MITIGATING FOULING OF HEAT EXCHANGERS WITH FLUOROPOLYMER COATINGS

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Fouling is a chronic problem in many heat transfer systems and gives rise to frequent heat exchanger (HEX) cleaning (see Figure 1). In the dairy industry, the associated operating cost and environmental impact are substantial. These are costs due to oversized HEX units, increased thermal inefficiency and pressure drop, loss of production, maintenance and cleaning. Cleaning introduces further, non-energetic, environmental impacts associated with consumption and disposal of cleaning chemicals and wasted product. Antifouling coatings, of which an example is shown in Figure 2, are one mitigation option. In this work, the fouling behaviour of fluoropolymer, polypropylene and stainless steel heat transfer surfaces in processing raw milk and whey protein solution were studied. Methodologies to assess the economics of antifouling coatings were developed and applied.

Figure 1: Milk fouling in a plate heat exchanger.

Figure 2: Example of a fluoropolymer antifouling coating in contact with a water droplet.

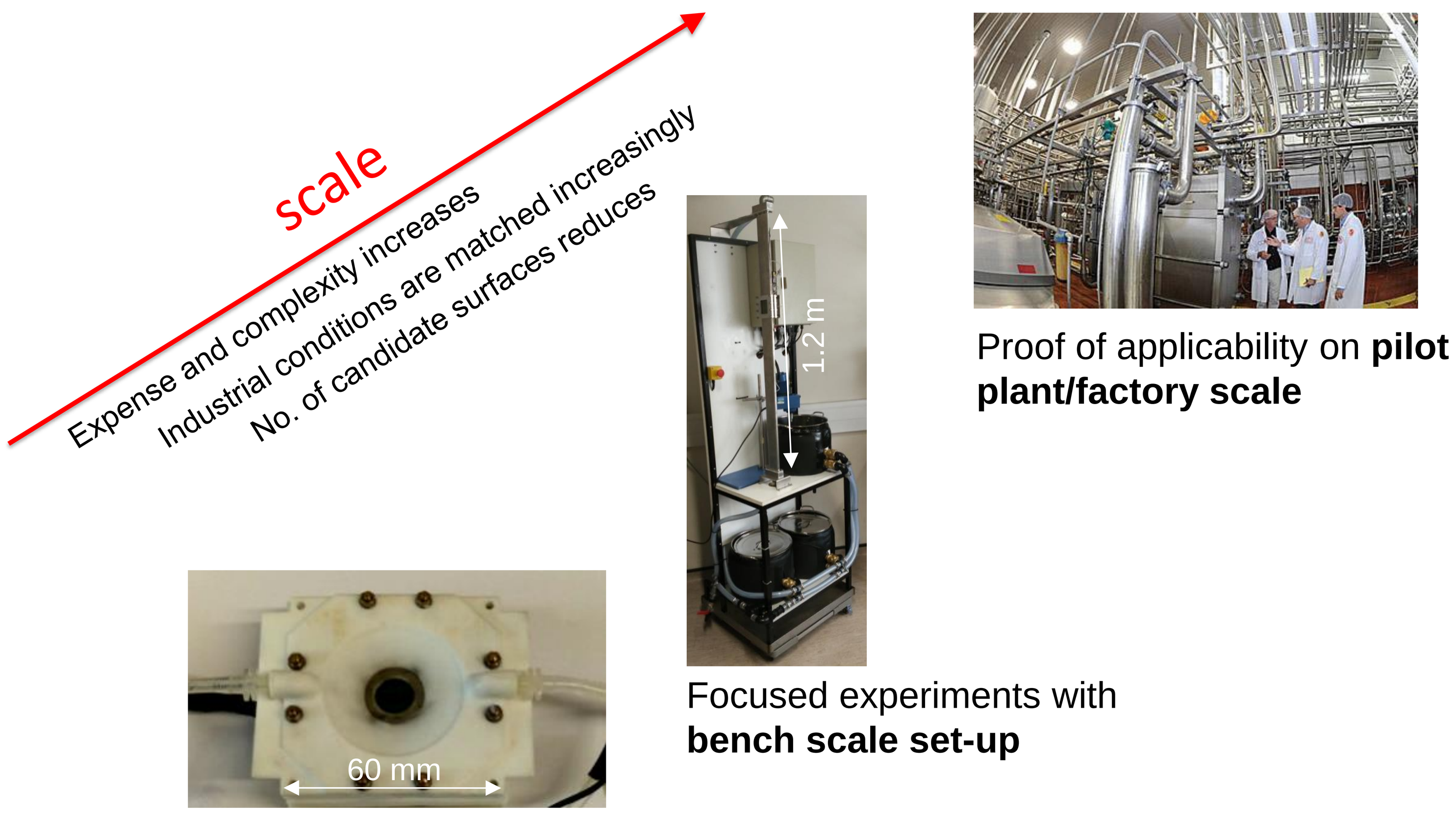

Figure 2: The fouling trails were successively performed at micro, bench and pilot scale.

Two experimental apparatuses, shown in Figure 2, were designed and constructed to study fouling at surface temperatures around 90 °C. A microfluidic system with a 650 x 2000 µm flow channel enables fouling studies to be carried out with batches of approximately 2 l of raw milk. The apparatus features laminar flow and the capability to probe the local composition of delicate fouling deposit *in-situ* with histology techniques employing confocal laser scanning microscopy. A larger bench-scale apparatus with a 10 x 42 mm flow channel was built to recirculate 17 l of solution in the turbulent flow regime more representative of conductions in an industrial plate HEX.

Experimental results demonstrated that fluoropolymer coatings can reduce fouling masses from raw milk and whey protein solution by up to 50 % (see Figure 3). Surface properties affect the structure and composition of the deposit. At the interface with apolar surfaces, raw milk fouling layers were high in protein (see Figure 4) whereas a strongly attached mineral-rich layer was present at the interface with steel. Whey protein deposits generated on apolar surfaces were more spongy and had a lower thermal conductivity and/or density than on steel, which is illustrated in Figure 5. The attraction of denatured protein towards apolar surfaces and the formation of a calcium phosphate layer on steel at later stages of fouling were explained with arguments based on the interfacial free energy of these materials in water.

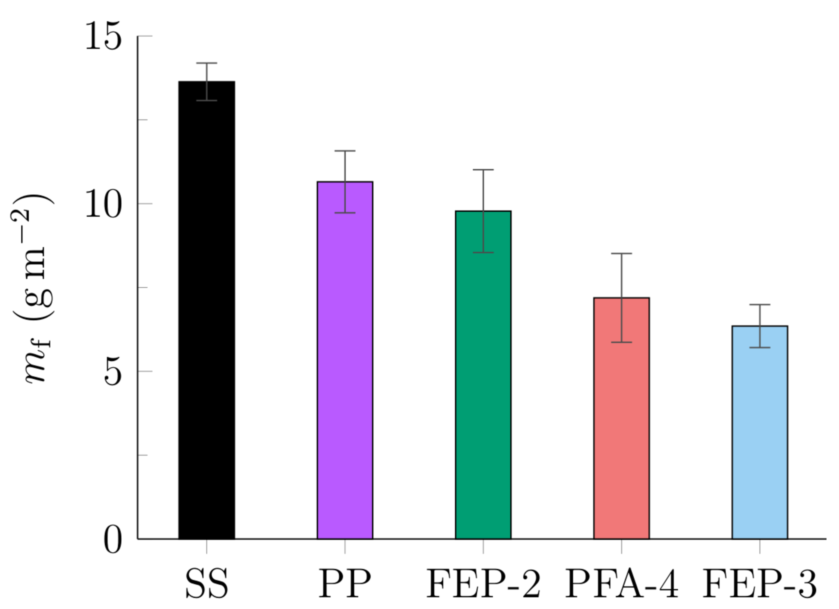

Figure 3: Deposit coverage (dry mass per area) from whey protein solution for different surfaces tested in the bench-scale HEX for a duration of 150 min at a surface temperature of 89 °C. SS – stainless steel, PP – polypropylene, FEP – fluorinated ethylene propylene, PFA – perfluoroalkoxy. Error bars show 90 % confidence intervals.

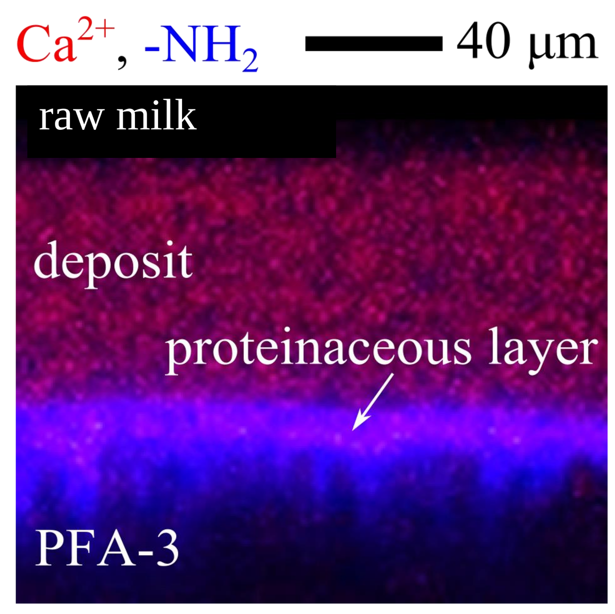

Figure 4: Orthogonal CLSM section of a raw milk fouling layer generated on a perfluoroalkoxy coating.

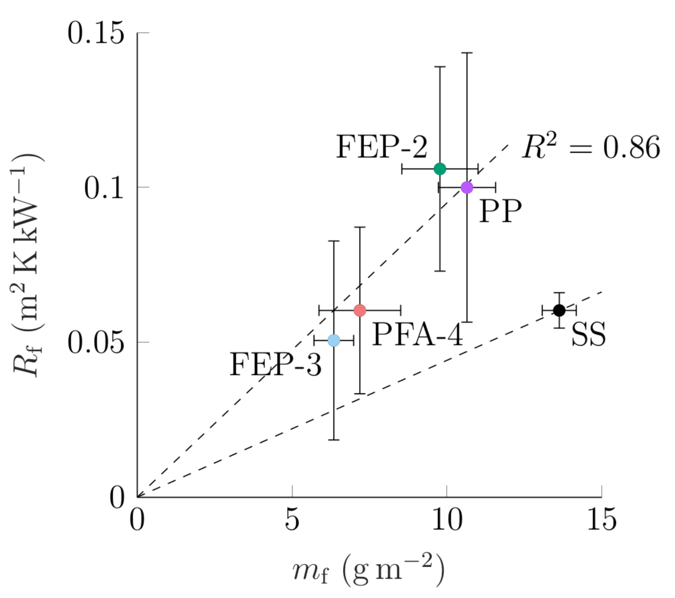

Figure 5: Final fouling resistance over whey protein deposit mass coverage for different surfaces tested with the bench-scale HEX. Dashed lines show root mean square fitted equation R_f = m_f /$\rho_f k_f$ to find values of $\rho_f k_f$ for polymer surfaces and stainless steel. For polymer surfaces $\rho_f k_f$ = 105 kg^{2}m^{-2}s $^{-3}$ K^{-1} and for stainless steel $\rho_f k_f$ = 226 kg^{2}m^{-2}s $^{-3}$ K^{-1}. Error bars show 90 % confidence intervals.

The financial attractiveness of coatings was considered for HEXs subject to fouling. An explicit solution to the cleaning-scheduling problem was presented for the case of equal heat capacity flow rates in a counter-current HEX. Scenarios where the use of coatings may be attractive or where there is no financial benefit in cleaning a fouled exchanger were identified. Finally, experimental data were used to estimate the economic potential of fluoropolymer coated HEXs in the ultra-high-temperature treatment of milk.

Publications:

Magens, O. M., Hofmans, J., Adriaenssens Y., & Wilson, D. I. (2018). Comparison of fouling of raw milk and whey protein solution on stainless steel and fluorocarbon coated surfaces: Effects on fouling performance, deposit structure and composition. Chem. Eng. Sci., *in press*

Magens, O. M., Ishiyama, E. M., & Wilson, D. I. (2016). Quantifying the 'implementation gap' for antifouling coatings. Appl. Therm. Eng., 99, 683–689.

Magens, O. M., Hofmans, J., Pabon, M., & Wilson, D. I. (2015). Value pricing of antifouling coatings in heat exchangers. In Heat Exchanger Fouling and Cleaning Conference (pp. 350–357). Enfield, Ireland.

Magens, O. M., Hofmans, J., & Wilson, D. I. (2017). A fouling micro-system for investigating fluoropolymer antifouling coatings in bovine milk pasteurisation, In Heat Exchanger Fouling and Cleaning Conference (pp. 140–147). Aranjuez, Spain.

Magens, O. M., Liu, Y., Hofmans, J. F. A., Nelissen, J. A., & Ian Wilson, D. I. (2017). Adhesion and cleaning of foods with complex structure: Effect of oil content and fluoropolymer coating characteristics on the detachment of cake from baking surfaces. Journal of Food Engineering, 197, 48–59.