Fouling of Heat Transfer Surfaces and Its Mitigation: Integration of Experimental and Novel Modeling Techniques

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1 Introduction

Fouling of heat transfer surfaces is one of the major unresolved problems in most industrial processes (Bott, 1997). It is estimated that fouling costs are about 0.2% of the countries Gross National Product (Müller-Steinhagen, 2002). Thus, the overall cost of fouling to industry is about 30 milliard euros per annum in the European Community. It consists of increased capital investments, maintenance costs including cleaning costs, energy loss and costs due to production losses. Even if numerous cleaning and fouling inhibition chemicals are available on the market, many of these are restricted in EU or will be unavailable due to tightening environmental, health and safety legislation. Novel non-fouling materials and new heat exchanger geometries would give sustainable solution to industry in order to mitigate fouling.

2 Objectives of the research

The goal of this work is to increase new understanding of the fouling phenomena and to develop new design methods and coatings in order to decrease fouling. The goal is going to be reached by modifying the construction material of the heat exchangers, the surface composition of materials, and shape of flow channels. Further, a design framework for Heat Exchanger Thermal Analysis will be developed based on the determination of interaction forces (chemical, colloidal, hydrodynamic and turbulent) between surfaces and fluids and combining them into a computational fluid dynamics (CFD) model.

3 Results

3.1 Experiment with Fouling Test Apparatus

A laboratory scale test apparatus is built for the experiments to study the fouling of heat transfer surfaces. Mildly aggressive process fluids with a tendency to foul surfaces can be used in experiments. The fluids can contain solid particles or crystallizing salts. In the test section, a test piece of sheet metal (0.1x0.2m) can be replaced for analysis and that enables also the use of different surface materials and coatings in the experiments. The test area is a rectangle flow channel where constant heat flux is directed through the test piece. The controlled variables are flow rate, fluid temperature, heat flux, surface material and solution composition (conductivity or pH control). By the deposition of crystals or particles on the heat transfer surface the heat transfer decreases. This can be quantified from the evolution of the temperature measured from a test piece. This apparatus is used to obtain data for the kinetic fouling models, and to validate the results of CFD and to study different coatings.

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Fouling experiments are done with a slurry containing $CaCO_3$ particles using stainless steel AISI 316L 2B as the surface material. The bulk fluid temperature, heat flux, flow rate and solid content are varied in the experiments. The fouling is found to be induced by nucleating air at temperatures already below boiling temperatures. The nucleation of air was eliminated by increasing pressure in further experiments. The background electrolyte ($MgCl_2$) was found to have a strong effect on the dispersion properties and the fouling rate of particle slurry.

Salt solution supersaturated with respect to $CaCO_3$ was made of soluble salts $CaCl_2$ and $NaHCO_3$. With this solution, fouling started after a delay period and so called induction time was obtained for non-coated and coated steels. Surface materials that have longer induction time than non-coated steel were regarded to mitigate fouling.

3.2 CFD modelling

A detailed CFD model for particulate fouling is developed using Eulerian two-phase model. The magnitude and the interaction regions of the forces acting on the particles in the vicinity of the fouling surface are evaluated. The most important forces affecting the particle transport to the near wall region and the adhesion of the particles on the wall surface are included into the CFD fouling model. The model will be used to estimate deposition formation in the heat transfer channels. The parameters for the models of different interaction forces (chemical, colloidal, hydrodynamic and turbulent) in the deposition formation are determined based on the materials used with the experimental studies. The validation of the fouling model is based on the experimental results obtained with the laboratory apparatus. The object is to develop a wall function model for particulate fouling. The fouling model will be further developed into a large scale CFD model that can be applied in modelling of fouling in an industrial heat exchanger.

3.3 Molecular modelling

Molecular modelling was used to investigate the specific chemical interactions between surface materials used in heat exchangers and compounds causing deposition formation. Fouling mechanisms are defined at the molecular level by starting from a unit cell structure of materials, predicting the morphologies of the materials and then predicting an effect of the process fluid on selected surfaces. Typically the most important component of process fluid is water. Therefore, the dissociation behavior of water molecules on surfaces was studied, and then the study was continued with adsorption and reaction path calculations of fouling components. As a result, the formation mechanism with detailed intermediate steps of $CaCO_3$ deposition was received. The fouling happens via hydrogen carbonate intermediates, but the final deposition structure was found to vary between surfaces.

4 Relevance of the research

The coatings that have non-fouling properties are verified in industrial scale testing in the connection with an industrial process. A small heat exchanger unit parallel to the industrial process unit is in use. Thus, the results (modelling, laboratory scale tests and industrial scale tests) of the work can be utilized in order to choose suitable surface materials for industrial equipments. Decreased and more controlled fouling of heat exchangers leads to economic savings for processes: reduced capital and maintenance costs, energy savings, and smaller heat transfer units. Therefore, economical and environmental benefits are achieved with non-fouling equipments.

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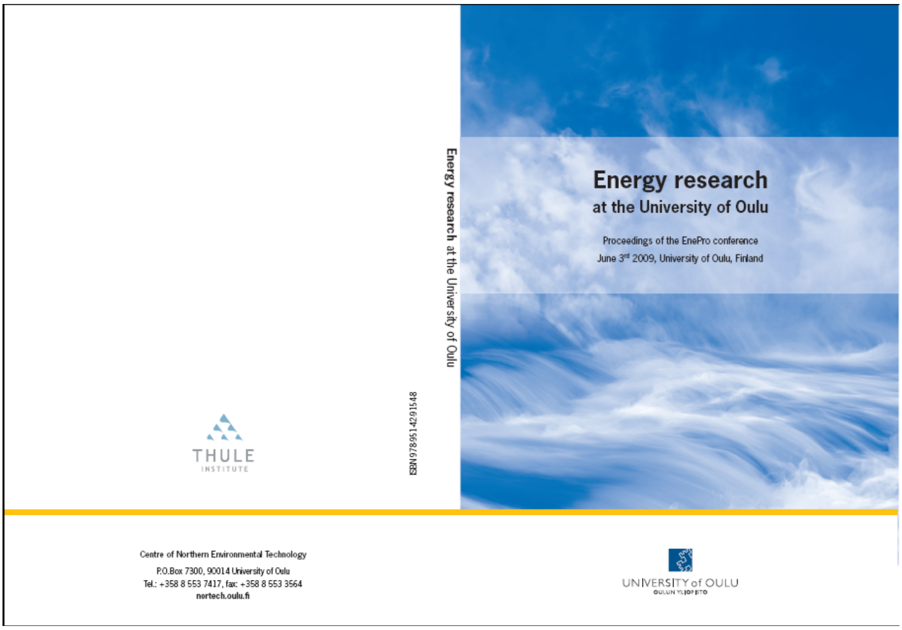

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