Overview of Microchannel Coolers
- Can be embedded directly into the substrate to provide highly localized heat removal.
- Many different forms: single vs. two phase fluid, silicon or ceramic substrate vs. alloys, working fluids, velocity, temperature, filtering, etc.
- No “one-size-fits-all” reliability solution.

Fundamentals of CFD Erosion Modeling
- Widely used in the Oil & Gas industry
- Conducted in three primary steps:
  1) Numerically compute flow field
  2) Calculate particle trajectories
  3) Model particle-wall interactions (erosion equation)

Degradation Mechanisms
- Deposition
- Reexpansion
- Apposition
- Clogging

Erosion Modeling Challenges
- Particle erosion models developed using “sandblasting” tests.
  - Significantly higher velocities and particle sizes than those present in microchannel cooling loops. Slurry erosion tests seldom include particles in the single-phase/liquid regime.
  - Effect of particle-induced “squeeze-film” is neglected as sandblasting tests are performed in air.
  - Difficult to capture particle-induced viscous dampening as particle approaches wall. Requires two-way particle-fluid coupling. Very computationally expensive, difficult to achieve convergence.

Particle Erosion Modeling of Microchannels
- Particle erosion models of single-crystal silicon were used for preliminary modeling purposes. An inlet velocity of 4 m/s (single-phase fluid) was assumed to determine to effect of particle size and concentration on the erosion rate.

Erosion Modeling Challenges
- Can erosion models calibrated for larger particles and velocities be used to predict erosion in microchannel coolers?

Literature suggests the existence of threshold particle and velocities under which no erosion will occur. Will this hold true over 10^5, 10^6: 10^7 hours?

Conclusions
- Particle erosion likely to be a concern for Si microchannels after 107 hours.
- Slurry erosion test apparatus has been constructed to determine threshold particle size and velocities for microchannel cooler materials.
- Clogging test setup designed to investigate major factors contributing to clogging and fouling. Identify how different manifold structures affect likelihood for clogging.

How to factor reliability in microchannel designs

Slurry Erosion Testing
- Gain insight into the removal mechanism of the various materials involved in microchannel coolers.
- Determine and calibrate model to predict erosion in microchannel coolers. Identify threshold velocities and particle diameters.

Factor Ranges:
- Velocities: 5 – 60 m/s
- Particle Sizes: 0.1 – 25 μm
- Impingement Angles: 0 – 90°
- Materials: Si, Al2O3, SS

Experimental Clogging
- Investigate major factors contributing to clogging of microchannel coolers including particle size, concentration, pH, velocity, particulate material.
- Identify how various manifold designs impact clogging.