

Dear JoVE Editors,

Enclosed please find our manuscript, entitled “Experimental Multiscale Methodology for Predicting Material Fouling Resistance,” submitted for publication in JoVE. In this paper, we present a multiscale experimental methodology for quantifying and predicting the resistance of materials to fouling, a multi-billion dollar material surface degradation problem that plagues the energy production, marine shipping, and fossil fuel refining industries, as well as most applications with heat transfer and a working fluid. While we present results specific to the formation of CRUD in nuclear reactors, we believe that this methodology is widely applicable to estimating the fouling resistances of many materials in different gaseous and fluid environments.

We believe that this work deserves to be documented in JoVE’s unique video format because of our initial trials and tribulations in conducting both successfully reactor-representative pool boiling studies and AFM force spectroscopy (AFM-FS) of CRUD-substrate adhesion in water. For pool boiling, numerous iterations of samples preparation technique, experimental facility design, preparation of simulated PWR water with dispersed nanoparticles, choosing appropriate nanoparticle concentrations, and confirming reliably repeatable experimental conditions took over a year to master. Tips such as using direct heat flux sensors, strongly sonicating nanoparticle solutions immediately before use, and polishing techniques for finicky Zircalloys were not told to us; we had to figure these out for ourselves. We hope to save future experimentalists this trouble. As for the AFM-FS measurements, performing them in air is relatively straightforward, while the introduction of a fluid environment presents additional challenges of laser refraction in the droplet, realignment, material selection, and using very different spring constants due to a lack of electrostatic “pop-in” and attraction in conductive water. The procedure itself is fraught with places to mess up. Breaking AFM tips is common, and the mounting/fixturesing procedure takes finesse. We were lucky enough to have Alan Schwartzman (one of our authors) guiding us through this work. His expertise is not reflected in any AFM-FS papers which we have read, and deserves to be visually documented. This will help take AFM-FS from a more specialized technique to something that is more easily learned by a wider variety of researchers. In addition, AFM-FS measurements specifically, and surface adhesion measurements in general, are quite lacking

compared to many modes of interfacial observation. A lack of easily available data can be filled by making this technique more accessible and error-free.

Pavlina Karafilis, Abdulla Alhajri, and Gabrielle Ledoux have performed AFM-FS measurements, with Pavlina and Abdulla performing the most. Pavlina, Rasheed, and Vikash have “cooked” most of our materials in the pool boiling facility. They are also responsible for redesigning the majority of the pool boiling facility after its initial conception, to make experimental measurements easier and more trouble-free. Alan Schwartzman operates the Nanolab at MIT’s Department of Materials Science and Engineering. He trained Pavlina, Abdulla, and Gabrielle in AFM-FS techniques, in addition to performing a few of the measurements himself. Leigh Lin built much of the first incarnation of the pool boiling facility, and together with Pavlina and Vikash designed and built the heater control boxes, pH system, Log-O-Matic data acquisition system, and iterations of the pool boiling chamber itself. Ekaterina worked with Prof. Short at the start of the project to “cook” the first samples, and analyze CRUD adhesion to substrates by SEM/FIB. Prof. Short conceived the project, built the first realization of the pool boiling facility and its associated electronics, and designed the experimental program.

Editor Mathew Solomon assisted us in the preparation process. It was through Mat contacting us that we learned about JoVE, and we immediately jumped on the opportunity to publish with the journal. I personally believe that the mission of JoVE is highly admirable and long-overdue in the world of science. When I think back to the years I could have saved if experimental techniques were this well documented, I wonder how much faster I could have graduated!

We recommend the following peer reviewers, based on their knowledge of the problems of CRUD and fouling, pool boiling techniques, AFM force spectroscopy, and adhesion:

1. Dr. Chris Stanek
Los Alamos National Laboratory (EPRI)
stanek@lanl.gov

Dr. Stanek is an expert scientist at the MST division of LANL, specializing in thermal conductivity. He also leads the Materials Performance and Optimization (MPO) focus area of the DOE Consortium for the Advanced Simulation of Light Water Reactors (CASL). One of CASL’s three main challenge problem is understanding CRUD formation in PWRs.

2. Dr. Dennis Hussey
Electric Power Research Institute (EPRI)
dhussey@epri.com

Dr. Hussey previously lead the PWR technical advisory committee (P-TAC) at EPRI, which primarily focused on operational challenges facing PWRs in the industry today. His long experience with CRUD's effects on power plants and strategies for their mitigation gives him unique scientific and industrial experience with the problem of fouling in PWRs.

3. Dr. William Byers
Westinghouse Electric Company (WEC)
byerswa@westinghouse.com

Dr. Byers holds a patent on CRUD-resistant fuel cladding, and has studied its formation in nuclear power plants for quite some time. He currently helps run the WALT loop at Westinghouse, a unique facility designed to grow CRUD in conditions (pressure, temperature, heat flux, chemistry) very similar to those found in a PWR.

4. Prof. Sung Joong Kim
Hanyang University, South Korea
sungkim@hanyang.ac.kr

Prof. Kim studies the formation of CRUD, and has performed numerous flow and pool boiling experiments. He will be well suited to judge the merits of the pool boiling experiments at simulating the formation of CRUD, as he has experience designing and running pool/flow boiling thermal hydraulic experiments for nuclear reactors.

5. Prof. Sandro Macchietto
Imperial College London, United Kingdom
s.macchietto@imperial.ac.uk

Prof. Macchietto has helped lead the effort to design fouling-resistant materials for the oil industry, under the CRude Oil Fouling (CROD) program of the UK Engineering and Physical Sciences Research Council (EPSRC). Prof. Macchietto's work includes AFM-FS measurements of asphaltenes on glass substrates, to simulate the initial adhesion event of these molecules, found in crude oil, on oil-facing materials. He is well-suited to judge the merits of the AFM-FS portion of this work, as well as to comment on its wider applicability to more problems of scientific and industrial interest.

6. Dr. Dalia Yablon
SurfaceChar LLC
dalia.yablon@surfacechar.com

Dr. Yablon is an expert on surface characterization, having worked in the oil industry for over a decade. She has founded her own company offering surface characterization services, and is a widely recognized expert in surface science, scanning probe microscopy, and atomic force microscopy. Dr. Yablon is also qualified to judge whether the AFM-FS based methodology put forth in this paper is suited to judge the anti-fouling properties of materials.

Thank you for your consideration of our article, we very much look forward to publishing with JoVE! Please feel free to contact me if you have any questions concerning our submission.

Sincerely,



Michael Philip Short