Model-based Process Monitoring and Optimization of Lactose Crystallization

Topic:	**Experimental and modeling application of ATR-FTIR measurement technique to monitor industrial lactose crystallization**
Type:	Master thesis, or with reduced scope Bachelor Thesis/Semester Project
Starting date:	Summer or Fall 2022
Breakdown:	40% experimental, 60% modeling
Advisor:	Prof. Dr. Marco Mazzotti, ML G27, marco.mazzotti@ipe.mavt.ethz.ch
Supervisor:	Silvio Trespi, ML G24, strespi@ipe.mavt.ethz.ch

Cheese whey, a major by-product of cheese production, represents one of the main waste streams in the dairy industry. Within the transition towards circular economy, several valorization strategies have been proposed to exploit cheese whey while minimizing waste production [1-2]. Particular attention is given to the recovery of lactose, one of its main components, which is a promising starting material for the production of high-value chemicals, such as prebiotics, bioplastics or as an excipient in pharmaceutical tablets[1].

In aqueous solution, lactose undergoes an intramolecular reaction leading to two diastereomers, α- and β-lactose, that slowly interconvert until equilibrium: the reaction is called mutarotation. Below 93 °C, α-lactose is the least soluble compound and is traditionally recovered from whey as monohydrate via seeded batch cooling crystallization [3-4]. Such process is governed by the complex interplay between secondary nucleation, growth and mutarotation. A fundamental process parameter to be monitored for process development is the lactose concentration in solution, in terms of both α- and β-lactose. Hence, the purpose of this research project is implementing an ATR-FTIR inline concentration-measurement technique to investigate the crystallization properties of lactose.

The first part of the project involves experimental work as well as modeling of the acquired IR spectra to extract the concentration of solute using multivariate data analysis techniques[5-7].

In the second part, the calibration model will be used to experimentally measure the concentration desupersaturation curve during crystallization runs. State-of-the-art parameter estimation techniques[8] will be used to estimate the growth rate parameters, using a rigorous population balance model (PBM).

Proposed Outline of the Main Project

- Short literature review on the research topic.
- Understand how to carry out ATR-FTIR measurements.
- Implementation and critical evaluation of existing calibration techniques for ATR-FTIR.
- Application of the developed model during lactose crystallization runs and preliminary parameter estimation.

Requirements

- Solid background in numerics and programming skills (Matlab or Python).

- No experience in the laboratory work is required. The experimental activities will be conducted in close collaboration with the supervisor.
- Proactive and independent attitude.

Deliverables

Short, schematic reports of what has been done during the week, including methods, results,and discussion and what is planned for the following week should be submitted by email to the supervisors every Friday. The results obtained will be presented in two oral presentations, one about halfway through the project and one at the end.

References

[1] I.K. Lappa, A. Papadaki, V. Kachrimanidou, A. Terpou, D. Koulougliotis, E. Eriotou, and N. Kopsahelis (2019): **Cheese Whey Processing: Integrated Biorefinery Concepts and Emerging Food Applications**, *Foods* 8, 347.

[2] F.J. Barba (2021): **An Integrated Approach for the Valorization of Cheese Whey**, *Foods* 10, 564.

[3] E. Simone, A.I.I. Tyler, D. Kuah, X. Bao, M.E. Ries, and D. Baker (2019): **Optimal Design of Crystallization Processes for the Recovery of a Slow-Nucleating Sugar with a Complex Chemical Equilibrium In Aqueous Solution: The Case of Lactose**, *Org. Process Res. Dev.* 23, 220−233.

[4] A.H.J. Paterson (2017): **Lactose processing: From fundamental understanding to industrial application**, *Int. Dairy J.* 67, 80-90.

[5] S. A. Schiele, R. Meinhardt, C. Eder and H. Briesen (2020): **ATR-FTIR spectroscopy for in-line anomer concentration measurements in solution: A case study of lactose**, *Food Control* 110, 107024.

[6] J. Cornel, C. Lindenberg and M. Mazzotti (2008): **Quantitative application of in situ ATR-FTIR and raman spectroscopy in crystallization processes**, *Ing. Eng. Chem. Res.* 47, 4870–4882.

[7] F. Milella and M. Mazzotti (2019): **Estimating speciation of aqueous ammonia solutions of ammonium bicarbonate: Application of least squares methods to infrared spectra**, *React. Chem. Eng.* 4, 1284–1302.

[8] S. Bötschi, A.K. Rajagopalan, M. Morari, and M. Mazzotti (2019): **Feedback Control for the Size and Shape Evolution of Needle-like Crystals in Suspension. IV. Modeling and Control of Dissolution**, *Cryst. Growth Des.* 19, 4029−4043.