the shear stresses computed by the CFD simulation are averaged across the soiled region, thereby determining a scalar reference stress, the hydrodynamic load τhyd. The swelling model is based on a diffusion analogy, whereby a diffusion equation for the water mass fraction in the soil is solved. The diffusion parameter and the initial and boundary conditions must be determined experimentally. The binding forces are assumed to be represented by a scalar quantity τad with the dimension of a stress. It is further assumed that this has a functional dependence on the water mass fraction, which must also be determined experimentally. To decide whether regions are cleaned or not, the hydrodynamic load is compared with the adhesion.

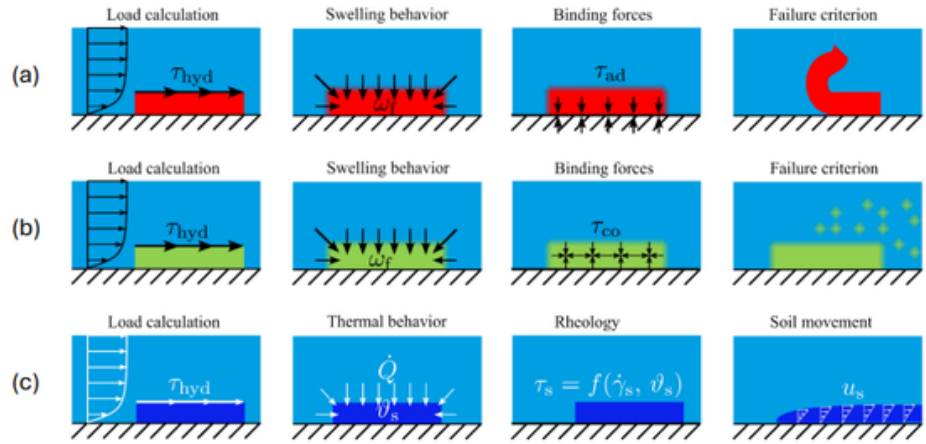


Figure 3. Overview about the cleaning models. (a) Adhesive detachment, (b) cohesive separation, and (c) viscous shifting. The model parameters were determined by evaluating swelling and binding force experiments. After that, the model was validated using over 100 cleaning experiments in two configurations with ketchup employed as model soil: cleaning in a straight duct with a rectangular cross-section and cleaning in a duct with a sudden square-to-square expansion. In each case, the parameters flow velocity, soil mass coverage, and soil pattern were varied. First, the calculated flow is first thoroughly validated, and then the results of the cleaning simulation are compared with the experiments. To achieve agreement with the cleaning experiments, it was necessary to calibrate a correction factor using one reference experiment. This is necessary as the load application differs between the binding force measurements, where the soil is removed by a scraper blade, and the cleaning experiments, where the soil is removed by the fluid flow. Once calibrated, the model can reliably predict the other experiments. The computation times for all simulations were below 10 minutes on a standard laptop.

Modeling of cohesive separation The structure of the model is consistent with the model for adhesive detachment. An overview of the model is shown in Fig. 3b. A key ingredient is the new removal criterion, which allows for the gradual removal of the soil layer. The core of the model is the description of cohesion within the model soil and connecting the cohesion to the swelling state of the soil. To obtain this, swelling and binding force experiments were evaluated systematically using the previously established methodology. Two different model concepts for swelling behavior are presented and compared. As another highlight, the model accounts for non-uniform soil distribution as it is usually encountered in real-world applications using a statistical approach. The validation is performed using cleaning experiments with a starch soil in a straight duct with a rectangular cross-section. As with the model for adhesive detachment, calibration of a correction factor is again necessary. While the model accurately predicts cleaning times for varying flow velocities and soil mass coverages, the qualitative agreement with the actual cleaning process leaves some room for improvement. Potential sources of error and next steps are discussed. The computation time for each case is less than 3 minutes on a standard laptop.

Modeling of viscous shifting The model formulation slightly deviates from the previous models. In this mechanism, the soil does not detach but flows along the walls, with the flow behavior being largely

determined by the rheological properties of the soil, which, in turn, are highly dependent on the temperature. The approach consists of dividing the soil into segments and establishing a mass conservation equation for each segment. In this process, incoming and outgoing mass flows are balanced. Based on a simplified approach for the velocity profile, the outgoing mass is determined in each segment. The incoming masses are then assigned based on the geometric arrangement of the segments relative to one another. To calculate the velocity profile, a rheological model is required that characterizes the soil. This provides a relationship between the applied shear stress, which is known from the CFD simulation, and the resulting shear rate. To account for temperature dependence, a simplified energy conservation equation is additionally solved for each of the segments. This considers both, enthalpy flows between the segments, and heat flows introduced by the cleaning fluid. To validate the model, two different reference cases were successfully analyzed: First, the removal of a thin oil film by a coherent liquid jet, and second, the layer removal phase in a flushing process of two liquid chocolate at different temperatures in a straight pipe were simulated.

Combined cleaning model For the final research objective, the three developed BCCMs were combined into one. In addition, the effect of sodium hydroxide concentration and temperature of the cleaning fluid are modeled, as these have a significant influence on the cleaning mechanism. The basic idea of the model is to divide the soil into segments, analogous to the viscous shifting model. In each segment, one-dimensional transport equations are solved in the wall-normal direction to calculate the influx of water, sodium hydroxide, and heat. Furthermore, the removal criteria for adhesive detachment and cohesive separation are evaluated in each of the segments. To incorporate viscous shifting, heat and mass transport due to flow of the soil between the segments are considered. This calculation of simplification into several one-dimensional transport problems significantly reduces computational effort. The greatest challenge lies in determining the model parameters for adhesion, cohesion, and the rheological model. For the model to be fully operational, these parameters must be known as a function of water mass fraction, sodium hydroxide concentration, and temperature, which entails an enormous effort in characterization. At the time the thesis was written, sufficient data for this purpose was not yet available, which is why the model was validated based on specific aspects only. Subsequently, however, the model was successfully applied to calculate the removal of ketchup at various temperatures and sodium hydroxide concentrations [15]. Within the thesis, the model's application potential is demonstrated by simulating and optimizing the Cleaning-In-Place of a heat exchanger in the dairy industry. Proteinaceous fouling is assumed as the soil, with the model parameters initially assumed from an extensive literature study for demonstration purposes. The cleaning process was assumed to be two-stage, with a pre-soaking step in sodium hydroxide solution and a rinsing step with clean water. The goal of the optimization was to find the ideal switchover time between the two phases. Possible optimization goals investigated are, for example, minimizing the cleaning duration or amount of water consumed. Depending on the selected goal, the ideal switchover time varied. The study impressively demonstrated that the developed simulation model has the potential to virtually optimize cleaning processes.

Summary Summarizing the thesis, an entirely new approach of identifying cleaning mechanisms in videos from cleaning experiments was developed. The first strategy features an approach where sub-regions of the videos, consisting of only a few pixels, are analyzed to construct input-output pairs for conventional classification algorithms. The second strategy interprets the videos as 3D images, allowing image segmentation algorithms like FCNs to be used. With the identification of cleaning mechanisms through objective ML algorithms, the theory of cleaning mechanisms was further underlined. The algorithms can be used to assist the evaluation of cleaning experiments. The development of the algorithms has been performed using image data from cleaning experiments. However, such data will not be available in arbitrary industrial applications. Building such a classification scheme based on available sensor data would be a reasonable next step. On the model side, four physically based models were developed and validated on various configurations involving a duct flow, a duct flow with sudden cross-sectional expansion, a pipe flow, and an impinging jet. Due to the low calculation times, the models are suitable for industrial applications. The probably most important open work item is whether and how the necessary model parameters, as well as a realistic initial state can be determined from the sensor data available in an industrial application.

Framework The dissertation was written between 2020 and 2024 at the Chair of Fluid Mechanics at TUD

16

Dresden University of Technology supervised by Prof. Jochen Fröhlich and examined by Prof. Jochen Fröhlich and Prof. D. Ian Wilson. The thesis comprises a total of 254 pages, with the main body spanning 166 pages, citing a total of 322 references. The findings of the research were published extensively in a total of 8 journal articles [10, 16–22] and 9 conference papers [23–31], as well as in numerous presentations.

References

[1] Wilson, D. I., Challenges in Cleaning: Recent Developments and Future Prospects, Heat Transfer Engineering, vol. 26, pp. 51–59, 2005. [2] Eide, M. H., Homleid, J. P., and Mattsson, B., Life cycle assessment (LCA) of cleaning-in-place processes in dairies, LWT - Food Science and Technology, vol. 36, pp. 303–314, 2003. [3] Kirby, R. M., Bartram, J., and Carr, R., Water in food production and processing: quantity and quality concerns, Food Control, vol. 14, pp. 283–299, 2003. [4] Pettigrew, L., Blomenhofer, V., Hubert, S., Groß, F., and Delgado, A., Optimisation of water usage in a brewery clean-in-place system using reference nets, Journal of Cleaner Production, vol. 87, pp. 583– 593, 2015. [5] Fryer, P. J., Robbins, P. T., Cole, P. M., Goode, K. R., Zhang, Z., and Asteriadou, K., Populating the cleaning map: can data for cleaning be relevant across different lengthscales?, Procedia Food Science, vol. 1, pp. 1761–1767, 2011. [6] Fryer, P. J., and Asteriadou, K., A prototype cleaning map: A classification of industrial cleaning processes, Trends in Food Science & Technology, vol. 20, pp. 255–262, 2009. [7] Goode, K. R., Asteriadou, K., Robbins, P. T., and Fryer, P. J., Fouling and cleaning studies in the food and beverage industry classified by cleaning type, Comprehensive Reviews in Food Science and Food Safety, vol. 12, pp. 121–143, 2013. [8] Tsai, J.-H., Huang, J.-Y., and Wilson, D. I., Life cycle assessment of cleaning-in-place operations in egg yolk powder production, Journal of Cleaner Production, vol. 278, pp. 123936, 2021. [9] Gillham, C. R., Fryer, P. J., Hasting, A. P. M., and Wilson, D. I., Cleaning-in-place of whey protein fouling deposits, Food and Bioproducts Processing, vol. 77, pp. 127–136, 1999. [10] Köhler, H., Liebmann, V., Golla, C., Fröhlich, J., and Rüdiger, F., Modeling and CFD-simulation of cleaning process for adhesively detaching film-like soils with respect to industrial application, Food and Bioproducts Processing, vol. 129, pp. 157–167, 2021. [11] Landel, J. R., and Wilson, D. I., The fluid mechanics of cleaning and decontamination of surfaces, Annual Review of Fluid Mechanics, vol. 53, pp. 147–171, 2021. [12] Joppa, M., Köhler, H., Rüdiger, F., Majschak, J.-P., and Fröhlich, J., Experiments and simulations on the cleaning of a swellable soil in plane channel flow, Heat Transfer Engineering, vol. 38, pp. 786–795, 2017. [13] Köhler, H., Liebmann, V., Joppa, M., Fröhlich, J., Majschak, J.-P., and Rüdiger, F., On the concept of computational fluid dynamics-based prediction of cleaning for film-like soils, Heat Transfer Engineering, vol. 43, pp. 1406–1415, 2022. [14] Rebel, R., Golla, C., Jain, R., and Frohlich, J., Using Machine Learning to Differentiate Types of Particle Jumps in DNS Data of Sediment Transport, in: 41st IAHR World Congress, International Association for Hydro-Environment Engineering and Research, Singapore EXPO, Singapore 2025, pp. 1812–1821. [15] Köhler, H., Golla, C., Drechsel, C., and Rüdiger, F., First insights into changing cleaning mechanisms based on experimental and numerical investigations, Food and Bioproducts Processing, vol. 155, pp. 45–52, 2026. [16] Golla, C., Köhler, H., Liebmann, V., Fröhlich, J., and Rüdiger, F., CFD-based three-dimensional modeling of an adhesively detaching soil layer in a channel flow with sudden expansion, Food and Bioproducts Processing, vol. 136, pp. 176–183, 2022. [17] Golla, C., Marschall, W. F., Kricke, S., Rüdiger, F., Köhler, H., and Fröhlich, J., Identification of cleaning mechanism by using neural networks, Food and Bioproducts Processing, vol. 138, pp. 86–102, 2023. [18] Golla, C., Köhler, H., Fröhlich, J., and Rüdiger, F., Numerical modeling of a cohesively separating soil layer in consideration of locally varying soil distribution, Heat and Mass Transfer, vol. 60, 2023. [19] Golla, C., Boddin, L., Helbig, M., Köhler, H., Rüdiger, F., and Fröhlich, J., Investigating the cleaning mechanism of film-like soils using fully convolutional networks, Food and Bioproducts Processing, vol. 145, pp. 78–96, 2024. [20] Golla, C., Liebmann, V., Rebel, R., Köhler, H., Fröhlich, J., and Rüdiger, F., Numerical model for the cleaning of a film-like soil by viscous shifting, Heat Transfer Engineering, 2025. [21] Golla, C., Köhler, H., Liebmann, V., Fröhlich, J., and Rüdiger, F., Data-driven identification and modeling for cleaning of surfaces covered with film-like soils, Food and Bioproducts Processing, vol. 157, pp. 96– 107, 2026. [22] Golla, C., Liebmann, V., Fröhlich, J., Rüdiger, F., and Köhler, H., A combined cleaning model for filmlike soils with transition between cleaning mechanisms accounting for the effect of temperature and sodium hydroxide, Heat and Mass Transfer, vol. 62, pp. 41, 2026. [23] Golla, C., Köhler, H., Liebmann, V., Fröhlich, J., and Rüdiger, F., CFD-based three-dimensional modeling of an adhesively detaching soil layer in a channel flow with sudden expansion, in: Fouling and Cleaning in Food Processing 2022, Lille, France 2022.

[24] Golla, C., Freiherr Marschall, W., Köhler, H., Rüdiger, F., and Fröhlich, J., Identification of cleaning mechanism by using machine learning methods, in: NAFEMS: Machine Leaning and Artificial Intelligence in CFD and Structural Analysis Conference Proceedings, Wiesbaden, Germany 2022. [25] Golla, C., Köhler, H., and Rüdiger, F., CFD-based modeling of a cohesively separating soil layer in consideration of local soil distribution, in: Proceedings of 14th International Conference on Heat Exchanger Fouling and Cleaning 2022, Wagrain, Austria 2022. [26] Golla, C., Freiherr Marschall, W., Köhler, H., Rüdiger, F., and Fröhlich, J., Identifikation von Reinigungsmechanismen mit Hilfe von Methoden des maschinellen Lernens, NAFEMS Magazin, vol. 63, pp. 54–66, 2022. [27] Golla, C., Boddin, L., Köhler, H., Rüdiger, F., and Fröhlich, J., Aspects of image data preparation to extend a classification scheme for cleaning mechanisms to realistic soils, in: Proceedings in Applied Mathematics and Mechanics, Dresden, Germany 2024, p. e202300142. [28] Köhler, H., Golla, C., Liebmann, V., Heide, M., and Rüdiger, F., Reinigungssimulation: Möglichkeiten und Herausforderungen Einblick in den aktuellen Stand der Forschung der TU Dresden, in: VVD 2024 - Verarbeitungsmaschinen Und Verpackungstechnik: Tagungsband, Dresden, Germany 2024. [29] Golla, C., Liebmann, V., Rebel, R., Köhler, H., Fröhlich, J., and Rüdiger, F., Numerical model for the cleaning of a film-like soil by viscous shifting under non-isothermal conditions, in: Proceedings of 15th International Conference on Heat Exchanger Fouling and Cleaning 2024, Lisbon, Portugal 2024. [30] Golla, C., Liebmann, V., Jena, S., Fröhlich, J., Rüdiger, F., and Köhler, H., A cleaning model for film-like soils with transition between cleaning mechanisms, in: Proceedings of 15th International Conference on Heat Exchanger Fouling and Cleaning 2024, Lisbon, Portugal 2024. [31] Golla, C., Köhler, H., Liebmann, V., Fröhlich, J., and Rüdiger, F., Data-driven identification and modeling for cleaning of surfaces covered with film-like soils, in: Fouling and Cleaning in Food Processing 2025, 2025.

'ACO. we care for water'

buildingdrainage.aco

'All together for value'

www.csf.it

'Taking care of what's precious'

diversey.de

'Protecting what's vital'

ecolab.com

17

Comparison of CIP Cleaning of Statically and Dynamically Grown Biofilms

Julia Löscher, Matthias Joppa, Feliz Schottroff, Enrico Fuchs, Henry Jäger;
BOKU University, Institute of Food Technology; Fraunhofer Institute for Process Engineering and Packaging IVV, Division Process Technology

1) Introduction and background

Biofilms are more resistant to cleaning and disinfection compared to planktonic microbial cells. As they can cause recurrent (re-)contamination of food as well as biocorrosion of processing equipment surfaces, profound knowledge on biofilm properties and removal mechanisms is crucial, as a basis for development of future, more effective control strategies.

2) Objectives

This study aims to systematically compare the efficacy of cleaning-in-place (CIP) in removing statically and dynamically grown biofilms on stainless steel surfaces under controlled process conditions. Microbacterium lacticum, known for forming robust biofilms, was used as a model organism for the trials.

3) Methods

M. lacticum biofilms were grown in skimmed milk broth at 30 °C on 20 × 40 mm stainless steel coupons under static conditions and under dynamic flow at 0.5 m/s for six days and dried at 25 °C overnight. CIP trials used either 3 % (w/v) NaOH, based on preliminary testing, or a commercial CIP cleaning agent (based on active chlorine) at 30 or 65 °C, with flow velocities of 0.5, 1.5 or 2.5 m/s. An integrated viewing window in the experimental setup enabled time and spatially resolved UV-based fouling detection. Cleaning progress was quantified from the UV image series by image analysis, and outcomes were compared across growth mode, cleaning agent, temperature, and flow velocity.

4) Results

Dynamic cultivation led to higher numbers of colony forming units (CFU) in the biofilm (average: 2.89 x 1010CFU/biofilm, compared to 1.21 x 109 CFU/biofilm) and biomass (average: 0.324 g/biofilm vs. 0.132 g/biofilm) compared to static growth. The cleaning trials showed that elevated cleaning temperatures are important for the reliable removal of biofilms. It was also shown that dynamically grown biofilms are more difficult to remove. In many cases, residue-free cleaning was not achieved under the used conditions.

5) Conclusions

In conclusion, dynamically cultivated M. lacticum biofilms, which more closely reflect industrial conditions, are more difficult to remove, and residue-free cleaning was often not achieved. This entails a heightened risk of renewed biofilm formation and (re-)contamination. Further research is necessary regarding the optimization of process parameters and cleaning agents for improved biofilm control, as well as the behaviour of additional biofilm-forming organisms under static and dynamic conditions.

References

Bachlechner, C., Zand, E., Eisenrauch, V., Mauermann, M., Jäger, H., & Schottroff, F. (2026). Biofilm Properties and Their Implications for Cleaning Processes in the Food Industry - A Review. Journal of food protection, 89(2). https://doi.org/10.1016/j.jfp.2025.100695 Tolker-Nielsen, T. (2015). Biofilm Development. Microbiology Spectrum, 3(2). https://doi.org/10.1128/microbiolspec.mb-0001-2014
Han, Q., Song, X., Zhang, Z., Fu, J., Wang, X., Malakar, P. K., Liu, H., Pan, Y., & Zhao, Y. (2017). Removal of Foodborne Pathogen Biofilms by Acidic Electrolyzed Water. Frontiers in Microbiology, 8. https://doi.org/10.3389/fmicb.2017.00988
Antoniou, K., Frank, J. F. (2005). Removal of Pseudomonas putida Biofilm and Associated Extracellular Polymeric Substances from Stainless Steel by Alkali Cleaning. Journal of food protection, 68(2). https://doi.org/10.4315/0362-028X-68.2.277

Keywords: Biofilm, removal, cleaning-in-place, Microbacterium, fouling detection

Acknowledgements

This presentation shows selected results from the research project Biomitate2 (FFG project No.:7752016417, IGF-Project No.: 01IF00388C), supported by CORNET (Collective Research Networking).

18 Sustainable Hygienic Design Validation in Food Processing Equipment: Integrating Cleanability and Environmental Sustainability

Raquel Ezcurra Barcos;
University of Limerick

1) Introduction and background

The food industry faces increasing pressure to maintain high hygienic standards while improving sustainability by reducing water, energy, chemical consumption as well as CO2 emissions (Nikmaram and Rosentrater 2019).

Hygienic design and sustainability are closely connected, as equipment geometry and surface characteristics can affect cleanability and resource requirements. For example, improving cleaning effectiveness may require greater water or energy consumption, while reducing cleaning resources may compromise soil removal or microbial control. These trade-offs highlight the need to evaluate hygiene and sustainability together. Although existing approaches address these areas, their quantitative integration is still limited, creating a need for a framework linking hygienic design, cleanability, microbiological safety and environmental performance (Faille *et al.* 2018).

2) Objectives

The objective of this initiative is to develop a novel integrated framework for sustainable hygienic design validation, linking equipment geometry and surface properties with cleaning and environmental performance through quantitative Key Performance Indicators (KPIs).

3) Methods

This research proposes to combine experimental cleaning trials, computational fluid dynamics (CFD), Life Cycle Assessment (LCA) and sensor-based monitoring to quantitatively evaluate sustainable hygienic design strategies. CFD will be used to model cleaning dynamics and fluid behaviour on equipment surfaces (Chai *et al.* 2024), while LCA will quantify environmental impacts associated with water, energy and chemical consumption (Tsai *et al.* 2021). Cleaning trials using realistic food soils under pilot-scale conditions will evaluate cleanability under representative conditions. Real-time sensor technologies, including optical, ATP, fluorescence, flow and temperature measurements, will be investigated for monitoring cleaning performance (Watson *et al.* 2021).

The project is at an early stage, and the integrated framework and associated assessment matrix have not yet been developed. The matrix is a planned outcome of the research and will be developed progressively based on the results of these activities.

4) Results

The investigation will explore relationships between equipment design parameters, cleanability and resource consumption to support the development of sustainability and hygiene KPIs, sensor-based indicators of cleaning performance, and the proposed framework.

This research aims to analyse how the assessment can adapt to differences between equipment applications, cleaning requirements, food soils, operating conditions and associated food safety risks, as well as sustainability considerations such as water availability.

5) Conclusions

Integrating hygienic design and sustainability could support food companies in balancing effective contamination control with reduced water, energy and chemical consumption, potentially contributing to lower food safety risks and more resource-efficient cleaning (Tsai *et al.* 2021). The intended outcome is an integrated evaluation framework to asses relationships between design parameters and cleanability, quantitative sustainability and hygiene KPIs, sensor-based cleaning indicators, and decision criteria to support sustainable hygienic equipment design (Faille *et al.* 2018).

6) References

Chai, J., Su, H., Li, X., Zhang, Y., Xiao, D., Kang, J., and Dong, A. (2024) 'Computational fluid dynamics (CFD) modeling and application for cleaning of food-contact surfaces: A review', *Journal of Food Process Engineering*, 47(4), e14605, available: https://doi.org/10.1111/jfpe.14605.

Faille, C., Cunault, C., Dubois, T., and Bénézech, T. (2018) 'Hygienic design of food processing lines to mitigate the risk of bacterial food contamination with respect to environmental concerns', *Innovative Food Science & Emerging Technologies*, Food Science and Technology in France: INRA's contribution to this area, 46, 65–73, available: https://doi.org/10.1016/j.ifset.2017.10.002.

Nikmaram, N. and Rosentrater, K.A. (2019) 'Overview of Some Recent Advances in Improving Water and Energy Efficiencies in Food Processing Factories', *Frontiers in Nutrition*, 6, available: https://doi.org/10.3389/fnut.2019.00020.

Tsai, J.-H., Huang, J.-Y., and Wilson, D.I. (2021) 'Life cycle assessment of cleaning-in-place operations in egg yolk powder production', *Journal of Cleaner Production*, 278, 123936, available: https://doi.org/10.1016/j.jclepro.2020.123936.

Watson, N.J., Bowler, A.L., Rady, A., Fisher, O.J., Simeone, A., Escrig, J., Woolley, E., and Adedeji, A.A. (2021) 'Intelligent Sensors for Sustainable Food and Drink Manufacturing', *Frontiers in Sustainable Food Systems*, 5, available: https://doi.org/10.3389/fsufs.2021.642786.

Keywords: Environmental Sustainability; Systems Integration; Hygienic Design; Cleanability; Food Processing Equipment

Acknowledgements

Niamh Burke Associate Professor, Department of Biological Sciences; *EHEDG* European Hygienic Engineering and Design Group; *UL* University of Limerick

19 From Open to Hygienically Enclosed Curd Processing: Risk Reduction and Sustainability Benefits in Cheese Production

Bahar Özyilmaz, Erol Çalışkan, Caner Küpçü;
Department of Food Engineering, Sakarya University; Kromel Makine San. Tic. A.Ş

1) Introduction and background

In pasta-filata cheese production, curd maturation and dewatering are traditionally carried out in open vats to achieve product-specific pH development before stretching; however, this practice exposes a highly sensitive process step to environmental contamination and cleaning challenges.

2) Objectives

This study aimed to quantitatively evaluate the impact of converting a conventional open curd processing operation into a hygienically enclosed, fully CIP-capable system on hygienic risk reduction, food safety, process control and sustainability performance in Kashar cheese production using the EHEDG Hygienic Design Risk Management (HDRM) methodology.

3) Methods

A hygienic redesign of the Kromel curd conditioning and whey drainage unit was performed according to EHEDG hygienic design principles by converting a conventional open cheddaring vessel into an enclosed, fully CIP-cleanable system equipped with hygienic access interfaces, integrated pH monitoring and hygienic drainage. The curd conditioning and whey drainage process was subsequently analysed using the EHEDG Hygienic Design Risk Management (HDRM) framework. Hygiene hazards associated with the conventional open vessel were identified using the Appendix 3 checklist, while the hygienic design principles and equipment assessment criteria described in Appendices 4-1 and 4-2 were applied to compare the existing open configuration with the redesigned closed system.

Individual hazards were scored before and after redesign, residual risks were quantified and comparatively evaluated using paired analyses, and the hygienic design improvements were evaluated in terms of food safety, process control, cleanability and sustainability performance.

The templates provided in EHEDG Guideline 58 were used as guidance for hazard identification and hygienic design assessment. For comparative evaluation, identified hygiene hazards were rated using a semi-quantitative risk matrix based on expert judgement, considering the process-specific hygienic characteristics, with likelihood and consequence scored on a 1–5 scale and risk scores calculated as the product of likelihood and consequence.

The assessment approach was adapted to the specific hygienic characteristics of the curd conditioning and whey drainage process rather than applying the GL58 templates as prescriptive requirements. Particular consideration was given to environmental exposure, operator intervention, cleanability, CIP capability and operational control measures. Individual hygiene hazards were scored before and after the redesign using a semi-quantitative risk matrix, residual risks were quantified, and the effectiveness of the hygienic design improvements was comparatively evaluated through paired analyses.

4) Results

Critical hygiene hazards associated with the curd conditioning and whey drainage process were identified using the EHEDG HDRM methodology. The cumulative hygiene risk score decreased from 190 for the conventional open system to 46 for the redesigned enclosed system, corresponding to an overall risk reduction of 75.8%. The highest-risk process steps, including curd transfer, curd conditioning and mixing, showed an 80% reduction in risk (25 to 5), while hazards related to environmental contamination, operator intervention, cleanability and process variability were consistently reduced to acceptable residual risk levels. Following implementation of hygienic design measures and supporting operational controls (CIP validation, SOPs, preventive maintenance and instrument calibration), all identified residual hygiene risks were considered acceptable according to the EHEDG HDRM assessment criteria.

Risk scores represent the cumulative sum of individual semi-quantitative likelihood × consequence ratings assigned to identified hygienic hazards.

5) Conclusions

The application of EHEDG hygienic design principles transformed a critical open processing step into a fully enclosed and CIP-cleanable system with substantially reduced hygienic risk. This study demonstrates that the EHEDG HDRM methodology provides a practical and quantitative framework for validating hygienic design improvements in dairy processing equipment, while supporting enhanced food safety, process control and sustainable cheese manufacturing. The study further illustrates how GL58 can be adapted to application-specific hygienic conditions while maintaining a structured and transparent risk assessment approach.

References

1. EHEDG Guideline Doc. 08: Hygienic Design Principles, 2018.
2. EHEDG Guideline Doc. 13: Hygienic Design of Open Equipment, 2024.
3. EHEDG Guideline Doc. 50: Hygienic Design Requirements for CIP Installations, 2019.
4. EHEDG Guideline Doc. 58: Hygienic Design Risk Management, 2024.
5. Kromel 12650 Technical Design Documentation, 2026.
6. Feng et al., Advances in Thermal-Mechanical Treatment of Pasta-Filata Cheese, 2025.

Keywords: *Kashar Cheese; Curd Processing; Hygienic Design; CIP; Sustainability*

Acknowledgements

This study was supported by the Kromel Machinery Industry and Trade Co. R&D Center through its research and development activities in hygienic equipment design and food safety. The authors sincerely acknowledge the company's technical support and commitment to innovation in hygienic process engineering.

20 Innovative Surface Decontamination: Using Plasma-processed Air to Decontaminate Dry Plant-based Products such as Oregano and Medical Cannabis to Improve Microbial Safety

Ulrike Spilker, Uta Schnabel, Jörg Stachowiak;
Leibniz Institute for Plasma Science and Technology (INP)

1) Introduction and background

Dry foods and plant-based raw materials such as oregano and medical cannabis are challenging biological matrices for product safety due to their complex surface structure, low water content, and often high initial microbial load, while conventional thermal or moisture-based decontamination methods can compromise quality, aroma, or active ingredients, which is why plasma-processed air (PPA) is being investigated as an innovative non-thermal alternative (1).

2) Objectives

The objective is to evaluate the potential of PPA or reducing microbial contamination on dried plant products, taking into account product safety, hygienic plant design, and quality preservation.

3) Methods

As a first step, Fourier-transform infrared spectroscopy (FTIR) was used to determine the antimicrobial chemical composition of the plasma processed air (PPA) generated by a microwave plasma source (2). To ensure compliance with industrial requirements in accordance with Good Manufacturing Practice, the PPA was applied in a 100% hygienic treatment chamber. The treated products were then analyzed using a colony-forming units (CFU) assay to detect and quantify cell proliferation and viability, as well as to investigate the antimicrobial efficacy of the PPA against the natural microbial load (1). In a final step, the quality of the treated and untreated products (e.g., color, texture) was analyzed.

4) Results

The analysed gas composition of PPA was dominated by NO, followed by NO_2 and N_2O_4; NO was detected as the initial reaction product, whereas NO_2 represented the major long-lived species (3). On oregano, PPA treatment led to a 4.5 log_{10} reduction of E. faecium after 30 min (2). In addition, treatment of medical cannabis for 60 min resulted in logarithmic reduction values of approximately 2.0–3.0 log_{10}. In both matrices, PPA effectively reduced microbial loads within the respective treatment times.

5) Conclusions

PPA shows promise as an effective non-thermal decontamination technology for oregano and medical cannabis dry and sensitive plant-based products, with the added advantages of decentralized use and low-cost consumables such as air and energy. However, its successful application depends on product-specific requirements, precise process control, validated dosing of active species, and hygienic equipment design to ensure reproducible results.

References

Nestel, S., Hedtfeld, C., Spilker, U. et al. Sanitation of medical cannabis flowers (Cannabis sativa L., flos): comparing current technologies and non-thermal plasma novelties from safety and quality perspectives. J Cannabis Res 8, 50 (2026). https://doi.org/10.1186/s42238-026-00417-9

Yao, Y., Meister, M., Zuber, S., Nierop Groot, M. N., den Uijl, K., Linthorst, M., Hoogland, H., Ehlbeck, J., Schnabel, U. and Karatzas, K. A. G. (2026), The potential of plasma-processed air (PPA) for industrial food safety in herbs and spices. Innovative Food Science & Emerging Technologies, 110, 104494. https://doi.org/10.1016/j.ifset.2026.104494

Yao, Y., Weihe, T., Stachowiak, J., Ehlbeck, J., Schnabel, U. and Karatzas, K.-A. (2026), Key Physicochemical Parameters Influencing Reactive Species in Plasma-Processed-Air (PPA) Originated from Microwave Discharge. Plasma Processes and Polymers, 23: e70092. https://doi.org/10.1002/ppap.70092

Keywords: *plasma processed air; food safety; hygienic design; dry plant products; non-thermal decontamination*

Acknowledgements

This first research was funded by the Federal Republic of Germany, Federal Ministry for Economic Affairs and Climate Action under the program "PlaDeCan", and funding reference: KK5069503AP4. The authors thank Herba Medica, especially Claas Hedtfeld and David Höhne, for their support and feasibility in this part of the project.
The second research is part of the TRANSIT project and has received funding from the European Union's Horizon 2020 Research and Innovation Program under the Marie Skłodowska-Curie grant agreement: 955431. The authors would like to acknowledge Thierry Cottineau (Institute of Immunology, Friedrich-Loeffler-Institute, 17493 Greifswald – Insel Riems, Germany) for the support in statistical analyses and Remco Hamoen (Wageningen Food & Biobased Research, Wageningen University & Research, Wageningen, The Netherlands) for the design of the treatment chamber.

21

Particle Adhesion Due to Different Surface Treatments of Stainless Steel

Thomas Scheidl, Arnulf Hörtnagl;
THWS - Technical University of Applied Sciences Würzburg-Schweinfur

1) Introduction and background

Particle adhesion on stainless-steel surfaces causes product losses, contamination risks, and cleaning challenges in hygienic industries. Despite EHEDG recommendations for roughness (Ra ≤ 0.8 µm), roughness metrics alone aren't reliable predictors of adhesion or cleanability.

2) Objective

This study evaluated how different surface finishes affect talc adhesion on stainless steel 1.4404, focusing on implications for Hygienic Design in the food, pharmaceutical, and cosmetic sectors.

3) Methods

Examined were four surface conditions: ground, ground and electropolished, Optimized Grind Finished (OGF) which represents a modified slide grinding procedure, and OGF plus electropolishing. Talc was used due to its low hygroscopicity, focusing on dry adhesion. Gravimetric analysis (240 measurements per condition; 960 total) and white-light interferometry assessed adhesion and topography. Additional characterization involved SEM, contact angles, and powder analysis, comparing roughness (Sa, Sq, Sz), surface volumes, and intensity ratios with adhesion. OGF, representing a modified slide grinding procedure, was investigated for the internal surfaces of rotationally symmetric vessels. The process has been demonstrated for vessels with capacities ranging from 2 to 300 L.

4) Results

OGF exhibited the lowest adhesion (0.909 ± 0.030 mg), reducing adhesion by ~29% compared to the ground surface (1.285 ± 0.030 mg). OGF-electropolished and ground-electropolished surfaces had intermediate results (1.101 ± 0.030 mg; 1.227 ± 0.030 mg). Electropolishing didn't consistently reduce adhesion, and no direct link between roughness and adhesion was noted, suggesting a complex interplay of topography and particle properties impacts adhesion. (SD = ± 0.030 mg; n = 960)

5) Conclusions

Roughness parameters alone are insufficient for assessing hygienic stainless-steel surfaces. Evaluating topography and adhesion behavior provides a more accurate basis for Hygienic Design. OGF could reduce particle retention, aiding in lowering product loss, improving cleanability, and enhancing efficiency, but further research is needed before standard application. In addition to its potential for reducing particle retention, OGF offers substantial economic benefits, with manufacturing costs reported to be up to approximately 70% lower than those of manual grinding. Its low operator demand also enables parallel overnight processing of multiple vessels.

Keywords: Stainless Steel, Particle Adhesion, Surface Topography, Cleanability

Acknowledgements

Tim Granath, Bolz Intec

22

ECOCIP – Optimization of the CIP Cleaning Process for Fermentation Tanks under CO_2 Atmosphere

Aryson Andrade, Kelly Calixto, Willian Vilela;
Diversey, a Solenis Company

1) Introduction and Background

Conventional alkaline Cleaning-in-Place (CIP) in large brewery fermentation tanks requires complete CO_2 removal before each cycle, a step consuming 4 to 6 hours per tank and wasting gas, energy, and water, because NaOH reacts with CO_2 ($2NaOH + CO_2 \rightarrow Na_2CO_3 + H_2O$), neutralizing active alkalinity and compromising detergent efficacy.

2) Objectives

This study presents the development, laboratory validation, and industrial results of ECOCIP, a CIP solution based on organic acids combined with accelerated hydrogen peroxide capable of operating directly under CO_2 atmosphere, eliminating the gas removal step while delivering measurable gains in productivity, energy, water, and CO_2 emissions.

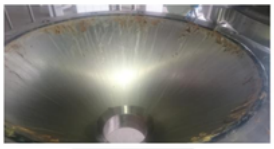
3) Methods

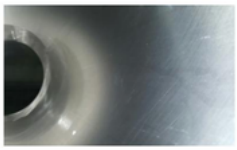
The ECOCIP solution combines Divosan Uniforce (glycolic, sulfuric, and octenylsuccinic organic acids) with Booster® (accelerated hydrogen peroxide, AHP), a formulation selected because brewery tank soil contains no saponifiable lipids, allowing AHP to replace alkaline action via hydroxyl radicals (OH•) on yeast proteins and polysaccharides while the acid blend dissolves the inorganic beerstone fraction in a single stage. Laboratory validation used stainless steel coupons contaminated with yeast and oven-dried to simulate extreme adhesion, cleaned under controlled flow rate (L/m²) with acid concentrations of 1.0 to 3.0% and AHP of 0.5 to 1.0%. The optimized protocol was then applied industrially through four stages: alkaline pre-wash (0.5%), rinse to pH ≤ 9, acid circulation for 40 to 60 minutes, and final rinse to pH ≥ 4.7, in vertical fermentation tanks of 600 to 1,300 m³ under CO_2 atmosphere at three breweries, following EHEDG DOC No. 51. Over 12 months (2024–2025), CIP execution time, electrical energy consumption, water volume, and CO_2 mass saved (PV = nRT) were monitored, alongside continuous microbiological control of fermenting beer and final rinse waters.

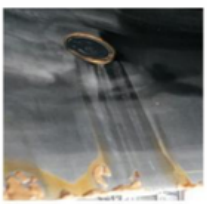
4) Results

The optimal laboratory combination was 2.0 to 2.5% acid with 0.5% AHP, achieving complete yeast soil removal under extreme adhesion, with no microbiological deviations recorded across the 12-month period. Industrially, ECOCIP reduced total CIP time by 52% (Client A), 74% (Client B), and 33% (Client C) versus the conventional method, generating up to 70,000 hl/year of additional production capacity per unit. Energy savings ranged from 100,000 to 300,000 kWh/year and water savings from 4,000 to 170,000 m³/year across clients. CO_2 mass saved per CIP cycle ranged from 1,014 to 2,029 kg per tank, depending on tank volume and operating pressure and temperature.









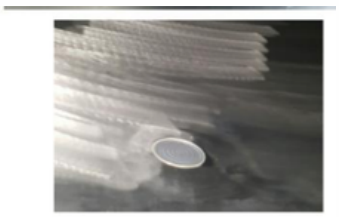


Figure 1: Laboratory cleaning test results on contaminated stainless-steel coupons — ECOCIP protocol; ***Figure 2:*** Internal surface of fermentation tank Before the ECOCIP; ***Figure 3:*** Internal surface of fermentation tank After the ECOCIP

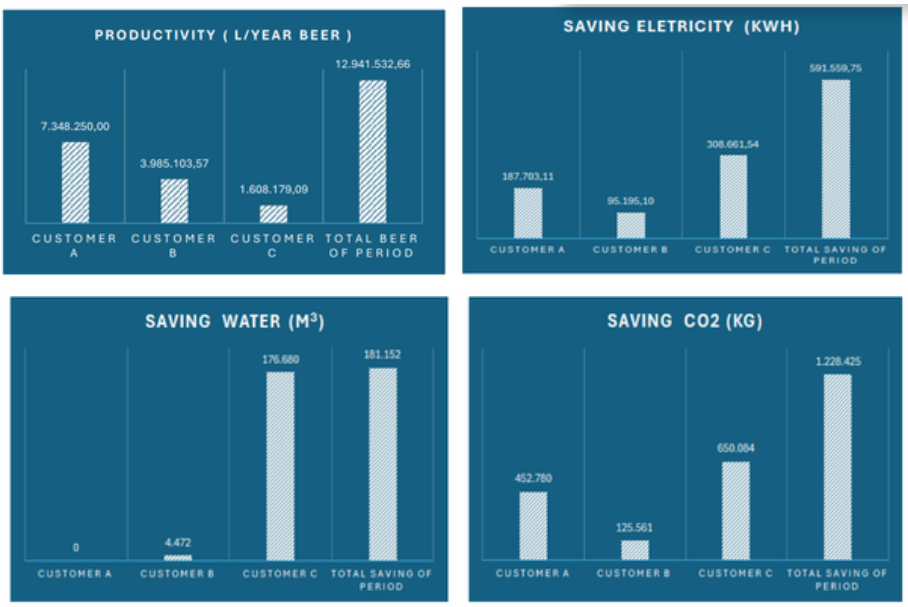


Chart 1: Productivity increase in liters of beer over 12 months, per customer; ***Chart 2:*** Electrical energy savings (kWh) over 12 months, per customer; ***Chart 3:*** Water savings (m^3) over 12 months, per customer; ***Chart 4:*** CO_2 savings (kg) over 12 months, per customer

5) Conclusion

ECOCIP eliminates the CO_2 removal step from fermenter CIP while delivering significant reductions in time, energy, water, and emissions and maintaining full microbiological safety. It offers an immediately deployable, sustainable pathway to production capacity growth without additional infrastructure, relevant to any beverage sector using CO_2-pressurized fermenters.

Keywords: CIP; sanitation; fermentation; CO_2; sustainability

Acknowledgements

The authors acknowledge William Santana Vilela, originator of the project, together with Aryson Andrade and the technical team at Solenis Diversey Brazil for their support in developing and implementing the protocol, and the partner breweries for their availability and collaboration in data collection.

References

BIER – Beverage Industry Environmental Roundtable. 2023 Water, Energy and GHG Benchmarking Study. January 2024. Available at: https://www.bieroundtable.com/news/bier-issues-results-2023-water-energy-ghg-benchmarking-study/

Krauss, M.; Rzehak, R. Reactive absorption of CO_2 in NaOH: Detailed study of enhancement factor models.Chemical Engineering Science, 2017. Available at: https://www.hzdr.de/publications/PublDoc-9556.pdf

Magnani, M. et al. Beta-glucans isolated from Saccharomyces uvarum (brewer's yeast): characterization and application. LWT – Food Science and Technology, 2019. DOI: 10.1016/j.lwt.2019.108382

Parkes, S. Removing and Preventing Beer Stone Buildup. Brewing Techniques / MoreBeer, 2014. Available at: https://morebeer.com/blogs/articles/removing-preventing-beer-stone-buildup

EHEDG DOC No. 51. Hygienic Design Aspects for Tank and Vessel Cleaning in the Food Industry Group, 2023

23 Microbiological Status of Reused Cleaning-in-Place Liquid in the Dairy Industry

Julia Löscher, Matthias Joppa, Feliz Schottroff, Enrico Fuchs, Henry Jäger;
BOKU University, Institute of Food Technology; Fraunhofer Institute for Process Engineering and Packaging IVV, Division Process Technology

1) Introduction and background

Biofilms are more resistant to cleaning and disinfection compared to planktonic microbial cells. As they can cause recurrent (re-)contamination of food as well as biocorrosion of processing equipment surfaces, profound knowledge on biofilm properties and removal mechanisms is crucial, as a basis for development of future, more effective control strategies.

2) Objectives

This study aims to systematically compare the efficacy of cleaning-in-place (CIP) in removing statically and dynamically grown biofilms on stainless steel surfaces under controlled process conditions. Microbacterium lacticum, known for forming robust biofilms, was used as a model organism for the trials.

3) Methods

M. lacticum biofilms were grown in skimmed milk broth at 30 °C on 20 × 40 mm stainless steel coupons under static conditions and under dynamic flow at 0.5 m/s for six days and dried at 25 °C overnight. CIP trials used either 3 % (w/v) NaOH, based on preliminary testing, or a commercial CIP cleaning agent (based on active chlorine) at 30 or 65 °C, with flow velocities of 0.5, 1.5 or 2.5 m/s. An integrated viewing window in the experimental setup enabled time and spatially resolved UV-based fouling detection. Cleaning progress was quantified from the UV image series by image analysis, and outcomes were compared across growth mode, cleaning agent, temperature, and flow velocity.

4) Results

Dynamic cultivation led to higher numbers of colony forming units (CFU) in the biofilm (average: 2.89 x 1010CFU/biofilm, compared to 1.21 x 109 CFU/biofilm) and biomass (average: 0.324 g/biofilm vs. 0.132 g/biofilm) compared to static growth. The cleaning trials showed that elevated cleaning temperatures are important for the reliable removal of biofilms. It was also shown that dynamically grown biofilms are more difficult to remove. In many cases, residue-free cleaning was not achieved under the used conditions.

5) Conclusions

In conclusion, dynamically cultivated M. lacticum biofilms, which more closely reflect industrial conditions, are more difficult to remove, and residue-free cleaning was often not achieved. This entails a heightened risk of renewed biofilm formation and (re-)contamination. Further research is necessary regarding the optimization of process parameters and cleaning agents for improved biofilm control, as well as the behaviour of additional biofilm-forming organisms under static and dynamic conditions.

References

Bachlechner, C., Zand, E., Eisenrauch, V., Mauermann, M., Jäger, H., & Schottroff, F. (2026). Biofilm Properties and Their Implications for Cleaning Processes in the Food Industry - A Review. Journal of food protection, 89(2). https://doi.org/10.1016/j.jfp.2025.100695 Tolker-Nielsen, T. (2015). Biofilm Development. Microbiology Spectrum, 3(2). https://doi.org/10.1128/microbiolspec.mb-0001-2014
Han, Q., Song, X., Zhang, Z., Fu, J., Wang, X., Malakar, P. K., Liu, H., Pan, Y., & Zhao, Y. (2017). Removal of Foodborne Pathogen Biofilms by Acidic Electrolyzed Water. Frontiers in Microbiology, 8. https://doi.org/10.3389/fmicb.2017.00988
Antoniou, K., Frank, J. F. (2005). Removal of Pseudomonas putida Biofilm and Associated Extracellular Polymeric Substances from Stainless Steel by Alkali Cleaning. Journal of food protection, 68(2). https://doi.org/10.4315/0362-028X-68.2.277

Keywords: Biofilm, removal, cleaning-in-place, Microbacterium, fouling detection

Acknowledgements

This presentation shows selected results from the research project Biomitate2 (FFG project No.:7752016417, IGF-Project No.: 01IF00388C), supported by CORNET (Collective Research Networking).

24

Cleaning of Surfaces with Water Jets Inspired by the Archerfish

Roman Murcek, Markus Klatte, Andy Spitzenberger, Enrico Fuchs, Marc Mauermann;
Fraunhofer Institute for Process Engineering and Packaging IVV; TU-Bergakademie Freiberg

1) Introduction and background

Jet nozzles play an important role in cleaning surfaces within the food industry, particularly when high impact forces are required to remove soil, such as during tank cleaning with targeted jet cleaners. To ensure that these processes are carried out with good resource efficiency, the nozzles used must be as effective as possible when the jet hits the surface. The archerfish serves as a role model for achieving this aim. It can use its mouth to modulate water jets so that they converge into a compact cluster, which it uses to hit insects above the water surface. This principle is imitated in this study.

2) Objectives

The aim of this work was to examine whether cleaning with a modulated liquid jet inspired by the archerfish could lead to an improvement in cleaning effectiveness, and to determine the influence of chemicals on the stable formation of the jet.

3) Methods

Using a linear motor and a jet nozzle, the jet modulation of the archerfish is imitated on a laboratory scale by continuously increasing the outlet velocity according to a pre-calculated profile, so that the trailing end of the jet catches up with the front end at the point of impact. The quality of the resulting jet cluster is characterized using high-speed photography. Cleaning tests are conducted to evaluate the effect of the jet impact. The soil type, the target distance and direction of ejection, and the cleaning fluid are varied in these tests. Gravity is also taken into account in the calculation of the jet modulation.

4) Results

It has been shown that sufficient jet modulation is possible with both water and cleaning fluids (NaOH, surfactants). However, the best jet quality is achieved at vertical ejection angles. When the spray is directed laterally, gravity leads to reduced compactness. Regarding cleaning effectiveness, it was found that, compared to a conventional pulsed jet without velocity modulation, the cleaned area can be increased by up to 50 % under suitable conditions.

5) Conclusions

The tests show a significant potential for improving cleaning performance compared to cleaning with conventional pulsed jets for stationary nozzles at short distances of up to 300 mm. For practical industrial application, further research is needed to adapt the system for moving jets and longer distances. In addition, solutions must be found to overcome the negative effects of gravity.

Keywords: spray cleaning, food safety, resource efficiency, archer fish, bionics

Acknowledgements

The IGF project BionicJet 2.0 (01IF23399N), in the context of which the results presented were achieved, is supported by the Research Association of the Industrial Association for Food Technology and Packaging (IVLV e.V.) and funded by the Federal Ministry for Economic Affairs and Energy through the DLR Project Management Agency (DLR-PT) within the framework of the Industrial Collective Research (IGF) programme, based on a resolution of the German Bundestag.

Endress+Hauser

'People for Process Automation'

endress.com

FREUDENBERG
SEALING TECHNOLOGIES

'INNOVATING TOGETHER'

fst.com

EHEDG

GOUDSMIT
MAGNETICS

Ensuring
food safety, purity and compliance



goudsmitmagnetics.com

KEOFITT®
WORLD LEADERS IN STERILE SAMPLING™



25 Predicting the Composition of Low Concentration Dairy Side-Streams to Reduce Wastewater Using Machine Learning

Julius Behrens, Christian Zscherpe, Stefanie Schawe, Saskia Schwermann, Corina Jantke;
Hochschule Hannover University of Applied Sciences and Arts

1) Introduction and background

Due to the complex composition of milk, inline measurement technologies such as turbidity and conductivity cannot accurately estimate the fat, protein, and lactose content of dairy streams, like wastewaters (Slavov, 2016). Machine learning is a field of study in artificial intelligence that identifies patterns and relationships in complex, high-dimensional data and therefore shows promise as a prediction tool (Hussain et al., 2025).

2) Objectives

The objective of this study was to develop statistical models to predict the composition of diluted dairy streams using only inline measurement systems.

3) Methods

We produced diluted dairy streams from milk, cream, whey (acid, sweet), UF permeate, sodium chloride solution, lactose and RO permeate. Then, we analyzed the streams inline for turbidity, density, conductivity, refractive index, pH, temperature, UV-absorption (280 nm) and color-absorption (430 nm). We also analyzed them for protein, fat, lactose, chemical dry matter (VDLUFA, 2020) and oxygen demand (COD) (ISO, 2002). Linear regression (LR) and machine learning models (artificial neural networks(ANN)) were developed from the collected data to predict the composition of diluted dairy streams using SPSS statistical software (SPSS V.29, IBM, USA). We designed the ANN as a multilayer perceptron with two hidden layers, using a hyperbolic tangent activation function in the hidden layers and an identity activation function in the output layer. To train the ANN, we randomly divided the data into 70% for training and 30% for testing using batch gradient descent as the optimization algorithm for a maximum of 300 epochs. Only datapoints with a COD of under 5000 mg O2 per L were included.

4) Results

Results are shown in Table 1. LR models have a good model quality for the components protein and dry matter, are average for fat and COD and perform poorly for lactose. ANN perform well with a model quality of over 99 % for all components.

Component	Linear regression (R^2)	Artificial Neural Networks (R^2)
COD	87.5	99.4 ± 0.3
Fat	83.0	99.7 ± 0.2
Protein	96.8	99.4 ± 0.1
Lactose	53.5	99.2 ± 0.1
Dry matter	96.0	99.4 ± 0.1

n = 75.479; COD = chemical oxygen demand as mg O_2 per L, R^2 values are given as percentages, Results for artificial neural networks are given as averages and standard deviation out of five analyses.

Rank	Inline parameter	Independent variable importance [%]
1	Conductivity	32.3 ± 19.8
2	Turbidity	16.9 ± 12.8
3	pH	14.5 ± 4.3
4	Color	14.2 ± 14.4
5	UV	11.4 ± 5.8
6	Density	4.2 ± 1.1
7	Refractive index	3.6 ± 0.6
8	Temperature	2.9 ± 0.6

Results for importance are given as averages and standard deviation out of five analyses.

Table 1: Model quality of linear regression and machine learning models to estimate the composition of dairy side-streams;
Table 2: Average importance of inline parameters for predicting dairy stream composition; The importance for parameters vary in regard to the analyzed components with conductivity having the highest average importance (see Table 2).

Results for importance are given as averages and standard deviation out of five analyses.
Interestingly, color and turbidity complemented each other. Turbidity was important for both protein and fat, whereas color was only important for fat. This enables the identification of the components that determine the value of dairy side streams, namely fat and protein, and therefore makes reintegrating them into the production process more feasible. Furthermore, fat is also associated with a high COD, which is a key environmental concern (Demirel et al., 2005).

5) Conclusions

The results show that ANN models enable accurate prediction of protein, fat, lactose, dry matter and COD content in diluted dairy streams. After estimating the composition of the side streams, the dairy can recycle them and reintegrate them into the production process, after an optional treatment, to reduce waste and raw material requirements.

References

Demirel, B., Yenigun, O. & Onay, T. T. (2005). Anaerobic treatment of dairy wastewaters: a review. Process Biochemistry, 40(8), 2583–2595. https://doi.org/10.1016/j.procbio.2004.12.015
Hussain, M. A., Khan, M. I. H. & Karim, A. (2025). Machine Learning in Transforming the Food Industry. Foods, 15(1), 90. https://doi.org/10.3390/foods15010090
Slavov, A. K. (2016). Dairy Wastewaters – General Characteristics and Treatment Possibilities – A Review. Food Technology And Biotechnology, 55(1), 14–28. https://doi.org/10.17113/ftb.55.01.17.4520
Verband Deutscher Landwirtschaftlicher Untersuchungs- und Forschungsanstalten (VDLUFA) (2020). Methodenbuch Band VI: Chemische, physikalische und mikrobiologische Untersuchungsverfahren für Milch, Milchprodukte und Molkereihilfsstoffe. VDLUFA-Verlag
ISO (2002). ISO 15705:2002. Water quality - determination of the chemical oxygen demand index (ST-COD) - small-scale sealed tube method.

Keywords: Machine learning, wastewater, dairy, product losses

26 CFD-Based Evaluation of Feed Spacer Geometry in Reverse Osmosis Channels Under Constant Porosity: Reducing Pressure Drop While Maintaining Membrane Performance

Mahmoud Saleh, Dominik Ulrich Geier, Thomas Becker;
Technical University of Munich

1) Introduction and background

Feed-spacer geometry governs local hydrodynamics and deposit formation in spiral-wound membrane modules, including protein accumulation in food applications and biomass accumulation in low-shear regions, making spacer design relevant to hygienic operation [1,2].

2) Objectives

This study investigates whether spacer cross-sectional shape can reduce pressure drop without increasing near-membrane solute accumulation, quantified by concentration polarization (CP), or compromising permeate flux under constant channel porosity.

3) Methods

Two-dimensional transient computational fluid dynamics (CFD) simulations were conducted for spacer-filled reverse osmosis (RO) channels at Reynolds numbers (Re) of 50–220. Rectangular, circular, and regular hexagonal, octagonal and decagonal cross sections of identical area were compared at constant channel porosity. Spacer pitch and position, channel dimensions, membrane properties and operating conditions were fixed, and fully developed CP, permeate flux and overall pressure drop were compared. Model validation reproduced the slit-channel experiments of Salcedo-Díaz et al. [3] using a sodium sulfate feed, a polyamide RO membrane and a transmembrane pressure of 6 bar and compared predicted CP profiles with their experimental and numerical results.

4) Results

Changing the spacer cross-sectional shape had a clear effect on hydraulic resistance but only a minor effect on membrane performance. The decagonal spacer reduced the pressure drop by about 13% compared with the hexagonal spacer. Over the investigated Re number range, membrane-averaged concentration polarization and permeate flux differed by less than 0.2% and 0.06%, respectively, between the tested geometries. Local CP profiles were nearly identical at lower Re numbers, with small deviations appearing only downstream of the first spacer at higher Re numbers.

5) Conclusions

Spacer-shape optimization can reduce pumping-energy demand without increasing near-membrane solute accumulation or compromising permeate flux. Since spacer design has been shown to influence cleaning efficiency through shear stress in ultrafiltration [4], these findings provide a basis for cleaning-focused assessment of RO spacer designs.

References

[1] Hartinger, M., Napiwotzki, J., Schmid, E.-M., Hoffmann, D., Kurz, F., and Kulozik, U. Influence of Spacer Design and Module Geometry on the Filtration Performance during Skim Milk Microfiltration with Flat Sheet and Spiral-Wound Membranes. Membranes 10 (2020), 57.
[2] Lin, W., Wang, Q., Sun, L., Wang, D., Cabrera, J., Li, D., Hu, L., Jiang, G., Wang, X.-M., and Huang, X. The critical role of feed spacer channel porosity in membrane biofouling: Insights and implications. Journal of Membrane Science 649 (2022), 120395.
[3] Salcedo-Díaz, R., García-Algado, P., García-Rodríguez, M., Fernández-Sempere, J., and Ruiz-Beviá, F. Visualization and modeling of the polarization layer in crossflow reverse osmosis in a slit-type channel. Journal of Membrane Science 456 (2014), 21–30.
[4] Sreedhar, N., Thomas, N., Al-Ketan, O., Rowshan, R., Abu Al-Rub, R.K., Hong, S., and Arafat, H.A. Impacts of feed spacer design on UF membrane cleaning efficiency. Journal of Membrane Science 616 (2020), 118571.

Keywords: Reverse Osmosis; Concentration Polarization; Feed Spacer; CFD

Acknowledgements

This IGF project of the FEI is supported within the programme for promoting the Industrial Collective Research (IGF) of the German Federal Ministry for Economic Affairs and Energy (BMWE)

27 Validation of Ultrasound-Assisted Pasteurisation for Hygienic Processing of Plant-Based Liquid Egg Analogues

Mahsa Farrokhi, Jorge Pinto, Natalia Casanova, Teresa R.S. Brandão, Daniela Machado, Ana M. Gomes, Cristina L.M. Silva;
Universidade Católica Portuguesa, CBQF – Centro de Biotecnologia e Química Fina

1) Introduction and Background

The commercialization of plant-based liquid egg analogues requires validated hygienic processing technologies to ensure microbiological safety comparable to conventional pasteurised egg products.

2) Objectives

This study evaluated the microbiological effectiveness of ultrasound-assisted pasteurisation compared with conventional thermal pasteurisation for a plant-based liquid egg analogue under mild processing conditions.

3) Methods

A plant-based liquid egg analogue, manufactured following good hygiene practices, was subjected to seven treatments: untreated control, ultrasound-assisted pasteurisation (55°C for 15 and 20 min; 60°C for 10 min) and thermal pasteurisation (55°C for 15 and 20 min; 60°C for 10 min). Total aerobic mesophiles, Enterobacteriaceae and yeasts/moulds were enumerated according to ISO methods. Experiments were conducted on three independent days with triplicate microbiological analyses. Data were analysed by one-way ANOVA and Tukey's test ($p < 0.05$).

4) Results

All pasteurisation treatments significantly reduced total aerobic mesophilic counts compared with the untreated control (7.48 log CFU/mL; $p < 0.05$). Ultrasound-assisted pasteurisation at 60°C for 10 min enabled the greatest reduction (5.21 log CFU/mL) significantly lower than thermal treatment at the same temperature (4.80 log CFU/mL). At 55°C, ultrasound-assisted and thermal treatments achieved comparable microbial reductions after 20 min (3.89 and 4.06 log reduction, respectively), whereas ultrasound produced lower counts after 15 min than thermal pasteurisation (3.20 versus 2.72, respectively). Enterobacteriaceae and yeasts/moulds viable cell numbers were below the detection limit following all ultrasound-assisted treatments and thermal pasteurisation at 60°C. The microbial counts were comparable to those reported for commercial pasteurised liquid egg products, supporting the potential of ultrasound-assisted pasteurisation as an alternative hygienic processing technology.

5) Conclusions

Ultrasound-assisted pasteurisation effectively enhanced microbial inactivation under mild thermal conditions and represents a promising hygienic processing strategy of plant-based liquid egg analogues, while maintaining composition functionality and nutritional quality.

References

ISO 4833-1 :2013. Microbiology of the food chain — Horizontal method for the enumeration of microorganisms.
ISO 21528-2 :2017. Microbiology of the food chain — Enumeration of Enterobacteriaceae.
ISO 21527-1 :2008. Microbiology of food and animal feeding stuffs — Enumeration of yeasts and moulds.
Lauteri, C., Ferri, G., Piccinini, A., Pennisi, L., & Vergara, A. (2023). Ultrasound Technology as Inactivation Method for Foodborne Pathogens: A Review. Foods, 12(6), 1212. https://doi.org/10.3390/foods12061212
Nagy, D., Baranyai, L., Nguyen, L. L. P., Taczman Brückner, A., Zsom, T., Németh, C., Felföldi, J., & Zsom-Muha, V. (2022). Combined Effect of Ultrasound and Low-Heat Treatments on E. coli in Liquid Egg Products and Analysis of the Inducted Structural Alterations by NIR Spectroscopy. Sensors, 22(24), 9941. https://doi.org/10.3390/s22249941
Piyasena, P., Mohareb, E., & McKellar, R. C. (2003). Inactivation of microbes using ultrasound: a review. International journal of food microbiology, 87(3), 207–216. https://doi.org/10.1016/s0168-1605(03)00075-8

Keywords: Plant-based liquid egg analogue, Ultrasound-assisted pasteurisation, Hygienic processing, Food safety, Microbiological validation.

Acknowledgements

The authors would like to acknowledge the support by National Funds from FCT - Fundação para a Ciência e a Tecnologia through project UID/50016/2025 and LA/P/0076/2020 https://doi.org/10.54499/LA/P/0076/2020), and VIIAFOOD - Plataforma de Valorização, Industrialização e Inovação comercial para o AgroAlimentar (n. °C644929456-00000040).

28 Industrial Case Study: Improving Crude Palm Oil Quality Preservation Through Temperature Management and Enhanced Magnetic Trap Maintenance

Muhammad Izhar Kairi, Noor Illi Mohamad Puad, Arif Syahmi Alias, Syahril Anuar Md Rejab, Rahmat Ngteni, Mohd Shafril Baharudin, Mohd Shiraz Aris;
Mills Research, Upstream Research

1) Introduction and background

The preservation of crude palm oil (CPO) quality during storage and dispatch remains an important challenge for the edible oil industry. Elevated storage temperatures and iron contamination can accelerate primary oxidation, resulting in quality deterioration and reduced product stability. Iron is a well-known pro-oxidant catalyst that promotes the formation of free radicals and increases the rate of lipid oxidation, particularly under elevated temperature conditions. Excessive oxidation may lead to faster development of rancidity, shorter product shelf life and reduced frying performance, potentially affecting compliance with customer quality requirements and increasing the risk of quality-related complaints. While storage temperature control and magnetic traps are commonly used in palm oil mills, their hygienic design, monitoring and maintenance practices are often not optimized for effective contamination control. This study evaluates the application of hygienic engineering principles to improve the cleanability, effectiveness and verification of contamination-control and storage systems for enhanced CPO quality preservation.

2) Objectives

This industrial case study aims to evaluate hygienic engineering and operational improvements designed to reduce iron contamination and primary oxidation during CPO storage and dispatch. The objective is to demonstrate how improved contamination-control barriers, enhanced cleanability, equipment monitoring and optimized storage management can strengthen food safety and product quality assurance within commercial palm oil mills.

3) Methods

Operational assessments were conducted at selected commercial palm oil mills to identify opportunities for improving contamination control and storage tank management. Improvement initiatives included increased magnetic trap cleaning frequency, standardized cleaning procedures and implementation of magnetic field strength verification using a Gauss meter to support the effectiveness and verification of contamination-control systems. An additional magnetic trap was recommended as a secondary contamination-control barrier immediately before product dispatch and was implemented at one commercial mill to evaluate its potential impact on iron contamination control. Recommendations were also made for the adoption of open-ended magnetic trap designs to improve cleanability, inspection accessibility and maintenance effectiveness. Storage tank improvements included reducing the operating temperature range from 45-55°C to 40-50°C, based on previous fundamental studies demonstrating lower primary oxidation rates under controlled moisture conditions at lower storage temperatures. Additional recommendations included relocation of temperature sensors from non-representative upper tank locations to middle and lower product zones and implementation of extended oil circulation prior to dispatch to improve temperature uniformity, reduce thermal stratification and minimise localized overheating. Operational performance, contamination-control observations and routine quality indicators were evaluated before and after implementation.

4) Results

The assessment identified several hygienic design and operational limitations that could compromise contamination-control effectiveness and temperature monitoring accuracy. An additional magnetic trap installed immediately prior to product dispatch at one commercial mill provided a secondary contamination-control barrier and enabled evaluation of its effectiveness in further reducing the risk of ferrous contamination entering the refinery. The assessment also identified opportunities to improve magnetic trap cleanability and inspection accessibility through the adoption of open-ended designs, which facilitate more effective cleaning and maintenance compared with enclosed configurations.

The implementation of Gauss meter verification improved monitoring of magnetic trap performance and supported a more structured contamination-control programme. For storage management, relocation of temperature sensors from upper tank positions to representative product-contact zones improved the accuracy of temperature monitoring.

In addition, reducing the storage temperature operating range from 45-55°C to 40-50°C, together with extended oil circulation prior to dispatch, improved temperature uniformity and minimized localized overheating. These improvements were consistent with previous fundamental studies indicating lower oxidation rates under controlled moisture conditions at reduced storage temperatures. Collectively, the hygienic design enhancements, contamination-control verification measures and optimized storage practices strengthened contamination prevention, improved process monitoring reliability and contributed to more consistent preservation of crude palm oil quality during storage and handling. As part of an ongoing research and development programme, the effectiveness of these interventions continues to be monitored at commercial scale. The findings will be used to develop evidence-based guidelines for producing higher-quality crude palm oil with lower peroxide value (PV) and iron content with the objective of supporting wider implementation across relevant palm oil mills.

5) Conclusions

This case study demonstrates that the integration of hygienic engineering principles with operational best practices can enhance crude palm oil (CPO) quality preservation during storage and dispatch. Hygienic improvements including enhanced magnetic trap cleanability, magnetic field strength verification, improved temperature monitoring and the introduction of an additional contamination-control barrier strengthened the prevention, monitoring and verification of ferrous contamination, a known pro-oxidant catalyst that accelerates lipid oxidation. Optimization of storage tank management through improved temperature sensor placement, reduced operating temperature range and extended oil circulation further improved temperature uniformity and reduced oxidation risk. Unlike conventional approaches that rely primarily on routine maintenance and process control, the proposed framework integrates hygienic design, contamination-control verification and scientifically based storage management to address both iron contamination and primary oxidation. This work forms part of an ongoing research and development programme to evaluate the effectiveness of these interventions and develop evidence-based guidelines for producing higher-quality CPO with lower peroxide value (PV) and iron content. The findings provide practical and scalable guidance for edible oil storage and handling systems and may support wider implementation across relevant palm oil mills seeking to enhance contamination prevention, product quality consistency, customer satisfaction and operational excellence.

References

1. Malaysian Palm Oil Board. (2025). Code of good milling practice for palm oil mills (3rd ed.). Malaysian Palm Oil Board.
2. Torquato, A. S., et al. (2020). Kinetic Parameters of the Thermal Oxidation and Degradation Reactions in Soybean Oil and Palm Olein. Journal of the Brazilian Chemical Society, 31(10).
3. Hashim, Z., Zaki, S. S. A. M., & Muhamad, I. I. (2017). Quality Assessment of Fried Palm Oils using Fourier Transform Infrared Spectroscopy and Multivariate Approach. Chemical Engineering Transactions, 56, 829-834.
4. Judijanto, L. (2026). Balancing risks and benefits: a review of palm oil consumption and cardiovascular health outcomes. Open Access Journal of Science, 9(1), 46-56.
5. Ikhajiangbe, H. I., et al. (2025). Lipid profile alterations in rats fed oxidized palm oil diets. ISA Journal of Medical Sciences, 2(4), 162-170.

Keywords: CPO, Premium, Storage Tank Management, Peroxide Value, Iron, Temperature Control, Oxidation, Magnetic Trap.

Acknowledgements

The authors would like to thank the SD Guthrie and all personnel involved in this study for their support, collaboration and technical contributions. Their efforts in operational implementation, monitoring and quality assessment were essential to the development of the findings presented in this case study.

29

Monitoring of Heat-Induced Fouling Using a Clamp-On Ultrasonic System

Yogesh Sharma, Phillip Müter, Dominik Geier, Jörg Hinrichs, Thomas Becker;
Brewing and Beverage Technology, TUM School of Life Sciences;
Department of Soft Matter Science and Dairy Technology, University of Hohenheim

1) Introduction and background

Fouling on heat-transfer surfaces and other process equipment during food manufacturing can compromise hygienic conditions and lead to conservative, time-based cleaning schedules.

2) Objectives

Reliable online fouling monitoring would enable cleaning decisions to be based on the actual fouling status of equipment rather than fixed intervals, thereby supporting both food safety and resource-efficient production. However, established fouling-monitoring approaches are often invasive or limited to offline assessment.

3) Methods

This study presents a non-invasive, clamp-on ultrasonic system for monitoring heat-induced milk fouling. Fouling was generated in a 0.5 m planar channel on a pilot-scale rig circulating a milk concentrate, with the heated surface held at 100 °C. Two ultrasonic sensors (transmitter and receiver) were mounted externally at opposite ends of the channel using PEEK wedges to couple guided ultrasonic waves into the channel wall. Across more than ten fouling experiments of different durations, gravimetric measurements of fouling mass were used as reference data.

4) Results

Ultrasonic signals were continuously acquired, and characteristic signal features were extracted and used as input variables for an artificial neural network with two hidden layers. The network was trained and evaluated against the gravimetrically determined fouling masses and achieved quantitative fouling prediction with $R^2 > 0.9$. Shapley-value analysis was applied to interpret feature contributions, and the trained model was subsequently used to estimate the temporal development of fouling from independent ultrasonic measurements.

5) Conclusions

The results demonstrate that clamp-on ultrasonic measurements can be used to monitor heat-induced fouling. The proposed approach could support cleaning strategies based on the actual fouling state and improve cleaning validation, thereby providing information on the timing and duration of cleaning procedures.

Keywords: Fouling Monitoring; Ultrasound; Feature Extraction; Artificial neural networks

Acknowledgements

This IGF project of the FEI is supported within the programme for promoting the Industrial Collective Research (IGF) of the German Federal Ministry for Economic Affairs and Energy (BMWE) on the basis of a decision by the German Bundestag. Project 01IF23335N.

30

30.Understanding the Fouling Mechanisms in Falling Film Evaporator by Microscopic and Microfluidics Approach

Margot Grostete, Jeehyun Lee, Maude Jimenez, Romain Jeantet, Luca Lanotte
INRAE, Institut Agro, STLO, 35042, Rennes, France
Unité Matériaux et Transformations (UMET) - UMR 8207, INRAE, 59651, Villeneuve d'Ascq, France
Institut Universitaire de France (IUF), 1 rue Descartes, 75231 cedex, Paris, France

Fouling refers to the accumulation of undesired solid particles from a process liquid stream onto equipments surfaces. It stands out as one of the most challenging and costly challenges in industrial operations, degrading performance. The dairy industry is no exception: fouling manifests as the progressive deposition of proteins and minerals on stainless-steel surfaces. Approximately 80% of non-raw material production costs are attributed to fouling (Saget at al., 2021). Fouling acts as a thermal insulator, reducing heat transfer efficiency and it can restrict or even obstruct the flow of process fluids, thereby increasing hydraulic resistance. It can also create favorable conditions for biofilm growth, increasing microbiological risks. As a result, regular cleaning is mandatory, consuming significant amounts of time, chemicals, water, and thermal energy (Wilson, 2018).

Fouling in the dairy industry occurs during thermal unit operations, such as heat treatment and concentration by evaporation. This phenomenon is attributed to the denaturation of whey proteins (WP) in the bulk liquid at high temperatures. In heat exchangers, the temperature exceeds the denaturation temperature of these proteins (70°C), often reaching 80-120°C while shear rates can reach 1000 s^{-1}, which can cause fouling layers to form rapidly on the surfaces. This temperature-driven interpretation has dominated the literature (Prakash et al., 2015; Visser & Jeurnink, 1997), reinforcing the idea that protein denaturation in solution (Erabit et al., 2014; Vilotte, 2021) is the primary origin of fouling.

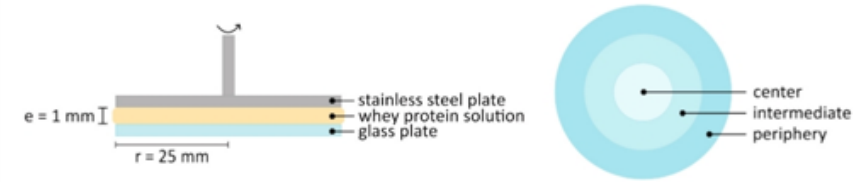
Notably, fouling can be observed at temperatures as low as 45°C-well below the denaturation temperature (Huppertz & Nieuwenhuijse, 2021). This has been reported in several studies - (Broom, 2005, Morison, 2015), contradicting the assumptions derived from behaviors observed in heat exchangers. This suggests that mechanisms other than bulk protein denaturation must contribute to fouling in evaporators. Indeed, falling film evaporators operate differently from heat exchangers. ; their goal is to remove some of the water from the product prior to a drying process, thereby reducing the energy required for drying. An evaporators typically consist of several stages operated under vacuum, with temperatures decreasing ranging from 80°C to 45°C, under vacuum. The process liquid flows downward along the heated surface as a thin film driven by gravity, generating relatively with low shear rates of around(100 s^{-1}). As the liquid film During the process, the liquid encounters the surface, it is heated and allowing it to be heated and the water to evaporates in the center of the tube, and the outgoing , leading to a product is more concentrated product at the outlet.

Most studies focus primarily on the effect of temperature in heat exchangers, leaving evaporators aside. They use offline analytical methods, examining only the inlet and outlet streams, and focusing on bulk analyses (Moakes et al., 2015), as well as fouling layers at the end of the process. Since industrial systems function as "black boxes," where direct observation is difficult, the studies rely on overall outcomes such as thermal performance or mass balance. However, fouling is ultimately a surface-driven phenomenon, as deposits form and grow at the interface between the process liquid and equipment surface. The prevailing on thermal denaturation of protein, coupled with the lack of direct observation of fouling formation, overshadows potential important factors influencing fouling formation, such as surface shear rate and concentration gradients in the case of falling film evaporatorsend of the process. Since industrial systems function as "black boxes," where direct observation is difficult, the studies rely on overall outcomes such as thermal performance or mass balance. However, fouling is ultimately a surface-driven phenomenon, as deposits form and grow at the interface between the process liquid and equipment surface. The prevailing on thermal denaturation of protein, coupled with the lack of direct observation of fouling formation, overshadows potential important factors influencing fouling formation, such as surface shear rate and concentration gradients in the case of falling film evaporators.

In my thesis, we sought to address this gap, by developing innovative experimental approaches to study the formation of whey protein deposits on surfaces under evaporator-like conditions: processing temperatures

that limit denaturation, a shear rate of 100 s^{-1}, and varying protein concentrations. Our primary objectives were twofold: i) to assess the impact of shear on deposit formation of whey proteins at temperatures below the denaturation threshold, and ii) to identify analytical methods for quantitatively observing surface deposition. Two complementary methodologies were employed: first a rheometer-based system that allowed precise control of shear, time, and temperature to determine whether shear had an effect; second a microfluidic device to directly observe the kinetics of deposit formation in a continuous flow environment.

To evaluate the shear rate effect without a predominant heat denaturation, experiments were conducted at 65°C, i.e., temperature slightly below the irreversible denaturation (70°C) and within the operational range of evaporators. The chosen shear rates range from 0 to 200 s-1, encompassing the typical value encountered in evaporators. The system shown in Figure 1 illustrates the methodology, using a rheometer to facilitate direct measurement and observation of surface deposits. It consists of a glass surface and a plate geometry, enabling the surface to be divided into different shear zones. This method allowed us to observe the effect of surface shear on deposit formation within a single sample. This method was subsequently reapplied using a plate-cone geometry to compare bulk aggregation with surface deposition, as well as to assess the effect of shear. The analyses performed include microscopic analyses to quantify the number and size of surface deposits using digital microscopy, as well as observation of their structure via Scanning Electron Microscopy (SEM) and Atomic Forces Microscopy (AFM). In a second step, the effect of shear on the denaturation of whey proteins, as well as the number and size of aggregates, was studied using HPLC-UV, turbidity measurements by spectrometry, and dynamic light scattering, respectively. The interaction between shear and whey protein concentration by testing three concentrations: 5, 10 and 12 wt. %.



The developed methodology enabled effective sampling of surface deposits and their observation through microscopy. This approach provided essential insights into the nature and morphology of the formed deposits. Shear was found to play a significant role in promoting deposit formation: increasing shear not only raised the number of deposits but also altered their morphology, leading to more complex structures. These deposits were categorized into two types: primary deposits and more complex branched aggregates. Additionally, the interaction between shear and protein concentration was highlighted. At high shear rates (200 s^{-1}) and concentrations (12 wt. %), the observed structures resembled gel-like networks, with significantly larger sizes. (Figure 2).

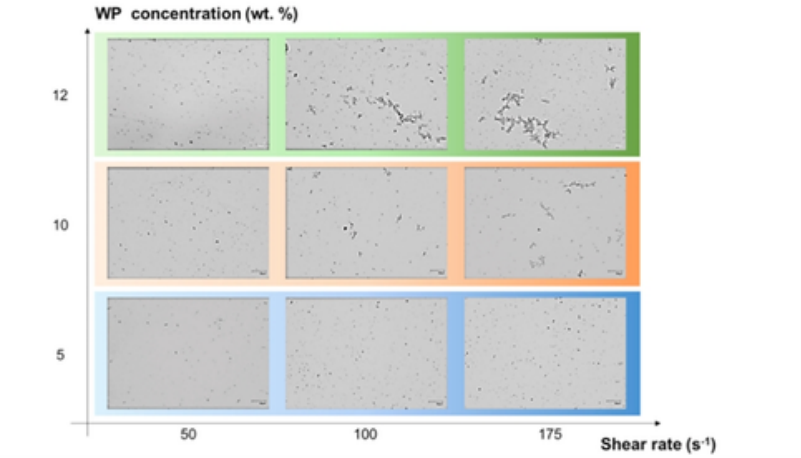


Figure 2: Qualitative characterization of whey protein surficial deposits forming under shear from solutions at 5 wt% (blue), 10 wt% (orange) and 12 wt% (green) (scale bar = 50 µm) (Grostete et al., 2026).

SEM further revealed a population of smaller deposits (< 1 µm) across all shear and concentration conditions tested. In the bulk solution, shear did not appear to affect the number or size of aggregates. However, protein concentration has a marked effect: higher concentrations lead to a greater number of aggregates, suggesting slight denaturation of proteins despite the low temperature. The size of the

aggregates observed in solution corresponded to the smallest deposits identified by SEM. Our hypothesis, illustrated in Figure 3, proposes that aggregates formed in solution are transported toward the surface. Under shear, these aggregates are brought more rapidly and in greater quantities to the surface, creating localized concentration zones. This promotes the formation of complex deposits, eventually leading to saturation and gel formation.

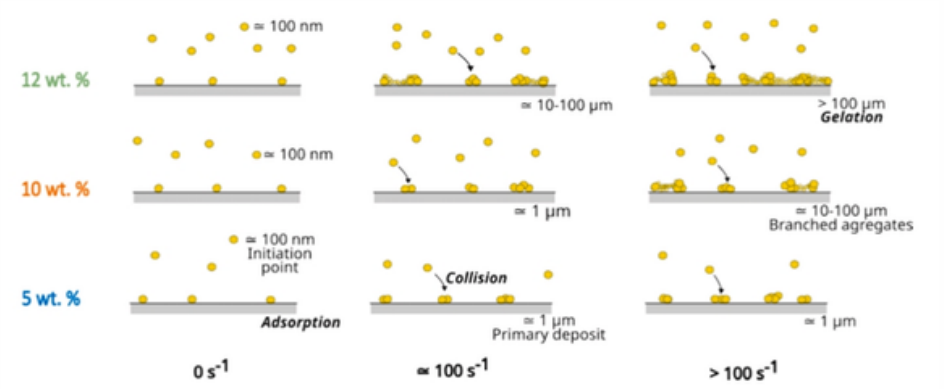


Figure 3: Scheme of solution and surface deposition mechanism as a function of whey protein concentration and shear rate (Grostete et al., 2026).

This section of the thesis has resulted in three publications: the first highlighting the rheometer based methodology and the effect of shear on surface deposition (Groste et al, 2024), the second on the origin of depositions, by comparing the phenomena at the surface and in the bulk solution (Grostete et al, 2026), and a third article on the effect of shear at high concentrations of gelling protein at 65°C (Grostete et al, 2025).

After demonstrating that shear stress affects surface deposition and formulating initial hypotheses regarding its interaction with protein concentration and kinetics of deposit formation, the goal was to establish a method capable of real-time observation and more representative of continuous-flow conditions. That is why we chose to develop microfluidics techniques within the STLO laboratory. We received training in lithography at the Rennes Institute of Physics and in temperature-control techniques at DICMAPI at the University of Naples.

Microfluidic offers a powerful solution to the lack of direct observations in traditional systems. It is the science and technology of manipulating small amounts of fluids, using channels with dimensions of tens to hundreds of micrometers (Whitesides G.M., 2006). The microfluidic system developed here enabled a direct observation while maintaining controlled temperature and wall shear rate. It served several key objectives: i) it allowed us to reproduce the temperature and shear conditions of falling film evaporators and ii) it enabled observation and quantification of the effect of shear and temperature. The objective is to study was to characterize the deposition kinetics as a function of shear rate (50, 100, 200 s^{-1}) at different temperatures (50, 65, 75 °C) corresponding to the operating conditions of evaporators.

The observation and experimentation system consists of a digital microscope positioned above the microfluidic channel. This cell is composed of PDMS and a glass substrate. It is placed on a glass incubator with continuous hot water circulation to control the temperature. The temperature was monitored in the incubator, at the surface of the microfluidic cell, and in the solution using a temperature-sensitive fluorescent probe. The cell consists of eight bends, with an inlet and an outlet; a 10wt% serum protein solution was circulated continuously through the cell for two hours. Various analyses are performed during the experiment: continuous imaging at the channel inlet and the first elbow (an area previously identified as a deposition zone) to measure the growth of the deposit on the surface, an assessment of the deposit structure at the end of the experiment using confocal microscopy at different heights within the cell, for these samples, a fluorescent marker (RITC) was added to the solution.

The effect of temperature was very pronounced. At a fixed shear rate (100 s^{-1}), deposition occurred much more rapidly at high temperatures. While experiments at 50 and 65°C could last for two hours or longer, those at 75°C typically lasted only 25 minutes before the channel became obstructed by accumulated deposits (Figure 4). This demonstrates the predominant temperature effect. Furthermore, at 50°C and 75°C, no significant differences were observed between the different shear rates. At 50°C, no deposit was

visible under optical microscopy, but confocal microscopy revealed a thin deposit (less than 5 µm), this shows that the deposit can form on the surface at a temperature lower than the denaturation temperature but with a very slow reaction rate relative to the temperatures.

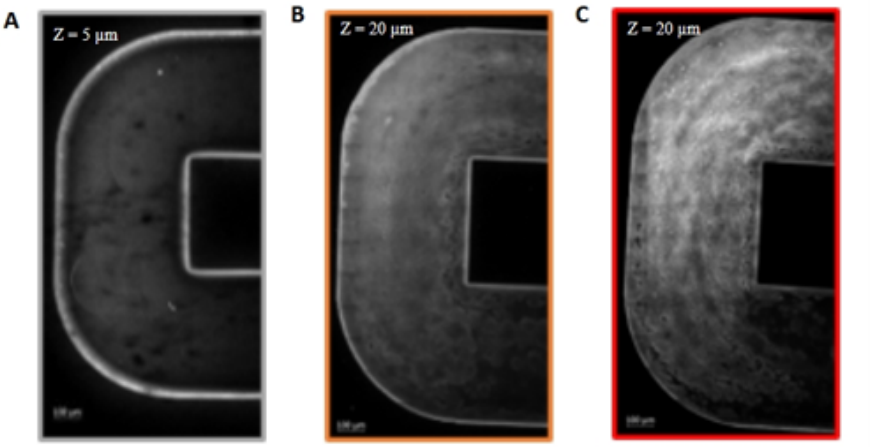


Figure 4: Confocal imaging of corner (scale = 100 µm) after treatment at 100 s-1 and (A) 50°C (grey), (B) 65°C (orange), (C) 75°C (red).

At 65°C, the effect of shear is visible: no surface deposits form, and a thicker deposit forms under high shear (Figure 5). An increase in accidental phenomena was also observed with shear, such as dust or the formation of air bubbles, which may facilitate deposit formation. When the shear rate is increased, more deposit clusters are formed, and a gel-like structure appears to bind these clusters. At lower shear (50 s-1), cluster deposits form but in small quantities, do not gel and remain mainly close to the walls. This difference in shear rates suggests that shear rate helps the formation of fouling by allowing the surface to be fed with aggregate in solution. This hypothesis was supported, in particular, by the calculation of the mean square displacement (MSD), which shows the distance a particle in solution travels along the length of the channel before reaching the surface; the higher the shear rate, the shorter this distance. This means that at high shear rates, proteins accumulate more quickly and earlier in the channel.

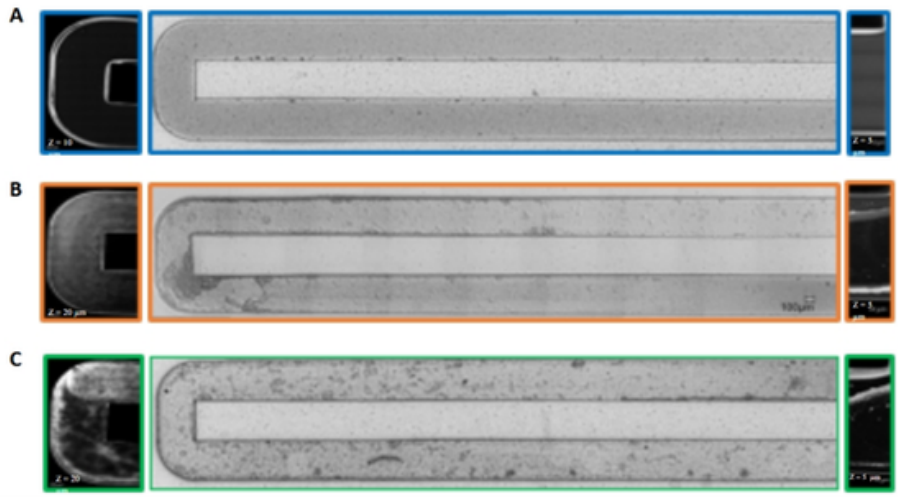


Figure 5: General observation of channel after treatment at 65°C and wall shear rate (A) 50 s-1 (bleu), (B) 100 s-1 (orange), (C) 200 s-1 (green).

A deposit-formation kinetics emerges (Figure 6) from the analysis of the surface area occupied by the deposit, regardless of the shear applied. The kinetics can be decomposed in four segments:

- i) 0 to 25 minutes: this initial lag phase corresponds to the onset of colour change with a slight increase in the surface density (delay). During time the surface density slightly increased with no difference between shear rates. Compared to other segments, this increase is not visible on the curve, considered like a delayas a lag phase for the deposit formation.
- ii) 25 to 75 minutes: a gradual increase in the surface density, during which the first small deposits began to form on the surface. The kinetics of deposit accumulation strongly depended on the shear rate.

30 [8] S.R. Broome, Liquid Distribution and Falling Film Wetting in Dairy Evaporators, University of Canterbury, Christchurch, New Zealand, 2005. [9] KR. Morison, Reduction of fouling in falling-film evaporators by design. Food and Bioproducts Processing. (2015) 93:211–6. [10] R.J.A. Moakes, A. Sullo, I.T. Norton, Preparation and characterisation of wheyprotein fluid gels: the effects of shear and thermal history, Food Hydrocoll. (45) (2015) 227–235. [11] M. Grostete, J. Lee, F. Boissel, M. Jimenez, R. Jeantet, L. Lanotte, Exploring the formation of surficial whey protein deposits under shear stress by rheofluidic approach, International Journal of Biological Macromolecules, (2024) 274. Doi.org/10.1016/j.ijbiomac.2024.133291 [12] M. Grostete, J. Lee, F. Boissel, M. Jimenez, R. Jeantet, L. Lanotte, Coupled bulk and surface mechanisms lead to surficial whey protein deposits under shear, International Journal of Biological Macromolecules, (2026) 340. doi.org/10.1016/j.ijbiomac.2026.150196 [13] M. Grostete, J. Lee, F. Boissel, M. Jimenez, R. Jeantet, L. Lanotte, Rheological response of whey protein deposits forming under shear in concentrated conditions, Rheological Acta (2025). doi.org/10.1007/s00397-025-01534-7 [14] G.M. Whitesides, The origins and the future of microfluidics. Nature, 44(27), (2006) 368–373. https://doi.org/10.1038/nature05058 Valorization Articles Grostete M., Lee J., Boissel F., Jimenez M., Jeantet R., Lanotte L. (2024), Exploring the formation of surficial whey protein deposits under shear stress by rheofluidic approach, International Journal of Biological Macromolecules, 274. Doi.org/10.1016/j.ijbiomac.2024.133291 Grostete M., Lee J., Boissel F., Jimenez M., Jeantet R., Lanotte L. (2025), Rheological response of whey protein deposits forming under shear in concentrated conditions, Rheological Acta. doi.org/10.1007/s00397-025-01534-7 Grostete M., Lee J., Boissel F., Jimenez M., Jeantet R., Lanotte L. (2026), Coupled bulk and surface mechanisms lead to surficial whey protein deposits under shear, International Journal of Biological Macromolecules, 340. doi.org/10.1016/j.ijbiomac.2026.150196 Congress Grostete M., Tanguy G., Khelifaoui S., Boissel F., Le Floch-Fouéré C., Jeantet R., Lee J., Lanotte L., 2023, A microscopic look at the fouling mechanisms in dairy protein mixes by rheometry and microfluidics, International Congress on Engineering and Food, 20 to 23th of June 2023, Nantes (France) Grostete M., Lee J., Boissel F., Jimenez M., Jeantet R., Lanotte L., 2023, Miniaturization of the fouling of whey proteins of Falling Film Evaporator by microfluidics, International Congress of Rheology, 29th of July to 4th of August 2023, Athens (Greece) Grostete M., Lee J., Tomaioulo G., Jimenez M., Jeantet R., Lanotte L., Investigation of the evolution of whey protein fouling on surface and in solution by microfluidics (Poster), Italian Society of Rheology Conference, 12th to 14th of September 2024, Anacapri (Italy) Grostete M., Lee J., Jimenez M., Jeantet R., Lanotte L., 2025, Microfluidic investigation of fouling mechanisms in falling-film evaporators, Fouling and Cleaning in Food Processing, 25th to 27th of March 2025, Dresde (Germany) Grostete M., Lee J., Jimenez M., Jeantet R., Lanotte L., 2025, Miniaturization of the fouling of whey proteins of Falling Film Evaporator by microfluidics, Annual European Rheology Conference, 14th to 17th of April 2025, Lyon (France) Grostete M., Lee J., Jimenez M., Jeantet R., Lanotte L., 2025, Exploring the dairy fouling process in miniaturized falling film Evaporators by microfluidics. Edible Soft Matter, Jul 2025, Rennes, (France)

- iii) 75 to 100 minutes: A sharp increase in the surface occupancy occured, caused by both the formation of deposits and the growth of existing ones. The surface density increased linearly at a similar rate, but their values were, higher at 100 and 200 s-1 than at 50 s-1.
- iv) 100 to 120 minutes: a final plateau with the decrease in the rate of deposit formation ; the deposition had stopped and reached a plateau under all conditions. However, the final surface density was greater at 100 and 200 s-1 than at 50 s-1.

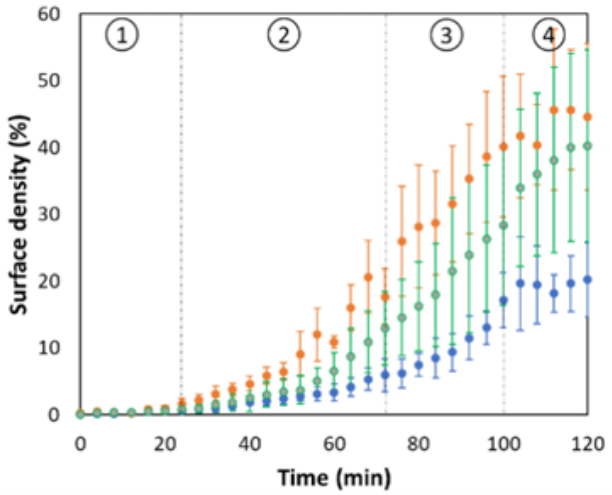


Figure 6 : Surface density analysis as a function of the shear rate applied at 65°C and wall shear rate 50 s-1 (blue), 100 s-1 (orange), 200 s-1 (green)

Thanks to this study, we understand that shear stress does not affect the initiation of the deposit but rather its development (segments 2 and 3). The microfluidic approach we have implemented enables us to control wall shear and surface temperature, while performing online observation. This system also makes it possible to approximate real evaporator conditions, such as surface/solution interaction, continuous flow and changes in direction. This research focus on microfluidics will be form the basis of a scientific paper currently being drafted. This thesis provided an opportunity to develop innovative methods to address the issue of fouling. These methods allowed us to control our experimental parameters and facilitated the observation of deposit formation. As a result, we have paved the way for and consolidated hypotheses regarding the mechanisms of fouling. We were able to define the different stages of deposit formation and begin studying the interaction between aggregation in solution and at the surface I under conditions representative of these in falling-film evaporators. Shear stress increased deposit formation on the surface and altered its morphology, leading to more complex, gel-like structures. We have also highlighted the interaction between temperature and protein concentration. This project opens up new possibilities and perspectives for understanding fouling, both in terms of improving the techniques used and the increasing the complexity of the parameters (such as solution composition or process conditions)

References

[1] M. Saget, C.F. Almeida, V. Fierro, A. Celzard, G. Delaplace, V. Thomy, et al., A critical review on surface modifications mitigating dairy fouling, Compr Rev Food Sci Food Saf. 20 (2021) 4324 4366;20(5). [2] D.I. Wilson, Fouling during food processing – progress in tackling this inconvenient truth, Curr. Opin. Food Sci. (23) (2018 Oct 1) 105–112. [3] S. Prakash, O. Kravchuk, H. Deeth, Influence of pre-heat temperature, pre-heat holding time and high-heat temperature on fouling of reconstituted skim milk during UHT processing. J Food Eng. 2015 May ;153: 45–52. [4] J. Visser, T.J.M. Jeurnink, Fouling of heat exchangers in the dairy industry, Exp. Thermal Fluid Sci. 14 (1997) 407–424. [5] N. Erabit, D. Flick, G. Alvarez, Formation of β-lactoglobulin aggregates during thermomechanical treatments under controlled shear and temperature conditions, J. Food Eng. 120 (1) (2014) 57–68. [6] A. Vilotte, H. Bodiguel, K. Ako, D.Z. Gunes, C. Schmitt, C. de Loubens, Kinetic and structural characterization of whey protein aggregation in a millifluidic continuous process, Food Hydrocoll. (2021) 110. [7] T. Huppertz & H. Nieuwenhuijse, Constituent fouling during heat treatment of milk: A review. (2021) https://doi.org/10.1016/j.idairyj.2021.105236. [8] S.R. Broome, Liquid Distribution and Falling Film Wetting in Dairy Evaporators, University of Canterbury, Christchurch, New Zealand, 2005.

31 Microbiological Assessment of Industrial Washing of Reusable Glass Packaging

Hugo Habert, Nicolas Nguyen Van Long, Pierre Gehannin, Florence Savin, Sonia Le Noc, Delphine Gomez;
ADRIA

In the context of reusable glass packaging development in France, a controlled approach is needed to assess the microbiological performance of industrial washing lines. Conventional analyses of washed containers describe their final contamination status but do not directly assess removal of a known microbial load.

This study aimed to develop and apply, under industrial conditions, a challenge-test protocol using artificially contaminated reusable glass containers. Bottles and jars were sterilized before being soiled with representative food residues and inoculated with Geobacillus stearothermophilus spores and late-exponential-phase Pseudomonas fluorescens cells. Protocol conditions (food residues used) were kept consistent within each container type. Containers were stored for 72 h at room temperature, dried for 72 h at 45 °C, then washed in industrial immersion systems. Approximately 2,800 containers were tested at six facilities over two years. Washing conditions ranged from 80 to 85 °C, 2.0 to 2.5% NaOH, and 8 to 11 min immersion time.

After washing, internal surfaces were sampled using sponges and analysed by culture methods. Thermophilic microorganisms, including G. stearothermophilus were detected in 12.6% of tested containers. G. stearothermophilus was recovered from some inoculated containers, whereas P. fluorescens was never detected after washing. However, other mesophilic microorganisms were recovered from some initially sterile negative controls. Environmental sampling at four facilities also detected microorganisms found on washed containers, suggesting a contribution of the washing-line environment to residual contamination on the containers.

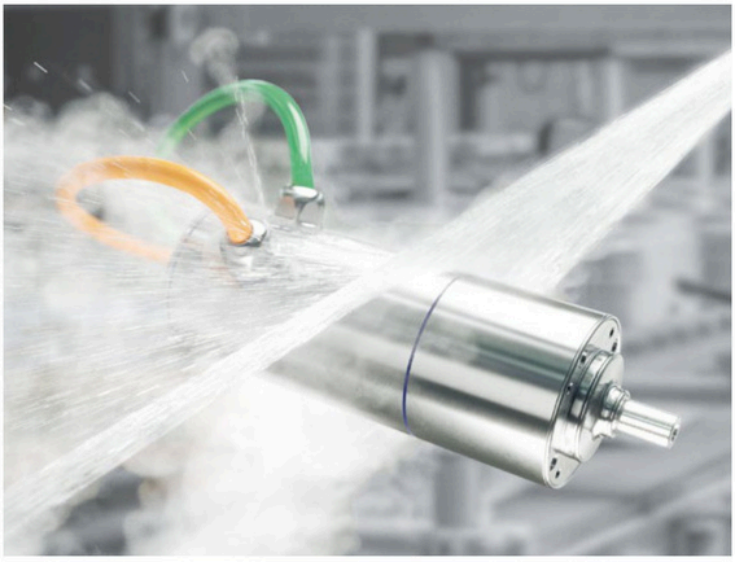
At sites where washing conditions were optimized, microbiological performance improved over successive trials as temperature and NaOH concentration were jointly increased. Their individual effects could therefore not be distinguished, while variations in immersion time showed no clear effect.
The proposed challenge-test approach directly evaluates removal of a controlled microbial contamination and complements end-point testing. The results highlight the combined importance of washing conditions and line hygiene for microbiological control of reusable glass packaging.

Keywords: reuse; glass packaging; industrial washing; microbiological challenge test; line hygiene
Acknowledgements
This work was primarily funded by CITEO.

Driving the world

SEW EURODRIVE

A clean automation solution



Stainless steel servo gearmotors
from the PSH..CM2H.. series

www.sew-eurodrive.de/stainless-steel-servo-gearmotors

Sika®

'Sustainability and innovation drive us to deliver high-performance solutions. Building trust beyond the expected'

www.sika.com

SMC

Industrial Automation

Safe, sustainable, forward-looking

Expertise
Passion
Automation

STONHARD

EST. 1922

Manufacturer and Installer of
Seamless, Hygienic Floor Solutions
for Industrial & Commercial Facilities

www.stonhard.com

32 Design and Industrial Validation of a Hygienic NIR Hyperspectral Inspection System for Foreign Matter Detection in Biscuit Manufacturing

Kübra Yağiz, Başar Bozbiyik, Bora Sağiroğlu, Deniz Algül;
Pladis Global Ülker

1) Introduction and background

Reliable detection of low-density foreign materials remains a significant challenge in biscuit manufacturing. Insufficient detection of foreign materials may cause some critical consequences such as threatening consumers health, legal obligations, product recall and destruction, and reputation loss of manufacturer.
Conventional food quality inspection and sorting technologies (including metal detectors, X-ray systems and color-based systems) are effective for various contaminants but exhibit limited capability in some cases, detecting several non-metallic foreign materials such as packaging films, paper and plastics, where color information regarding the foreign material is ambiguous. Near-infrared (NIR) hyperspectral imaging enables material discrimination based on spectral characteristics rather than color or morphological features and therefore represents a promising technology for industrial food inspection.
However, successful industrial implementation requires not only optical performance but also stable product flow, hygienically designed mechanical integration, and sophisticated software designed for this purpose.

2) Objective

The objective of this study was to design and industrially validate an NIR hyperspectral imaging-based inspection system capable of reliable foreign matter detection in continuous biscuit production.

3)Methods

An integrated inspection platform was developed by combining NIR hyperspectral imaging system with a hygienically engineered mechanical handling structure. A software-controlled feeding hopper was designed to provide continuous and homogeneous product flow towards the inspection zone. A vibratory transfer tray operating at a lower speed than inspection conveyor was introduced to distribute the product into a single layer which is essential for maintaining proper imaging, thereby minimising product overlap, shadow formation and spectral mixing, which are critical factors affecting hyperspectral classification accuracy. To ensure stable image acquisition, the inspection conveyor and camera gantry were isolated from vibration sources. The complete mechanical assembly was designed according to hygienic engineering principles, including stainless-steel construction, cleanable geometries, continuous welds, minimised product retention areas and food-contact compliant components. The spectral classification module was designed based on an anomaly-detection approach that classifies each pixel either as product or foreign object (including paper, OPP film, plastic packaging and metallic contaminants) considering known spectral features that biscuits expose at specific wavelengths in NIR range which corresponds to 900-1700 nm. To obtain appropriate imagery under manufacturing conditions, an industrial-grade hyperspectral imaging camera, the HELIOS EC64 manufactured by EVK – Austria, was used. The overall system design and commissioning, including the mechanical structure and software development, were performed by Visratek – Finland. The system was validated under real industrial operating conditions at a conveyor speed of 15 m/min and an average throughput of approximately 900 kg/h.



4) Results

Distinct spectral responses enabled reliable discrimination between food products and foreign materials. Detection performance exceeded 93% for all evaluated contaminant groups and reached 100% for metallic materials while maintaining low false-positive rates. Minimum detectable foreign object sizes ranged from 0.8 mm for metallic contaminants to approximately 1.5 mm for paper and plastic materials.
The controlled feeding strategy together with optimised product distribution significantly reduced spectral interference caused by overlapping products, resulting in stable inspection performance throughout continuous industrial operation.

A. Spectral Separation Results

Material	900 nm Reflectance	1400 nm Reflectance	Separation Score
Cookie	0.32 ± 0.03	0.41 ± 0.02	—
Crema	0.28 ± 0.02	0.36 ± 0.02	—
Paper	0.71 ± 0.04	0.69 ± 0.03	High
OPP	0.64 ± 0.05	0.61 ± 0.04	High
Plastic Bag	0.58 ± 0.03	0.56 ± 0.03	High
Metal	0.66 ± 0.07	0.67 ± 0.05	High

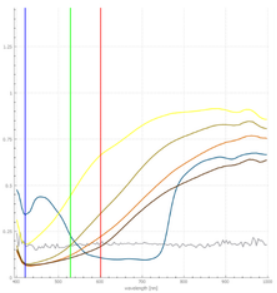
B. Detection Performance Results

Foreign Material	Sample Count	Detection Rate (%)	False Negative (%)	False Positive (%)
Paper	100	99	1	0
OPP	100	93	7	2
Plastic Bag	100	95	5	1
Metal	100	100	0	0
Mixed Foreign	100	94	6	3

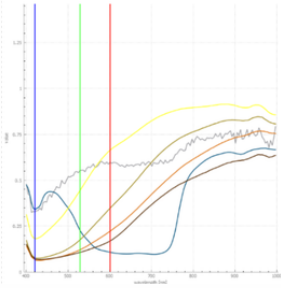
C. Minimum Detectable Foreign Size

Material	95% Detection Limit
Paper	1.5 mm
OPP	1.0 mm
Plastic Bag	1.5 mm
Metal	0.8 mm

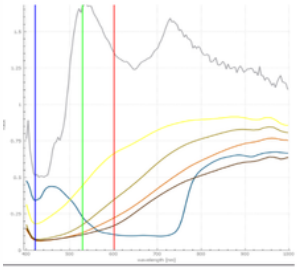
Conveyor speed 5m/min
Çizi=1.75kg/m2 ,Çokoprens=3.8kg/m2 , Biskrem=4.5kg/m2, Bebe=3.2kg/m2
Average=~3kg/m2 It is calculated at 900 kg/hour. You can see the below hyperspectral graphics and hyperspectral images;



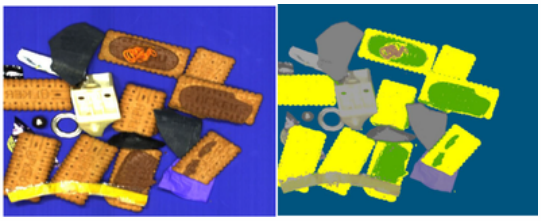
Hard plastic(gray line) (400-1000nm)

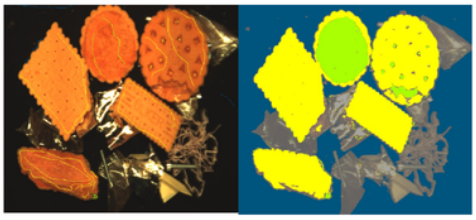


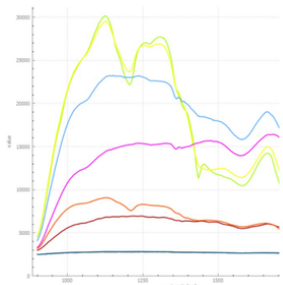
Plastic bag(gray line)(400-1000nm)



OPP(gray line)(400-1000nm)

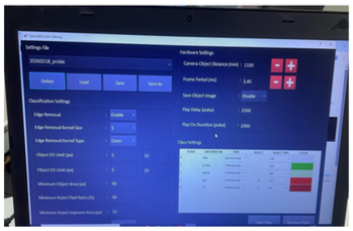


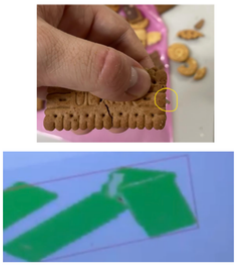






Detectable size display on PLC Screen





Detection under the shadow

5)Conclusions
This study demonstrates the successful implementation of an NIR hyperspectral imaging based industrial inspection system designed for detecting various foreign objects in which conventional quality inspection and sorting systems remain insufficient.. The proposed inspection platform provides a practical engineering framework for integrating hyperspectral imaging into continuous food manufacturing and demonstrates that appropriate product flow is essential for reliable spectral classification and foreign matter detection under real production conditions.

References:
Hyperspectral Imaging in Agriculture, Food and Environment. Alejandro Isabel Luna Maldonado, Humberto Rodríguez Fuentes, and Juan Antonio Vidales Contreras (Eds.). Hyperspectral Imaging in Agriculture, Food and Environment. CRC Press, Taylor & Francis Group, 2020.
Hyperspectral Imaging Technology in Food and Agriculture
Bosoon Park and Renfu Lu (Eds.). Hyperspectral Imaging Technology in Food and Agriculture. Springer, Food Engineering Series, 2015.
Keywords: Hyperspectral imaging ,food safety , hygienic design , foreign body detection , Biscuit Manufacturing
Acknowledgements
The authors would like to thank Dr. Fatih Ömrüuzun from Visratek for his technical support and valuable contributions to the hyperspectral imaging system development. Special thanks are also extended to İsmail Özturan (Manufacturing Lead), Bora Sağıroğlu (Quality Director), Kübra Yağız (Quality Manager), and Deniz Algül (Maintenance Manager) for their continuous support throughout the project implementation and industrial validation process.

TEK SER

'The Expert Solution Partner in Industrial and Hygienic Floor Applications Since 1980...'

tekser.org

UQESH®
Polyurethane Floor & Wall Coating

Engineered for Hygiene Built for Food Safety

Waterborne
Sustainable
Hygienic



VISIT OUR WEBSITE
www.uqesh.com

VIBROFLOORS
WORLD GROUP

Built for Decades, Proven Every Day.

INDUSTRIAL FLOORING SPECIALIST
FOR THE FOOD PROCESSING INDUSTRY

Improve Food Safety through Colour Coding and Hygienic Design



Colour-coded, hygienic cleaning solutions for the food industry.

Vikan
ADVANCING HYGIENIC CLEANING

ZAHNA FLIESEN



www.zahna-fl iesen.de

The Next Generation of Hygienic Design Professionals

STUDENT ENGAGEMENT OPPORTUNITIES

Students can connect with the EHEDG network and gain valuable exposure to the food industry and hygienic design sector through dedicated development pathways

THE EYE MENTORSHIP PROGRAMME



The EYE (EHEDG & Young EFFoST) Mentorship Programme connects young professionals in food science and technology with experienced mentors from academia and industry. Through regular 1:1 mentoring, networking events and the use of the LIFO® method for mentor-mentee matching, the programme supports personal growth, leadership development and meaningful professional connections for the next generation of food industry leaders.

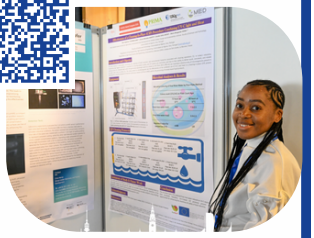
SUMMER SCHOOL PROGRAMMES



The EHEDG Summer School is a 5-day immersive programme that introduces Master's and PhD students to hygienic engineering and design in food production environments. Combining expert knowledge, practical case studies, hands-on learning and teamwork, the programme helps students bridge academic learning with industry practice while expanding their professional network within the EHEDG community.

NETWORKING OPPORTUNITIES & EVENTS

EHEDG offers young professionals valuable networking platforms through regional events and activities across the globe. In addition, students and researchers can showcase their work through research poster presentations at the EHEDG World Congress, enabling meaningful connections with industry experts, academics, and peers within the international food engineering and hygienic design network.



ATT INOX ENGINEERING

Over two decades of expertise have enabled us to deliver durable, hygienically designed structures that enhance safety, reliability and operational efficiency throughout the food processing industry.

www.att.eu | www.agatt.com

EiQ industrial

'Complete Solutions for stainless steel enclosures.'

eiqindustrial.com

habasit

'Keeping your industry in motion'

habasit.com

hillbrush®

'Engineered For Performance. Built On Partnership. Trusted Worldwide.'

hillbrush.com



Inspect. Protect. Comply.

Proven Product Inspection Solutions
Designed with Hygiene in Mind

Learn more www.mt.com/pi-ehedg

METTLER TOLEDO

TOTAL HYGIENIC SOLUTIONS

Protect hygiene. Prevent damage. Simplify cleaning.

30 YEARS ANNIVERSARY

POLYSTO
strong in hygienic construction

Everything you need for a food-safe food facility

Hygienic walls & ceilings
- Glasbord®
- CleanSheet
- FRP sheets & coils
- Laminated panels

Hygienic wall protection
- CleanRock® kerbs
- PVC coved skirtings
- Polyethylene wall ledges
- Stainless steel posts & barriers
- Stainless steel column protection

Technical solutions
- Windows & doors
- (LED) lightings
- Durable HygiSeal®
- Food-safe silicone
- Hard Fix Glue
- Stainless steel drainage systems

Discover more about hygienic construction on **www.polysto.com**

SKF®

'We fight friction to move the world forward'

skf.com


Key locations
1 Austria Center Vienna
Bruno-Kreisky-Platz 1, 1220 Vienna
Nearest metro: Kaisermühlen VIC (U1)
Walking time: approx. 6 minutes
2 Congress Dinner
Orangerie Schönbrunn
Schönbrunner Schloßstraße, 1130 Vienna
Austria Center Vienna
Kaisermühlen VIC (U1)
St. Stephen's Cathedral
Hofburg Imperial Palace
Vienna State Opera
Westbahnhof
Belvedere Palace
Hauptbahnhof Vienna Central Station
Congress Dinner: Orangerie Schönbrunn
Schönbrunn Palace
Discover Vienna
Some highlights near the Congress
3 St. Stephen's Cathedral
Iconic landmark in the heart of the city centre.
4 Hofburg Imperial Palace
Former imperial residence with museums and the Spanish Riding School.
5 Vienna State Opera
World-famous opera house in the city centre.
6 Belvedere Palace
Baroque palace with impressive art collections and gardens.
Getting to the Congress
From Vienna Airport (VIE)
Bus: approx. 35 min
Train + U1: approx. 40 min
Taxi: approx. 20–25 min
From Vienna Central Station (Hauptbahnhof)
U1 to Kaisermühlen VIC
Approx. 28 min
The congress venue is located at the Austria Center Vienna.
Nearest metro station: Kaisermühlen VIC (U1).
More information
on venue, accommodation and exploring Vienna