

## **Mechanisms of Gas Hydrate Adhesion and Cohesion in Conventional Energy Transportation**

Zachary Aman<sup>S</sup>, E. Dendy Sloan, Amadeu Sum and Carolyn Koh<sup>C</sup>

*Colorado School of Mines, Department of Chemical and Biological Engineering, Golden, CO, U.S.A.*

*ckoh@mines.edu*

Gas hydrates are comprised of water cages which enclathrate lighter organic species (e.g., methane), typically at high pressure and low temperature. Hydrates may form in conventional oil and gas flow lines, leading to operation and safety hazards. In these systems, hydrate particles may be exposed to multiple bulk phases (oil, water, or gas), and may share interfaces with a variety of solids and fluids. The present work includes direct measurements of hydrate adhesion and cohesion forces, where gas-phase cohesion forces were 2x large than in the hydrocarbon phase and 6x larger than in the water phase. Interpreting these measurements through fundamental thermodynamics and fracture mechanics, we decouple force contributions from capillary liquid bridges, solid-solid cohesion, and sintering (growth) between particles. At shorter timescales, we show how the interparticle force may be predicted through a free energy balance across a capillary liquid bridge. At longer timescales, we observe increases in adhesion and cohesion force by 70% for each order of magnitude in contact time. We hypothesize that this time dependence may be due to particle sintering (growth), and show an empirical relationship to predict the onset of sintering as a function of driving force to the hydrate phase. Based on this experimental data, we present the first direct model to describe hydrate interparticle forces, and show the preliminary implementation of this model in multiphase flow predictions where hydrate aggregation may significantly increase the viscosity of the hydrocarbon phase.