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Section 1

Membrane fouling and cleaning - Part 1

KEY ASPECTS OF MEMBRANE PLANT OPERATIONS RELATED TO FOULING AND CLEANING IN THE FOOD INDUSTRY

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ABSTRACT

Fouling is one the most important challenges to apply membrane technology on industrial scale in the food industry. Despite significant progress in understanding and preventing fouling and in developing appropriate membrane cleaning protocols, both fouling and cleaning remain key challenges in membrane plant operation in the food industry with a significant impact on membrane plants capital (CAPEX) and operating expenditures (OPEX) and thus the sustainability of membrane processes. The goal of this presentation is to show a relationship between fouling, pre-treatment, operation conditions and cleaning and how this can impact industrial membrane processes from a techno-economical point of view.

The first part of the presentation will analyze the state-of-the-art of membrane cleaning in the food industry. The impact of e.g. number of cleaning cycle per day, cleaning cycle length and cleaning chemicals as well as type of cleaning chemicals and water quality will be discussed with regard to their impact on membrane plant OPEX and CAPEX.

In the subsequent part of the presentation different approaches to reduce fouling and minimize the need for cleaning will be highlighted. The focus will be on the impact of pre-treatment but also on membrane module and membrane selection.

The final part of the presentation will be an application study related to the removal of impurities e.g. retrograded starch, proteins and fat in the production of starch-based sweetener after liquefaction and saccharification of the starch. For this production step - which is often referred to as demudding - a new concept has been developed consisting of a decanter and membranes. The application study will demonstrate how the membrane part of the process was adjusted to overcome some serious fouling and thus capacity challenges encountered during the start-up of the first installation. The resulting new concept did not only control the fouling and minimized the cleaning but it also resulted in an improved sweetener quality.

Overall the presentation will show approaches to reduce fouling and cleaning in order to support the long-term sustainability of membrane processes in the food industry.

HOW MICRO-WAVES CAN HELP TO STUDY MEMBRANE AGEING AND CONSEQUENCES ON FOULING

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ABSTRACT

The study aimed at proposing and discussing original protocols of rapid PES/PVP membrane NaOCl degradation, both chemical and mechanical ones that can be used at lab scale for fundamental studies of the impact of membrane ageing on behavior in UF (fouling and cleaning mastering). The key of all protocols was the use of ageing acceleration thanks to micro-wave activation that can be further associated with short ageing time in UF conditions To evaluate the representativeness of obtained aged membranes comparisons were achieved between pristine, voluntary laboratory aged membranes and an industrial membrane at end of its service-life. Several physico-chemical analyses were used (ATR-FTIR, SEM-EDX, contact angle, SEC-HPLC). Evaluation of UF performances were made in UF of a model protein (Lysozyme, 14,300 $g.mol^{-1}$).

STRUCTURAL ORGANIZATION OF CASEIN MICELLES IN CONCENTRATED LAYER DURING CROSS-FLOW ULTRAFILTRATION

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ABSTRACT

Small-Angle X-Ray Scattering (SAXS) has been coupled to cross-flow ultrafiltration to determine the behaviour of casein micelles concentrated layers at the membrane surface. The concentrated layer formation and its reversibility was followed. We also studied the effect of temperature on the structural organization of casein micelles during cross-flow filtration. Concentration profiles have been deduced from the scattering intensities registered in-situ in the course of the cross-flow ultrafiltration of casein micelles dispersions. SAXS and filtration results for a reference experiment (110 kPa, 0.03 $m.s^{-1}$, 3h of filtration, 25°C) show the formation of a thick fouling layer of 150 µm and reaching 195 g/L near the membrane surface. Furthermore, results show some reversibility of the upper layer of those accumulated casein micelles layers and an irreversibility of fraction close to the membrane surface. A change of temperature (45°C or 12°C instead of 25°C) led to a different organization of concentrated layer with a thicker layer when increasing temperature. However, for the three different temperature, an irreversible fouling layer reaching 3.5 C0 close to the membrane is still lasting after a pressure relaxation. Those results are important for understanding the concentrated layer properties of casein micelles during cross-flow ultrafiltration and they could be used to adjust the filtration parameters in order to avoid the formation of an irreversible concentrated layer at the membrane surface.

COHESIVE STRENGTH OF MEMBRANE SURFACE FOULING LAYERS – EFFECT OF CROSSFLOW REGIMES

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ABSTRACT

Understanding the properties of the membrane fouling layer is crucial in mitigating fouling and developing cleaning strategies. However, one of the most important factors that determines the requirement of membrane cleaning, i.e., the strength of the membrane fouling layer, is rarely investigated. Here fluid dynamic gauging (FDG) was introduced to the crossflow microfiltration of microcrystalline cellulose (MCC), to investigate the cohesive strength of formed fouling layers in situ and the impact of crossflow regimes on the fouling behaviour. Results show that the FDG method was stable and repeatable at both flow regimes. Fouling layers formed at turbulent flow condition (Re_{duct} = 4170) were stronger and required more liquid shear stress to remove compare to the layers formed in laminar crossflow (Re_{duct} = 1560). At the turbulent crossflow condition, a thicker fouling layer of 294 μm on average was resistant to the minimum shear of 35 Pa from the FDG gauge tube, compare to 144 μm for laminar flow. However, similar permeate flux was obtained in all experiments. Therefore, this work also show that membrane cleaning protocols should be developed based on the nature of the fouling layer, instead of permeate flux decline.

CLEANABILITY AND SANITIZABILITY OF AQUAPORIN INSIDE™ BIOMIMETIC HOLLOW FIBER FORWARD OSMOSIS ELEMENTS FOR USE IN FOOD DEWATERING

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ABSTRACT

One of the world's biggest water consumers is the food industry. Moreover, food production and supply chain used 30% of total global energy consumption in 2015. While the potential of water reuse and energy-effective process technologies in food industry is high, and associated economic benefits are evident, such sustainable industrial technologies are yet to be developed. In this context, studies have shown that forward osmosis membrane technology has the potential to reduce energy consumption in food dewatering. The benefits of using biomimetic membrane materials in the FO process have been studied extensively, finding superior rejection of valuable compounds, while maintaining sustainably high water fluxes. The lifetime of the biomimetic membranes is crucial for this technology to be sustainable in terms of water and energy use. In addition, strict food safety requirements demand highly robust membrane materials. This study investigates the cleanability and sanitizability of the biomimetic Aquaporin Inside™ hollow fiber membranes. The membranes, especially designed for forward osmosis, were found to withstand a wide range of commercial and non-commercial cleaning chemicals used in food industry. The series included 6 cleaning chemicals of the alkaline, acidic as well as the enzymatic type, and the cleanings were performed at 45 ºC to 50 ºC. Allowing permeation during cleaning-place cycles showed significant benefits to membrane performance. A continuous CIP cleaning, simulating a 6-month exposure at pH 2 and 11 at 45 ºC, did not compromise membrane performance significantly. Moreover, the effects of citric acid enhanced heat sanitization were investigated by exposing the membrane elements to 12 sterilization cycles at 85 ºC.

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THE FOULING OF ULTRAFILTRATION MEMBRANES DURING THE FRACTIONATION OF PHYTOSTEROLS FROM ORANGE JUICE

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ABSTRACT

Ultrafiltration (UF) offers the possibility of separating bioactive compounds from by-products of agro-industrial applications. Plant bioactive compounds such as phytosterols are well known for their health benefits, including the lowering of blood cholesterol levels and a decreased risk of developing coronary heart disease. Natural rubber serum (NRS) contains phytosterols which have a great potential to be used as an alternative source for the nutraceutical industry. Orange juice was selected as a model solution to NRS due to the presence of a similar profile of bioactive compounds. The aim of this study is to separate phytosterol compounds from orange juice using UF. Flat sheet UF membranes (Alfa Laval) with molecular weight cut-off (MWCO) values of 10 kDa fabricated from regenerated cellulose (code RC70PP), polyethersulfone (code GR80PP) and fluoropolymer (code ETNA10PP) were tested to determine the feasibility of isolation of phytosterols. The experiments were performed in a cross flow filtration rig at a transmembrane pressure (TMP) range of 0.5 - 2 bar, and a cross flow velocity (CFV) range of 0.5 - 1.5 m s^{-1}, and at an ambient temperature. Total phytosterol content was analysed using a Liebermann-Burchard based assay. Permeate flux and fouling index was determined. Membrane rejection towards total phytosterols, proteins and sugars was determined, along with antioxidant activity. The regenerated cellulose membrane displayed the highest permeate flux of those tested (22 L/m^2 h), along with a higher fouling index (100%) and a good separation efficiency of phytosterols (45% rejection towards phytosterols) from orange juice. Although the yield of phytosterols was relatively low (40 mg/L), there is potential to modify the filtration process and optimise the analysis procedure to produce a greater amount of phytosterols. However, fouling limits the filtration process, and understanding the nature of fouling will be the key to determining the viability of the technology. The effects of cleaning agent upon the restoration of permeate flux is also reported. All membranes investigated displayed cleaning efficiencies of > 95%.

Section 2

Monitoring and analysis of fouling and cleaning

DEVELOPMENT OF A METHOD TO DETERMINE NORMAL AND SHEAR STRESS NECESSARY TO REMOVE A SWOLLEN SOIL FROM A SURFACE

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ABSTRACT

To simulate cleaning processes is of constantly growing importance with regard to optimising the cleaning efficiency in food production lines. This requires suitable parameters to describe the cleaning behaviour of different soils. Therefore, a method was developed to determine the normal and shear stress which are necessary to remove a swollen soil layer from a surface by an impinging jet. The method consists of a cleaning procedure in combination with normal force measurements. For the cleaning tests a stainless steel plate with a defined soil layer was soaked reproducibly for a defined time. Subsequently, a very short impulse of a liquid jet impinged on the surface in order to determine the gauge pressure limit state which is necessary to remove the soil from the surface in the impact area. At this determined limit state the measurement was repeated with the same parameters, but with a piezo-based force sensor instead of the soiled surface. Out of this measured forces, it was possible to calculate the target values: the normal and the shear stress.

Measurements were performed with petroleum jelly and egg yolk as a food based model soil at different jet angles and for different swelling times. As a result, it was possible to draw the calculated stress as a function of the jet angle, similar to Mohr's circle for plane stress, known from the solid mechanics. By that, it is possible to quantify and compare the cleaning behaviour of different substances and at different swelling states. In the future, this data can be implemented into a cleaning simulation in order to optimise the cleaning system for a certain soil without elaborate cleaning tests.

DETECTION OF ATTACHMENT/DETACHMENT OF DEPOSITS ON SOLID SUBSTRATE BY CODA WAVES INTEROMETRY

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ABSTRACT

Fouling is a kind of deposit on solid surface, which causes problems of quality in industry. To launch and achieve an efficient cleaning processing, monitoring both the attachment and detachment of deposit is necessary. Coda Wave Interferometry (CWI) has been attempted to detect the formation/elimination of a deposit on a surface. Coda waves are the late part in signals with multiple reflections and strong scattering, so this kind of waves is sensitive to small change in sample. Experimentally, a wax cleaning processing is used to simulate the detachment of a fouling deposit, and a biofilm formation is used to simulate the attachment of fouling. The results of the experiments show that the attachment and the detachment of fouling are detectable by ultrasonic coda wave.

DETERMINATION OF CLEANING MECHANISMS BY MEASURING PARTICLE SIZE DISTRIBUTIONS

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ABSTRACT

Knowledge of the dominant removal mechanism (diffusive vs. convective mass transport) is an important goal on the way of understanding, modelling and predicting cleaning behaviour of food soils. The size of the removed particles is thereby a useful physical quantity, since small particles, which are fully immersed within the viscous sublayer of the flow, will rather be removed due to diffusion than caught from the flow itself. For this reason, the dimensionless particle diameter relates the particle size to the thickness of the viscous sublayer. Therefore, it allows to identify whether the particles were removed rather by diffusive or convective mass transport.

This contribution presents the online measurement of particle size distributions during cleaning of starch and egg yolk soils in an automated laboratory test rig. In order to achieve accurate results for the particle sizes, measurements with Fraunhofer and Mie theory were compared. Furthermore, the influence of the cleaning temperature on the dimensionless particle diameter was examined for both soils.

COMPARISON OF DETECTION METHODS USED TO DETERMINE *ESCHERICHIA COLI* AND MEAT EXUDATE REMOVAL FROM STAINLESS STEEL SURFACES FOLLOWING DIFFERENT PHYSICAL CLEANING METHODS

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ABSTRACT

Food products can be contaminated by residual organic materials and food-borne pathogenic microorganisms through contact with biofouling present on surfaces. Efficient cleaning is needed to maintain hygienic requirements and for quality assurance of food contact surfaces. To evaluate the efficacy of cleaning procedures, it is essential to use reliable detection and quantification methods that can detect both organic material and microorganisms retained on surfaces.

Repeated fouling with both organic material (meat exudate) and microorganisms (*Escherichia coli*) on 304 2B finish stainless steel surfaces was carried out in this work. The surfaces were then cleaned using either a soak, spray or wipe method (in water) in order compare various biofouling detection methods.
Following enumeration of the microorganisms by plate counting, the results demonstrated that the soak and spray washes were the best cleaning methods, whereas the wipe clean produced the least hygienic surface. ATP bioluminescence further demonstrated that the spray cleaned surface was the most hygienic followed by the soaked cleaned surfaces. However, percentage coverage counts demonstrated that the number of retained cells on following the soak wash was the greatest (77.38 % after 30 washes) and the amount of organic material retained was greater than 50% on all the surfaces, and was not significantly different between the different types of cleans or number of washes. Visualisation of the surfaces using epifluorescence microscopy and scanning electron microscopy demonstrated that the soak clean was the least hygienic in terms of bacterial retention. This suggests that the biofouling on the surface was difficult to remove following the soak cleaning method. UV detection demonstrated that it was difficult to detect organic material, regardless of the cleaning method used. However, when using more intense UV at selected wavelengths, the 330-360 nm illuminated the retained biofouling on the surfaces with the greatest intensity.
The use of the different cleaning assays resulted in differences in cell and organic material distribution across the surfaces. The recorded level of contamination varied depending on the detection method used in this study. Our results highlighted that, in addition to the quantification method, visual images and quantification may help to better understand the fouling process on surfaces since certain cleaning methods may result in organic material being difficult to remove and detect.

LABORATORY METHODS TO PREDICT THE CLEANING BEHAVIOUR IN A FLOW CHANNEL EXEMPLIFIED BY EGG YOLK LAYER

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ABSTRACT

Cleaning-in-place (CIP) has been established as technique to clean industrial plants for food processing. The design of the CIP protocols is the key to economic and ecological cleaning. The analysis of the cleaning behaviour of respective deposits at industrial plants involves a high economic and ecological effort. Laboratory methods for predicting the cleaning behaviour have the potential to reduce the number of such costly investigations.

In this work we use different laboratory methods (DSC, rheology, swelling measurements, micromanipulation) to describe the strength of the deposit and mass transfer between deposit and cleaning agent. The suitability of these laboratory methods to predict the cleaning behaviour is discussed using egg yolk layers as example. The cleaning behaviour of egg yolk in a flow channel (technical scale) clearly depends on the properties of the cleaning agent. The necessary cleaning time to remove the deposit was evaluated using an optical detection method. The temperature (24 °C to 60 °C) and sodium hydroxide concentration (0 to 1.5 wt%) were investigated as influencing factors. The cleaning experiment shows a reduction of the cleaning time with increasing temperature and a minimum of the cleaning time depending on the sodium hydroxide concentration. These influences were helpful to evaluate the laboratory methods for predicting the cleaning behaviour. In case of egg yolk layers, the results of the micromanipulation method correlate notably with the cleaning behaviour in a flow channel. Swelling, diffusion and rheological measurements also tend to show the expected cleaning behaviour as a function of temperature and concentration. Depending on the cleaning mechanisms of the respective deposit, these are possibly more relevant.

DIMENSIONAL ANALYSIS OF CLEANING-IN-PLACE PROCESSES FOR FOULED ORGANIC MATERIAL IN FOOD PROCESSES

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ABSTRACT

In this study the dimensional analysis is used for the description of complex cleaning mechanisms of organic deposits. This approach allows the consideration of natural and technical phenomena while the exact physical laws are unknown. The influence of the substrate properties and interactions between substrate and deposition are considered in the modelling of cleaning characteristics. Therefore, all relevant cleaning parameters, material properties and their interactions with each other are analytically identified and compiled in a relevance list. The non-significant or dependent variables are eliminated to reduce the list to the truly relevant influencing factors and the correlations are found mathematically. The data for the validation is provided by cleaning experiments in lab scale test rigs with the soils starch, gelatin and egg yolk on different substrates. The model is capable of indicating promising cleaning strategies for the specific organic systems. This basis leads to a tool for the classification of food soils regarding their cleaning behaviour.

Poster

REAL TIME MONITORING OF WHEY FOULANTS ADSORPTION ON POLYETHERSULFONE SURFACE

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ABSTRACT

The worldwide growing demand for whey proteins and derivatives requires more efficient and sustainable whey protein production processes. Whey is an important by-product from cheese manufacturing. In whey industry membrane processes such as microfiltration, ultrafiltration, nanofiltration and reverse osmosis are well-established to concentrate, fractionate and purify whey proteins as well as whey derivatives in large scale.
In particular, ultrafiltration is used to separate whey proteins and derivatives in aqueous mixtures in an energy efficient way under mild process conditions maintaining the natural properties of the proteins. However, membrane fouling is one of the key challenges when applying membrane processes in the whey industry. Fouling occurs because of adsorption of e.g. whey proteins onto the membrane, which results in a decrease of permeate flux over the filtration time and a formation of a fouling layer on top of the membrane surface, which can alter separation performance. Frequent cleaning with chemical cleaning agents or enzymes is standard in the industry to overcome fouling but results in plant downtime, reduction of membrane lifetime as well as costs for cleaning agents and water/wastewater.

In order to gain a deeper understanding of the complexity of membrane fouling, the adsorption process and viscoelastic properties of the fouling layer formed by whey proteins over time on the surface of polyethersulfone were studied. Polyethersulfone is the most common ultrafiltration membrane material in the dairy industry. The adsorption was studied by real-time monitoring techniques such as quartz crystal microbalance with dissipation (QCM-D) and surface plasmon resonance (SPR).

The results obtained will help to gain further understanding of the fouling behavior and thus to develop tailored cleaning strategies to minimize/overcome fouling. Furthermore, the knowledge gained might also support development of new membrane materials to minimize/eliminate fouling.

The work reflects on and builds upon previous work in the field [1, 2] with the aim to provide further information on the adsorption and desorption of whey proteins and other whey foulants onto polyethersulfone surfaces to support the broad employment of membranes in food processing.

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METHODOLOGY FOR THE DEMONSTRATION OF HARMLESSNESS OF A DETERGENT ON A POLYAMIDE REVERSE OSMOSIS MEMBRANE

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ABSTRACT

An original approach has been proposed to shorten the time required for the validation of new detergents/biocides mainly aiming at evidencing the harmless or harmlessness of the solutions toward the membrane material. This approach is based on the comparison of physico-chemical characterisations (mainly ATR-FTIR) for membranes submitted to two types of ageing tests. On one hand, membrane was voluntary aged by immersion in the given formulated detergent/biocide but using microwave acceleration of ageing mechanisms. This experience aimed both at the identification of potential long term degradation and at evidencing adsorption of detergent components on the membrane that must be further efficiently removed. On the other hand, either short or classical long term filtrations were achieved by filtering the studied formulated detergent/biocide on the membrane, aiming at confirmation of the first step conclusions and at checking the membrane performance behaviour. The methodology has been successfully applied to screen different detergents/disinfectants with two membranes commonly used in dairy industry: RO polyamide membrane and UF PES/PVP membrane. The overall procedure allowed to confirm the well-known trends of degradation by NaOCl of the two above cited membranes but also the validation of a new formulated biocide for RO membranes.

DEVELOPMENT OF ZERO DISCHARGE NET FLOW FLUID DYNAMIC GAUGING FOR STUDYING CLEANING

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ABSTRACT

The fluid dynamic gauging (FDG) technique was developed to monitor the thickness of soft fouling layers immersed in liquid to provide quantitative information on fouling and cleaning processes. The latest version of the technique, scanning zero net flow FDG, allows measurements to be made aseptically at different locations on the same sample. Its potential for studying removal of high-risk soils is demonstrated in quantifying the shear stress required to remove bacterial spores from glass and stainless steel, and measuring the rate of erosion of *Rhodopseudomonas Palustris* biofilms from standard and graphene-coated carbon paper. The adhesion of *Bacillus cereus* and *B. megaterium* spores was shown to differ significantly between spore type, spore cultivation conditions and substrate. The manner and rate of biofilm erosion was again strongly dependent on substrate. A new erosion modelling approach is presented.

SYSTEMATIC STUDY OF THE IMPACT OF MEMBRANE AGEING ON FOULING AT CRITICAL AND LIMITING FLUXES AND SUBSEQUENT CLEANING OF A POLYMER MEMBRANE USED FOR SKIM MILK ULTRAFILTRATION

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ABSTRACT

The mastering of membrane fouling and cleaning remained a bottleneck at industrial scale. This paper reports a systematic in-depth study of the impact of membrane chemical ageing by NaOCl, a commonly disinfecting solution, on both flux in skim milk UF and on the actual cleanability of membranes. The filtration at critical or limiting flux has an impact on the irreversible fouling and its cleanliness with new membranes. On the contrary, no more differences were evidenced with NaOCl aged membranes being simultaneously highly irreversibly fouled and more difficult to clean.

AN *IN SITU* METHOD FOR QUANTIFYING THE STRENGTH AND THICKNESS OF BIOFILMS GROWN UNDER CONTROLLED FLOW CONDITIONS

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ABSTRACT

This study centres around cleaning investigations on biofilms of *Escherichia coli* and *Burkholderia cepacia* grown on polyethylene, stainless steel and glass, to detect their adherence behaviour under controlled hydrodynamic conditions. The biofilms were tested using the non-contact technique of Fluid Dynamic Gauging (FDG), which utilises flow data to estimate the adhesive (between biofilm and substrate) and cohesive (between cells and extracellular polymeric substances) strengths, and thicknesses of biofilms. The results suggest that biofilm thickness increases with time and peaks at approximately 14 days with a reduction thereafter. The confocal laser scanning microscopy results confirmed the increase number of dead cells after 21 days, hence contributing to the weakening of biofilms. Interrupting the flow of media during biofilm development has negligible impact on the thickness but it significantly increases the strength.

RHEOLOGICAL CHARACTERIZATION OF VISCOUS BIOFILMS USING MICRO-JET IMPINGEMENT

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ABSTRACT

The formation of biofilm, i.e. biofouling, on food process surfaces is a critical problem in a wide range of food industries that causes risk to food preservation and thus consumer safety. Approximately 80% of persistent bacterial infections in the U.S. were found to be associated with biofilms. Since the extracellular polymeric substance (EPS) produced by several species of microorganisms can render the colonies more resistant to disinfectant, traditional clean-in place (CIP) process involving water rinsing and chemical cleaning which is active against lanktonic cells could be absolutely ineffective against cells protected by biofilm. Additional mechanical stress applied on the EPS slime is required to facilitate the removal of biofilm. Therefore, characterization of the mechanical properties of biofilms has been rightfully justified in terms of the resistance of EPS to the stresses applied by cleaning fluids, which have a significant impact on the cleaning of processing equipment. Biofilms are typically modeled as soft complex fluids. However, due to their thin thickness, it is very difficult to obtain an in situ measurement of their rheological properties. While jet impingement-based techniques have been applied for measuring the mechanical properties of biofilms; the information about biofilm deformation resulting from the impact of liquid jets is very limited. The objective of this study was to characterize how the rheological properties of biofilm affect its deformation under jet impingement through numerical simulations. Here we solved the full Navier-Stokes system of equations for the impinging jet flow. The biofilm was assumed to be a viscous Newtonian fluid, and its deformation was modeled through two phase flow. We found that the biofilm deformation induced by submerged jet impingement depends largely on the flow conditions and the rheological properties of biofilm. Further studies will be conducted to include the viscoelastic property of biofilm. These results will help understand fundamentally the underlying physics during biofilm cleaning, and better design an efficient cleaning method.

ANTIFOULING BLEND POLYSULFONE-PLURONIC F127 MEMBRANES

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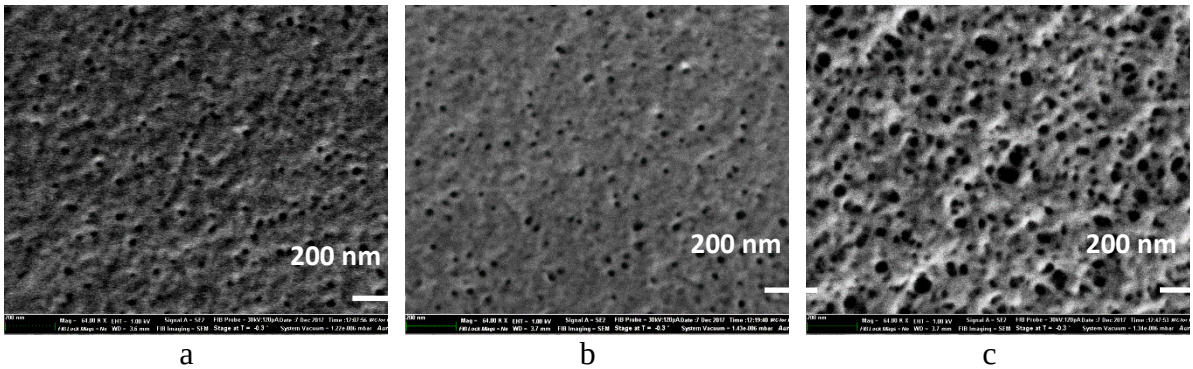
ABSTRACT

To increase the antifouling resistance of the ultrafiltration membranes an approach utilizing self-organizing blends of hydrophobic polymers and amphiphilic polymers containing polyethyleneoxide (PEO) segments has been proposed [1]. The influence of Pluronic F127 addition to the casting polysulfone (PSF) solution on the structure, performance and physico-chemical properties of ultrafiltration membranes was studied. Flat-sheet ultrafiltration PSF/Pluronic F127 membranes were prepared via phase inversion technique using water as a coagulant. The hydrophilic-hydrophobic balance of the selective layer, structure and composition of PSF/PluronicF127 membranes were characterized by water contact angle measurements, scanning electron microscopy (SEM), nuclear magnetic resonance, and atomic force microscopy (AFM). It was found that increase of Pluronic F127 concentration in the PSF solution yields the increase of the pure water flux and decrease of the bovine serum albumin rejection due to the formation of larger pores in the skin layer (Figure). A substantial decrease of the water contact angle of the membrane's skin layer was observed upon increasing of Pluronic F127 concentration in the casting solution (from 72° to 45°), however the roughness parameters of the membrane's skin layer determined by AFM increased. The antifouling properties of the membranes were evaluated in the long-lasting experiments on ultrafiltration of bovine serum albumin solution. It was shown that the introduction of Pluronic F127 into the casting solution significantly improves antifouling stability of ultrafiltration membranes compared to the polysulfone membranes with addition of the polyethylene glycol with M_w=4000 g·mole^{-1}.



a b c

Figure. SEM micrographs of the surface of the selective layer of the membranes with different Pluronic F127 concentration in the casting solution: a – 5 wt.% Pluronic F127; b – 7 wt.% Pluronic F127; d – 10 wt.% Pluronic F127.

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Section 3

Heat transfer fouling and cleaning

EFFECTS OF NITROGENOUS SUBSTANCES ON HEAT TRANSFER FOULING USING MODEL THIN STILLAGE FLUIDS

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ABSTRACT

Fouling is unwanted deposition of materials on surfaces of processing equipment, which leads to additional capital investment and lower processing efficiency. During fuel ethanol production, fouling occurs when thin stillage is concentrated into condensed distillers solubles. Investigations of protein impact on fouling are limited despite high protein concentration in thin stillage (17 to 33% db). Protein contributions to fouling have been verified in the dairy industry. Whey proteins and calcium phosphate interact with each other or other proteins and form aggregates on heated surfaces. Due to complex components in thin stillage, it is difficult to study a single effect on fouling without interference from other factors. The objective was to investigate fouling properties of nitrogenous substances (urea and yeast) using model fluids; effects of protease addition on fouling properties of model and commercial thin stillage fluids. Urea addition did not lead to fouling while glucose-yeast model fluids displayed fouling tendencies. Protease from pineapple stem (bromelain) incubation increased fouling in model and commercial fluids, which were indicative that hydrolyzed molecules such as peptides, amino acids or protease can be involved in deposit formation.

A COMPARISON OF THE MECHANICAL CONSTITUTIVE BEHAVIOR OF MILK PROTEIN DEPOSITS AND FOULING DEPOSITS FROM RAW MILK

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ABSTRACT

In milk processing industries, thermal treatments of raw milk entails the formation of fouling deposits on the inner surfaces of the heating equipment. Many experimental analyses have been carried out to explore the cleaning process by using whey protein isolate due to its chemical similarity and formation mechanisms in comparison to raw milk deposit. In view of the mechanical constitutive behavior of raw milk deposits, in this work we aim to identify whether whey protein isolate fouling behaves in a mechanically comparable way to raw milk fouling. To compare the mechanical behavior of both deposits, indentation tests are performed. By comparing the force strain response of raw milk and whey protein isolate deposits, we elucidate that with a similar heating process whey protein isolate fouling features a much higher mechanical stiffness in comparison to raw milk fouling.

ANALYSIS AND IMAGING OF FOULING DEPOSITS IN DAIRY HEAT EXCHANGERS

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ABSTRACT

Milk contains several thermally unstable components, such as proteins, sugars, salts and lipids, which can cause complex fouling mechanisms and varied deposit layer compositions on heat transfer surfaces. Effective strategies for controlling of fouling and cleaning in the dairy industry benefit from the information on the chemical structure and spatial distribution of depositions on the surfaces. Analytical methods, which enable microanalysis and imaging, are applied in this study. The methods are used for both laboratory test samples as well as samples collected from dairies. Chemical imaging is found to be an effective tool to show occurrence and to characterize milk components in the deposit layers in the spatial resolution of microns.

STRUCTURAL AND COMPOSITIONAL CHANGES DURING UHT FOULING REMOVAL – MECHANISMS OF THE CLEANING PROCESS

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ABSTRACT

Ultra-high temperature (UHT) treatment of milk causes deposits or fouling in the processing equipment that is challenging to remove due to its structure with intertwined mineral-based and protein networks. We will discuss the structure of the fouling layer and the structural and compositional changes during the cleaning process. The experiments are performed on fouling produced on coupons in a dairy production plant. The cleaning was performed in a special designed pilot plant designed to mimic relevant cleaning processes. Structure analysis was performed with scanning electron microscopy (SEM) and confocal laser scanning microscopy (CLSM) on samples that were quenched at different stages of the cleaning process. The fundamental mechanisms that control the removal of this deposit will be discussed. The break-up of the organic network structure and the depolymerization of the proteins were found to control the cleaning efficiency. The weakening of the protein network facilitates the removal of the UHT fouling layer during the acid cleaning step and allow for an efficient cleaning cycle. The chemical reactions that occur within the fouling layer between the hydroxyl ions and the protein network was modeled according to a depolymerization reaction.

EFFECTS OF SUGARS ON WHEY PROTEIN FOULING CHACTERISTICS

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ABSTRACT

Fouling is a serious problem in food processing especially in dairy industry since almost all dairy products need to be pasteurized or treated by other types of thermal processing to ensure their safety and quality (de Jong, 1997). Sugar as a sweetener is very commonly added in various dairy products, such as flavored milk, ice cream mix, functional drinks, etc. However, severe fouling is found in on-site operations when processing sweetened dairy products. While milk fouling has been studied extensively (Hooper et al., 2006; Jimenez et al., 2013; Xin et al., 2002), the compositional effect of sugar content in dairy products on fouling formation is not well known.

In this study, we investigated the effects of sugars (glucose, fructose and sucrose) on the fouling behavior of whey protein isolate (WPI) solution. The effect of sugar addition on the thermal stability of whey protein was characterized using differential scanning calorimetry (DSC). Rheometer was used to determine the viscosity change of sugar-added WPI solutions under heating conditions. Fouling studies were conducted using the Spinning Disc Apparatus (Huang et al., 2012) with the surface temperature of 76 ºC and the Reynolds number of 5000.

The DSC results show that the addition of sugars stabilized whey protein by increasing the temperatures of protein denaturation and aggregation by 2−5 ºC, and glucose exhibited the most significant effect, which agreed with the results of rheological tests. In the fouling experiments, adding 10 wt% of sugars in 5 wt% of WPI solution decreased the fouling resistance by 30% after 2 hours. A brown color development was observed in the deposits obtained from the tests with glucose and fructose added, however, the sucrose-whey deposits showed no color development.

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Section 4

Surfaces and modifications

THE ANTIMICROBIAL EFFECT OF METAL SUBSTRATES ON FOOD PATHOGENS

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ABSTRACT

The development of alternative surfaces and surface coatings as antimicrobial materials is important to the food industry to help the reduction of microbial contamination and transmission. This study investigated the antimicrobial potential of a range of metal coated surfaces including silver (Ag), titanium (Ti), copper (Cu), iron (Fe), molybdenum (Mo), zinc (Zn) and also a control surface silicon (Si) against a range of potentially pathogenic foodborne bacteria; *Staphylococcus aureus, Escherichia coli* and *Listeria monocytogenes*. The leaching potential of the metals in growth media and media suspensions were measured by Inductively Coupled Plasma – Atomic Adsorption Spectroscopy (ICP-AAS) and were compared to the antibacterial activity of the metals using several methods including microbial counts using a Nitroblue tetrazolium (NBT) assay and an adapted BS ISO 22196:2011 standard method. The investigations revealed that that leaching into solution from the surfaces alone could not be solely responsible for the antimicrobial activity of metals. While copper and zinc showed the greatest propensity to leach from the surfaces, silver, titanium, iron and molybdenum did not leach out in large quantities and silicon showed no evidence of leaching. Copper demonstrated the greatest antimicrobial potential followed by silver and zinc. Titanium was highly stable in solutions but displayed the least antimicrobial potential, and using the standard method in humid conditions resulted in increased growth of Listeria. This study provides evidence of the efficacy of copper and silver as effective antimicrobial metal surface coatings, however the selection of surfaces for use in the food industry need to be given careful consideration and be thoroughly tested before use.

COMPARISON OF FOULING OF RAW MILK AND WHEY PROTEIN SOLUTION ON STAINLESS STEEL AND FLUOROCARBON COATED SURFACES

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ABSTRACT

Fouling from raw milk and from whey protein solutions mimicking the protein content of milk have been performed at two length scales, using a microfluidic heat transfer cell and a bench-scale device with hydraulic diameters 1.0 mm and 16.1 mm, respectively. The microfluidic cell allows raw milk to be studied in once-through mode and was used to identify polymer coated surfaces to test against stainless steel. Several of the fluorocarbon coated surfaces reduced the mass deposition but the pressure drop and thermal resistance did not match these directly, indicating that the nature and structure of the deposit is affected by the surface. A fluoroethylene propylene coating was identified as a promising candidate for large scale tests. More calcium was found in the deposit from raw milk than would be expected given the concentration in solution, and more calcium was found on the 304 stainless steel plates used as reference than the fluoropolymers.

VMT IS A NEW MULTIFUNCTIONAL ANTIFOULING FILLER

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ABSTRACT

In this work, we have demonstrated that vermiculite (VMT) blended polyethersulfone (PES) ultrafiltration membranes have shown improvements in biofouling. Flux and antifouling properties of mixed matrix membranes (MMM) are yet to attain satisfactory status. This study aims to find a method for mitigating the biofouling of PES ultrafiltration membranes via blending of thermoexfoliated VMT. Flow cytometry analysis shows that the behaviors of *Bacillus subtilis* 168 as a gram-positive bacterium and Escherichia coli DH5 alpha as a gram-negative bacterium were different. Hence, cell property is a suspected contributory factor in biofilm formation. Accordingly, considering the local predominant bacterial strains, regionally customized membrane could scientifically be an expert solution for biofouling mitigation. Fabricated composite membranes have shown a higher flux compared to control PES membrane. Among all composite membranes, the PES-VMT0.10 had the highest flux of 476.4 L/m^2h (LMH) before fouling, and the highest flux of 210.7 LMH after three cycles of usage. Also, the rejection rate of the PES-VMT0.15 BSA sample was greater than 77%, while that of the PES-VMT0.10 was over 84%. The results of static BSA adsorption test and the bacterial attachment test indicated that the membranes with macro-roughness on their surface showed better anti-biofouling resistance. The antifouling properties of the modified membranes were also improved due to their optimal wettability. In one hand, the hydrophilicity of membranes caused damaging both gram-positive and gram-negative bacteria and bacteriocidal effect. On the other hand, BSA adsorption and bacterial attachment on the membrane surface were affected by pores diameter.

SURFACE MODIFICATIONS OF STAINLESS STEEL TARGETING DAIRY FOULING MITIGATION

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ABSTRACT

Fouling is an ongoing issue in dairy industries, where thermal treatments are essential to ensure food safety and extend the products' shelf-life. The heat-induced accumulation of proteins and minerals on the equipment walls impairs the proper execution of thermal treatments and burdens the processes' cost and environmental impact through production loss and heavy water and chemical use (clean-in-place procedures). Fouling control would then allow to progress toward less expensive and more eco-responsible processes. Modification of the surface properties of stainless steel is one possible pathway toward fouling mitigation, as it would impact the interactions at the substrate/fluid interface. Previous research showed that, in isothermal conditions, control of protein adhesion on stainless steel was crucial to limit fouling. This work presents the antifouling behaviour of several surfaces targeting fouling reduction – namely atmospheric plasma-sprayed silane-based thin films, biomimetic femtosecond laser textured lubricated slippery surfaces and amphiphilic coatings – designed through cutting-edge technologies. Fouling tests were conducted on a pilot scale pasteurization plant fed with a model whey protein and calcium solution. Tested samples were placed in isothermal holding-like conditions. Detailed characterizations of the substrates before and after fouling test allowed connecting their surface properties to their antifouling properties. The antifouling performances of the engineered surfaces were all interesting, as, on the one hand both the slippery surfaces and the plasma coatings showed great fouling-release properties (respectively -100% wt. and -90% wt. of fouling compared to bare stainless steel after a simple water rinse). On the other hand, the amphiphilic Si-PEO coatings exhibited outstanding antifouling properties and stayed perfectly clean for five consecutive pasteurization runs.

Section 5

Membrane fouling and cleaning - Part 2

VIBRATION OF 3-D PRINTED SPACERS FOR FOULING CONTROL IN A SUBMERGED MEMBRANE FILTRATION PROCESS

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ABSTRACT

In this study, a novel turbulence promoter based on vibrating 3-D spacers was investigated to control fouling in a submerged flat sheet and hollow fibre membrane filtration system at a constant flux using a mixture of bentonite and sodium alginate as model foulants. The impacts of spacer configuration, vibration frequency and amplitude on membrane fouling potential were examined. Results showed that vibration of 3-D spacers could more significantly reduce membrane fouling than 1-D plate turbulence promoter. Increasing vibration frequency of the 3-D spacer from 1 to 2.5 Hz and increasing amplitude from 0.8 to 2 cm improved membrane fouling control efficiency by 33% and 34% respectively. The reduced membrane fouling rate was attributed to the enhanced liquid velocity and shear force along the membrane surface induced by the 3-D spacer movement, illustrated by three-dimensional computational fluid dynamics (CFD) simulations. A comparison of membrane performance and energy consumption for spacer vibration fouling control method and for gas sparging/vibrating membrane method was conducted. This study highlights the feasibility of vibration of 3-D spacers in membrane performance enhancement and the potential for membrane fouling control in fractioning high viscosity food products.

MEMBRANE FOULING DURING MICROFILTRATION OF MILK INTO CASEIN AND WHEY FRACTIONATIONS

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ABSTRACT

Environmentally friendly, economical and sustainable methods of food processing are required due to the projected growth in global population, and the current environmental impacts linked to food production.[1] In the case of dairy products, the need to separate the main milk proteins - casein and whey, has led to the development of several technologies. The potential advantages of using membranes over chemical separation techniques has made them an attractive option for the food industry. However, it is important to be able to understand the fouling present, and being able to use it in the best way to optimize both fractionation and flux.

Proteins represent 3.4 wt% of whole milk composition. Casein and whey represent 2.8 wt% and 0.6 wt% of the total composition respectively.[2] The commercial interest in these products are in the production of cheese using whey free casein to reduce production costs, and the production of sports drinks using casein free whey.

The two main aspects to consider for membrane separations are the selectivity of the process and the flux. Both of these parameters are affected by fouling. To determine membrane performance, fouling patterns have been studied by running pasteurized skimmed milk through two sets of commercially available polymeric PVDF membranes (800 kDa and 0.1 µm nominal pore size respectively, *Synder Filtration*). Filtration was carried out using a *DSS M10* apparatus with four flat sheet membranes with a combined area of 336 cm^2.

Figure 1 shows the flux decline curves for four milk filtration runs, operated at a cross flow velocity (CFV) of 1.5 ms^{-1}, transmembrane pressure (TMP) of 0.5 bar, temperature of 10°C and a period of 3650 s. The retentate and permeate were continuously recycled. The cleaning cycle used involved a combination of rinsing steps and chemical cleaning, at a CFV of 1.5 m s^{-1} and a TMP of 1 bar. The cleaning agent used was 0.5 wt% NaOH.

The first filtration cycle showed that a relatively low but stable flux of 11 litres m^{-2} hr^{-1} (LMH) was achieved after one hour of filtration. Following cleaning, subsequent filtration cycles showed an improvement in flux to *ca* 14 LMH after one hour. It is postulated that this is due to fouling masking the negative charge on the virgin membrane. It is also possible that the membrane is becoming more hydrophilic following filtration. The surface science of the fouling and cleaning phenomena are currently being studied in depth to improve our mechanistic understanding of these processes.

Preliminary rejection studies show that proteins are rejected by the 0.1 µm membrane at an increasing rate, starting at a rejection of 46% at time 500s and increasing to 67% by the end of

the filtration process (3650 s). It is postulated that the increase in rejection is due to fouling acting as an added selective layer.

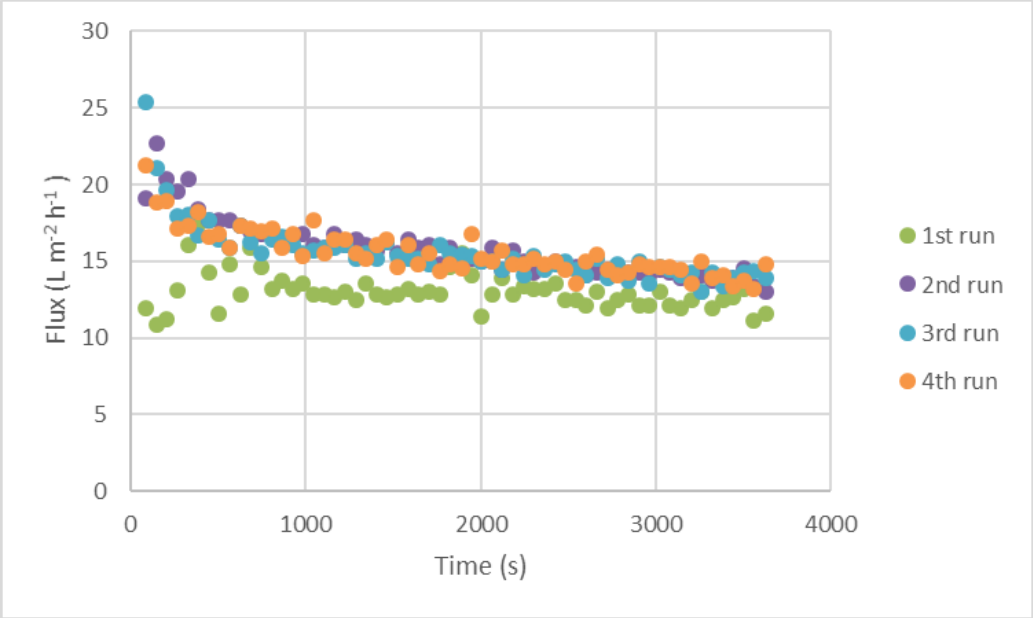

Figure 1: Flux decline curves for a 0.1 µm pore sized *Synder Filtration* membrane over four operational cycles.

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MEMBRANE MODIFICATION IN ULTRAFILTRATION OF SKIM MILK

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ABSTRACT

The fouling in the process of skim milk ultrafiltration using membranes with the nominal molecular weight cut-off (MWCO) 100 kDa from various polymers (polysulfone (PSF), polysulfonamide (PSA), aromatic polyamide (PA), polyacrylonitrile (PAN), cellulose acetate (CA) and regenerated cellulose (RC)) was studied. It was found that according to the decrease of the contact angle of the selective layer the studied membranes can be arranged in the following sequence:

PSF > PSA> PA > PAN>CA>RC:

The flux of the skim milk at the constant product concentration, protein adsorption, resistance and specific resistance of the formed gel layer of the membranes were studied. It was found that there is no correlation between the hydrophilic-hydrophobic balance of the membrane skin layer and the protein adsorption: the most hydrophilic membrane RC-100 was modified to the minimum extent, the protein adsorption for the PSF-100 and PA-100 was a folder higher and the maximum adsorption is observed for the PAN-100 membrane (figure).

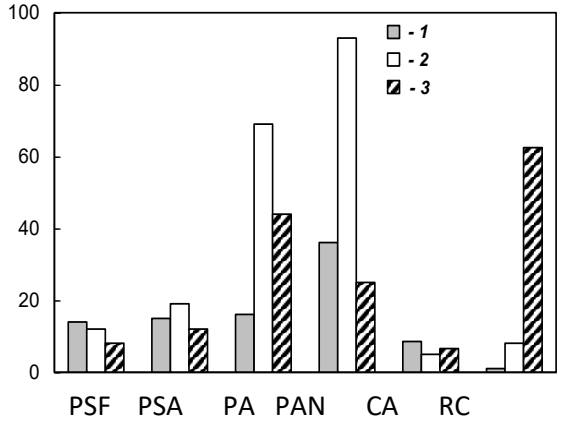

Figure. Membrane modification during the skim milk ultrafiltration:
1 – protein adsorption, $mg \cdot m^{-2}$
2– resistance of the gel layer, 10^{-3} $MPa \cdot s \cdot m^{-2}$
3 – specific resistance of the gel layer, 10^{-8} $MPa \cdot s \cdot m^{-2} \cdot kg^{-1}$

Comparison of the two parameters – water contact angle of the membrane selective layer and normalized dipole moment (average effective dipole moment (D) related to the mole volume of the monomer unit V_m) of the studied membrane polymers with the adsorption values of the protein molecules during ultrafiltration process proves that the binding of the protein molecules with membrane surface increases with the increase of the hydrophobicity and polarity of the membrane polymer matrix. High protein adsorption by the moderately hydrophilic PAN membrane is due to the contribution of the normalized dipole moment of the polymer.
It was found that the studied membranes have significantly different hydraulic resistance of the adsorbed gel-layer, which can be considered as a secondary dynamic membrane. PSA-100,

PSF-100 and PA-100 membranes were shown to have close protein adsorption values, however the gel-layer resistance of the PA-100 membrane was found to be 4-5 times higher compared to the PSA-100 and PSF-100 membranes. RC-100 membrane was found to have the highest value of the specific resistance of the adsorbed gel layer among the studied membranes and a folder higher compared to CA-100 membrane. Consequently it can be concluded that the properties of the gel-layer depend on the physical-chemical properties and structure of the membrane polymer matrix.

Section 6

Cleaning methods including jet nozzles

QUANTIFYING THE EFFECT OF SOLUTION FORMULATION ON THE REMOVAL OF SOFT SOILD FOOD DEPOSITS FROM STAINLESS STEEL SURFACES

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ABSTRACT

The role of detergent formulation on the mechanisms controlling cleaning of a complex carbohydrate soil mixture was studied using a modified version of the millimanipulation device described by Ali *et al*. (2015). The device measures the force imposed on a scraper blade which passes through the soil layer at a set translation velocity. The modification allowed the flow of cleaning solution across the sample, at set flow rate and temperature, so that the effect of contact time with the reagent(s) can be studied. The configuration also allows the composition of the cleaning solution to be manipulated during the test. The force required to remove the deposit was found to change noticeably over time, associated with a transition in adhesion.

FLOWING FOAM FOR THE REMOVAL OF B. SUBTILIS AND B. CEREUS SPORES FROM STAINLESS STEEL SURFACES

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ABSTRACT

Bacillus spores in food processing environments are known to induce food cross-contamination and possible consumer health concerns. Spores are also known to attach firmly to any kind of solid surfaces. Cleaning efficiency is of prime importance for food industries to ensure both the quality and safety of the products [1]; however, with present standard cleaning in place (CIP) operations, high level of energy and potable water are being enormously consumed and this can be a main concern for many governments. Flowing foam cleaning may highly reduce water and energy consumption. Preliminary works have shown that flowing foam can produce the same wall shear stress conditions than a single phase flow but under a flow rate divided by a factor of 40. In this work pilot plant CIP and foam cleaning setup were used. Removal kinetics were obtained by cleaning stainless steel AISI 314 L coupons inserted in stainless steel pipes after soiling by *B. cereus*, and *B. subtilis* spores at a surface load of 10^5cfu cm^{-2}, strains being chosen for their differing surface properties of their spores. Using CIP conditions (sodium dodecyl sulfate (SDS) 0.15%ww, 20°C and a mean wall shear stress of 5 Pa) up to 1 log10 spores of *B. subtilis* were removed compared to only 0.25 log10 for B. *cereus* after 20 min cleaning. Flowing foam (same SDS conditions and 50% air/liquid) generated a thin liquid film at the coupon surfaces under identical mean wall shear stress, inducing an increase in the cleaning efficiency by a factor of 20 for *B. subtilis* and a factor of 7.5 for *B. cereus*.

ENZYME-BASED CLEANING OF COCONUT MILK FOULANTS

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ABSTRACT

This work aimed to investigate cleaning of coconut milk foulants by enzymes to find alternative cleaning method which is more efficient and more environmental friendly than the current cleaning method using sodium hydroxide (NaOH). Swelling studies of the foulants in cellulase (Celluclast®) (1-4 wt%, 55˚C, pH 5.5, 2 hr) were conducted using a gravimetric method. Continuous reduction of foulants mass was observed but the foulants were not completely removed at the end of 2 hr. Larger mass reduction during swelling was observed when protease (Alcalase) was mixed with cellulase at a ratio corresponding to the ratio of carbohydrate to protein in the foulants. Nevertheless, when lab-scale tests for cleaning in place (CIP) using enzymes as cleaning agents were conducted, the highest mass removal achieved was only 64.7%. This was significantly lower than 88.1% removal obtained with 1 wt% NaOH (70˚C, pH 12.2). Removal percentages of enzymatic cleaning also largely varied with foulants samples formed at different positions in a heat exchanger. Surfactants (LAS 24 and LAS 95) were then used to assist enzymatic cleaning. Cleaning with enzyme (cellulase) and surfactants were conducted at 55˚C and pH 5.5. It was found that using enzymes and surfactants together gave lower cleaning efficiencies than using either only enzyme or surfactant. Hence, cleaning in 2 steps was studied. Based on 1-stage CIP results, only cellulase and LAS24 were used in 2-stage CIP studies. Cleaning time of each step was varied but total cleaning time was fixed at 2 hr. Using LAS 24 in the first stage showed higher cleaning efficiency than using cellulase first. Lower concentration of enzyme could also be used and foulants formed at different position in a heat exchanger were removed to similar extent. Using LAS 24 (1 g/l) for 1 hour and cellulase solution (0.12g/l) for 1 hour could remove the foulants by 94.2%; this efficiency was higher than 88.1% obtained by using 1 wt% NaOH. Although, slight improvement in cleaning efficiency was made by using LAS24 and cellulase, these cleaning agents are biodegradable. The lower pH and temperature used during cleaning also made this new cleaning method more environmentally friendly than using NaOH.

EFFECT OF JET LENGTH AND SURFACE CURVATURE ON CLEANING OF TANK WALLS

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ABSTRACT

The effect of jet length on the flow pattern generated by a water jet impinging on a vertical surface was investigated for jets of diameter 2-4 mm for lengths, *L*, up to 1 m. The amount of liquid lost to splatter was measured and found to be insensitive to *L* for short *L* and strongly related to *L* for longer values. The shape of the radial flow zone agreed with existing models once the fraction of liquid lost to splatter was accounted for. This correction was not able to account for all the differences observed in the cleaning of two viscoplastic model food soils, namely a hydrophobic petroleum jelly and a water-soluble gel. The curvature of the impinged surface was found to affect the shape of the region of radial flow to a small amount, and there was no appreciable effect of curvature on cleaning behaviour.

INFLUENCE OF THE NOZZLE DISTANCE ON THE CLEANING RESULT COMPARED TO THE JET BREAK UP AND THE MECHANICAL FORCES ON AN INDUSTRIAL SCALE

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ABSTRACT

This paper presents the influence of the standoff distance L = 0.5…5.0 m of a stationary full jet nozzle (d_N = 3 mm) on the cleaning effect. Two nozzle pressures p_N = 2.0 bar, 4.0 bar (Re_{Jet} = 42187…60191), and four different soiling types with significantly different cleaning behaviour were investigated (petroleum jelly, ketchup, mustard, starch + diatomaceous earth). The results show that for a long time scale the cleaned area increases with raising standoff distance. This can be attributed to the appearing jet break-up with increasing standoff distance, which enlarges the pressurised area. For stationary liquid jets, the use of large cleaning distances is recommended. For short cleaning times, which are necessary e. g. for moving jet nozzles in combination with soils that are difficult to clean, a small distance is suitable. On the other hand, with soils that are easy to clean, such as the ketchup examined here, an optimum of approximately L = 2 m is achieved.

Furthermore, the impact force respectively impact pressure of the liquid jet was measured. The presented results of the cleaning only partially correspond to measurements of jet impact force and impact pressure.

In addition to the performed experiments, the binding force within the soils was determined with a micromanipulation apparatus. It was found out that the basic cleaning behaviour can also be reproduced on a laboratory scale without using a liquid jet. It was also possible to determine a fundamental tendency of the expected cleaning result.

SIMULATION OF JET CLEANING: DIFFUSION MODEL FOR SWELLABLE SOILS

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ABSTRACT

A physical-numerical simulation model for the cleaning of swellable soils by diffusive dissolution or cohesive separation of small soil particles, which was developed targeting a low computational effort, is presented and validated. The flow calculation, based on the Reynolds averaged Navier Stokes equations (RANS), and the calculation of the soil transport, modelled following the unsteady RANS concept, are performed successively. The behaviour of the soil is modelled as a transient Dirichlet boundary condition, its parameters being determined in laboratory experiments using plane channel flow. A validation is performed for a coherent water jet impinging vertically on a substrate, which is covered by a starch-based model soil, at a distance of 100 mm to the nozzle. Using a nozzle diameter of 1.69 mm and pressures in the nozzle ranging from 1.5 to 5 bar, corresponding to Reynolds numbers between 17700 and 55600, the wall shear stress in this configuration exceeds the values given in the laboratory tests by two orders of magnitude. Despite this difference, the simplicity of the model and the complexity of the test case, the simulated cleaning times correspond very well to the measured values. Thus, the targeted scalability and transferability of the model to other flow configurations are ensured.

AN INVESTIGATION IN TO THE CLEANING MECHANISMS OF LIQUID JETS AND SPRAYS USED IN BATCH CLEANING

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ABSTRACT

Flow network analysis was used to model the transportation of water through washing racks used in batch cleaning in the pharmaceutical industry. This allowed the distribution of flow rates through nozzles to be determined and subsequently identified those which were not operating optimally. Experimental work was carried out to simulate the cleaning of components by matching operating conditions to those of the rack, as opposed to the more frequently studied cleaning-in-place, using a specially designed test rig. A jet or spray was set up to impinge against a vertical Perspex wall coated with white soft paraffin, an excipient commonly used in pharmaceuticals processing. Tests were run using water at room temperature with no surfactant and recorded using a video camera in order to observe the cleaning process from a purely mechanical perspective. Additionally cleaning performance was measured and evaluated as a function of the volume of paraffin removed and the energy required to achieve this.

CLEANING OF TANK SURFACES FOULED BY EGG YOLK

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ABSTRACT

The purpose of this work was to examine the effects of burst or pulsed flows on the cleaning of a pilot-scale tank surface soiled by egg yolk, under alkaline conditions, using a rotary spray head. Four cleaning approaches (continuous flow without pre-wetting, continuous flow with pre-wetting, pulsed flow with a shorter period and pulsed flow with a longer period) were tested on uncooked and cooked fouling materials, keeping the same effective circulation time of chemicals in all recipes. The effects of temperature, flow rate and alkali concentration were investigated. The results show that pulsed flows improve cleaning behaviour, where pulsing with a shorter period and higher frequency results in the most deposit removal for the same detergent consumption. The impact of pre-wetting is less significant for the investigated conditions. Some findings are consistent with earlier reports, stating that higher temperature and flow rate improve cleaning by reducing cleaning time. An optimal alkali concentration is obtained, which is in line with results reported by other researchers when investigating other protein soil types.