Design Considerations for Thin Liquid Film Wall Protection Systems

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OBJECTIVES

- **Assess feasibility of "attached" thin liquid film protection schemes for IFE systems**
- **Identify optimum design parameters & "parameter space windows" for reliable operation of such systems**
- **Evaluate impact of wall protection scheme on other sub-systems operation**

Primary Question #1

- **Can we assure "full coverage" and "attachment" of film on cavity wall? — Do we have to?**
  - **Impact on geometry — flowing films on downward facing surfaces**
  - **Effect of beam ports**
  - **Fluid injection point(s)**
  - **Inherent instabilities (temperature gradients)**

Primary Question #2

- **Can the film really "protect" the first wall?**
  - **Solid wall response (thermal and mechanical) to microexplosions in the presence of an attached thin film**
    - **Shock wave strength**
    - **Direct energy deposition**
    - **Spectra of incident radiation**
    - **Wall material**
    - **Liquid film material & thickness**

Primary Question #3

- Can the film "survive" between shots? Or does it have to be re-established after each shot?
  - Film response (thermal & hydrodynamic) to reflected light & X-rays
  - Film "condition" when ions arrive (ablation driven instability; mist formation)
  - Response of "disrupted" film to ions
  - Film response to "off-normal" events

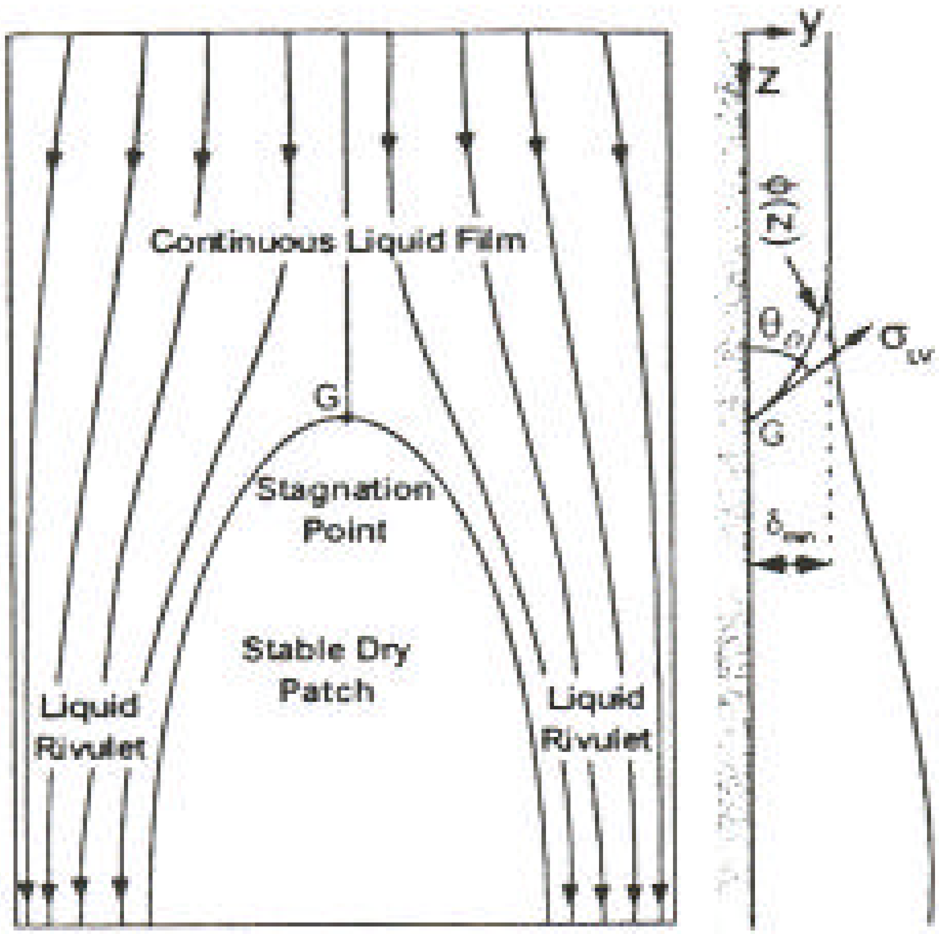
Approach -- Methodology

- Use HEIGHTS-IFE/SPLASH-IFE package (Hassanein — ANL)
  - Multi-layer structure (liquid film/solid wall)
    - Laser & X-ray deposition in composite structure
    - Up to ten ion debris species with various spectra
    - Detailed energy deposition & thermal response with phase change and vaporization
  - Liquid film stability (hydrodynamic &

Preliminary Question

- **What are the minimum film thickness & wetting rate (average film velocity) for a stable dry patch?**
  - **Isothermal film on a vertical adiabatic surface**
  - **Recent Model (El-Genk & Saber; 2001)**
    - **Earlier work by Hartely & Mugatroyd (1964); Hobler (1964); Bankoff (1971); Mikielewicz & Moszynski (1976); Doniec (1991)**

Dry Patch Stability



(b) A schematic of a stable dry patch

Minimum Film Thickness & Wetting Rate

- **Dimensionless Film Thickness Δ_{min} & Wetting Rate Γ_{min}**

$$\Delta_{min} = \delta_{min} / [\rho_l^3 g^2 / 15 \mu_l^2 \sigma_{lv}]$$

$$\Gamma_{min} = \gamma_{min} / [\rho_l \mu_l \sigma_{lv}^3 / g]^{1/5}$$

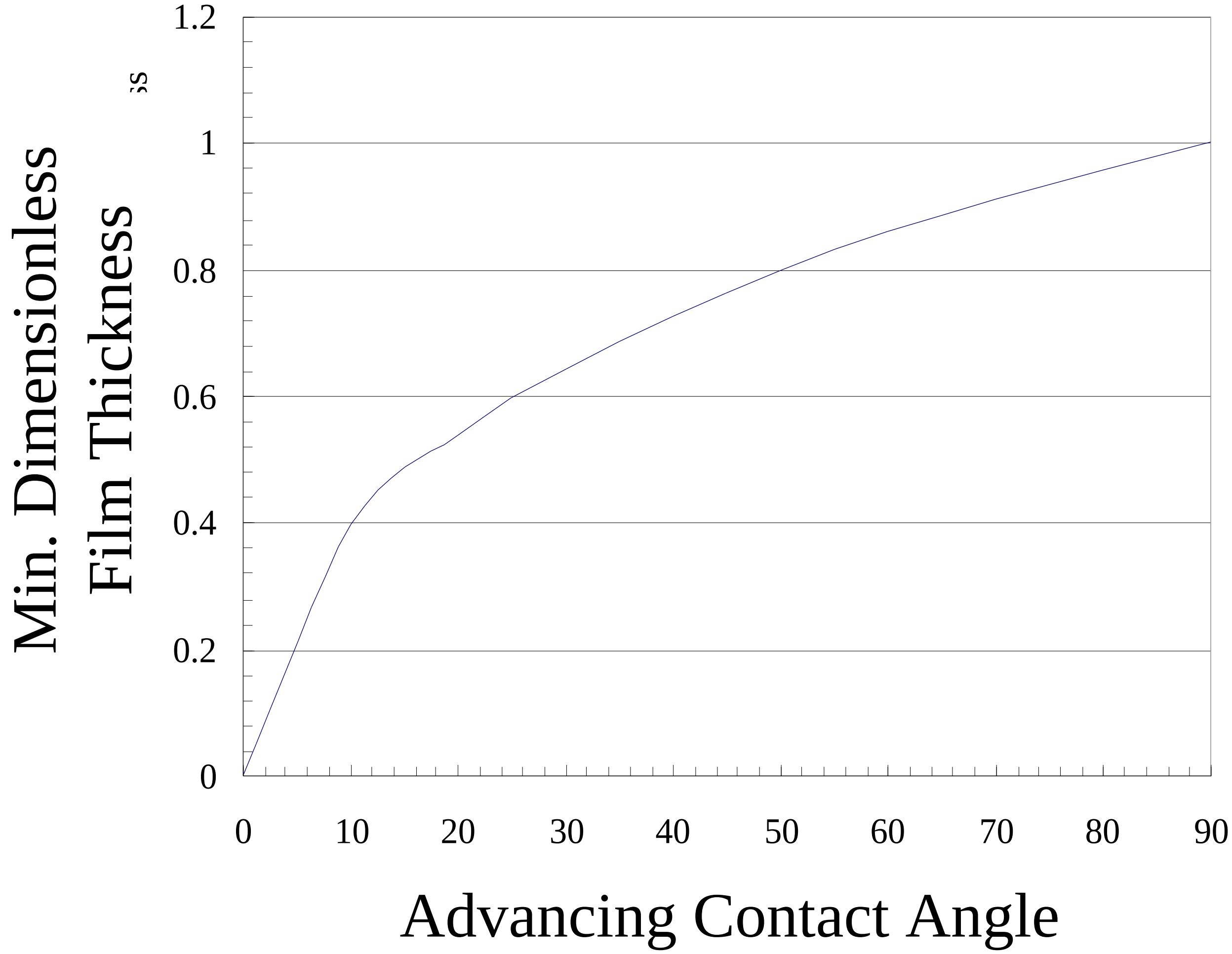
δ_{min}, γ_{min} = **min. film thickness, wetting rate**

ρ_l , μ_l = **liquid density, viscosity**

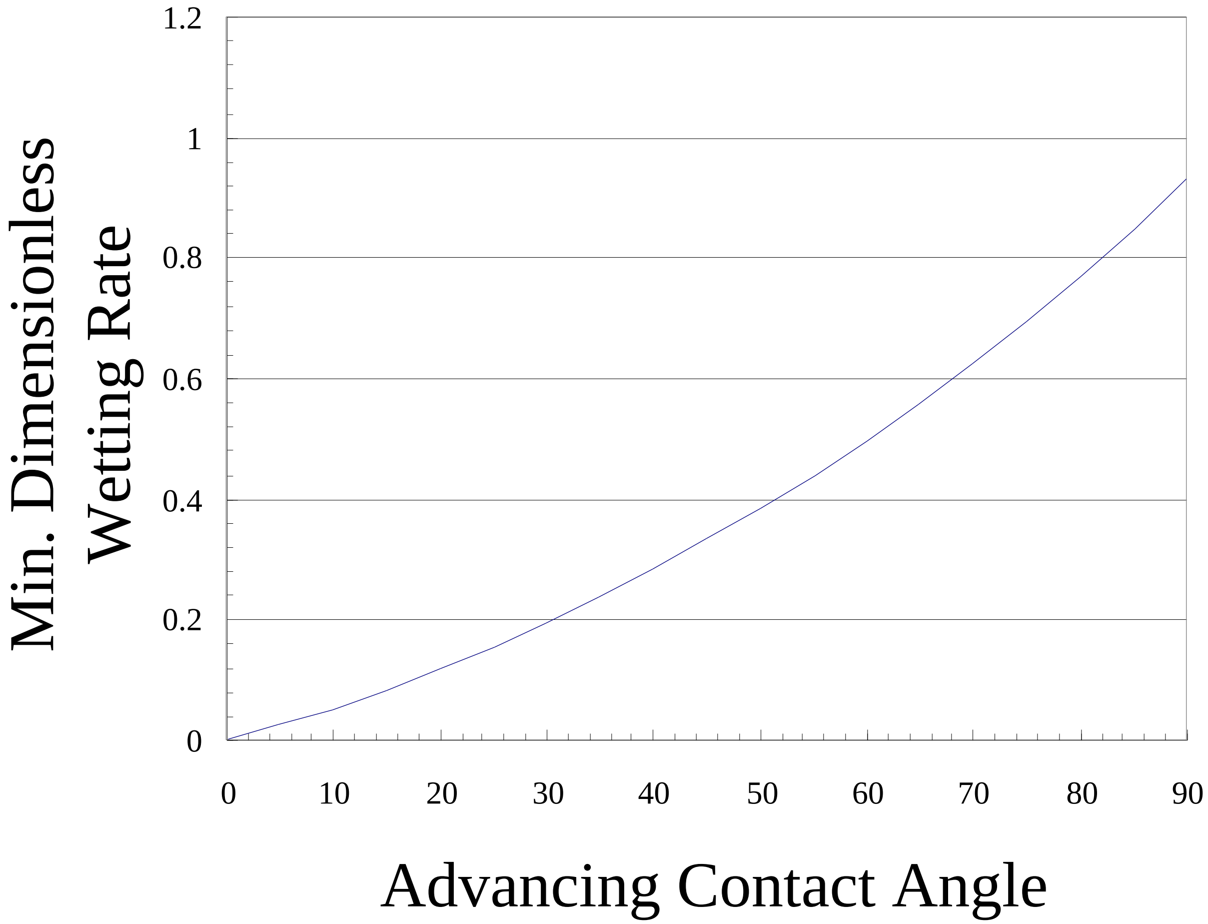
σ_{lv} = **liquid-vapor surface tension**

g = gravitational acceleration

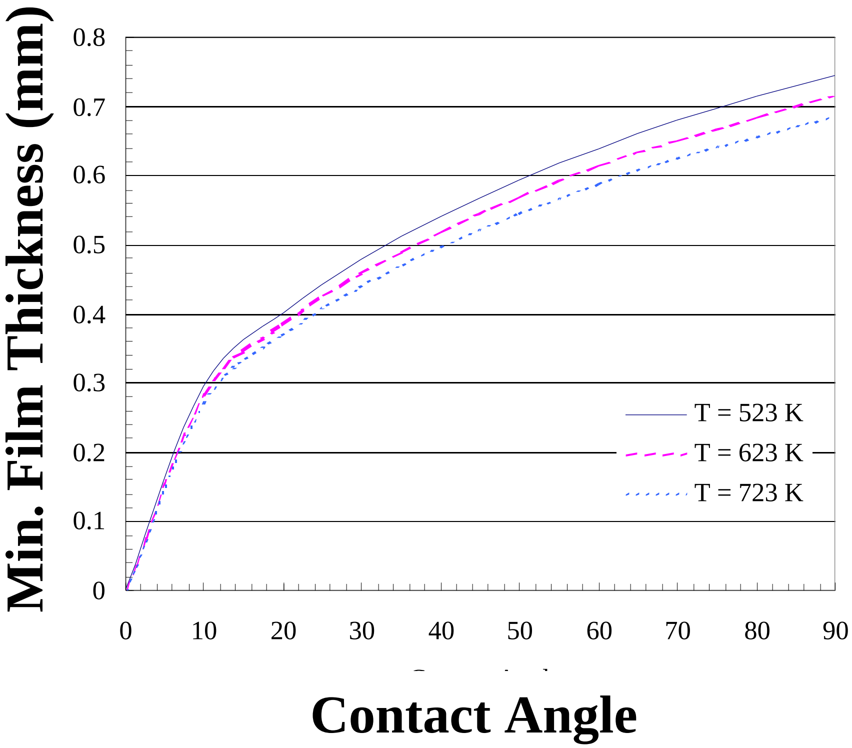
Minimum Dimensionless Film Thickness Δ_{min}

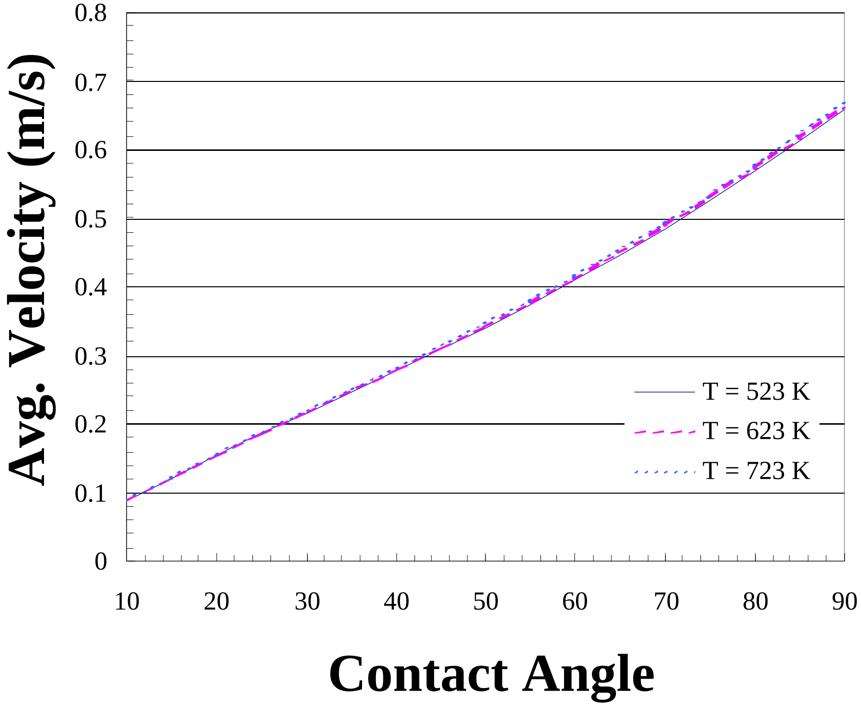


Minimum Dimensionless Wetting Rate Γ_{min}

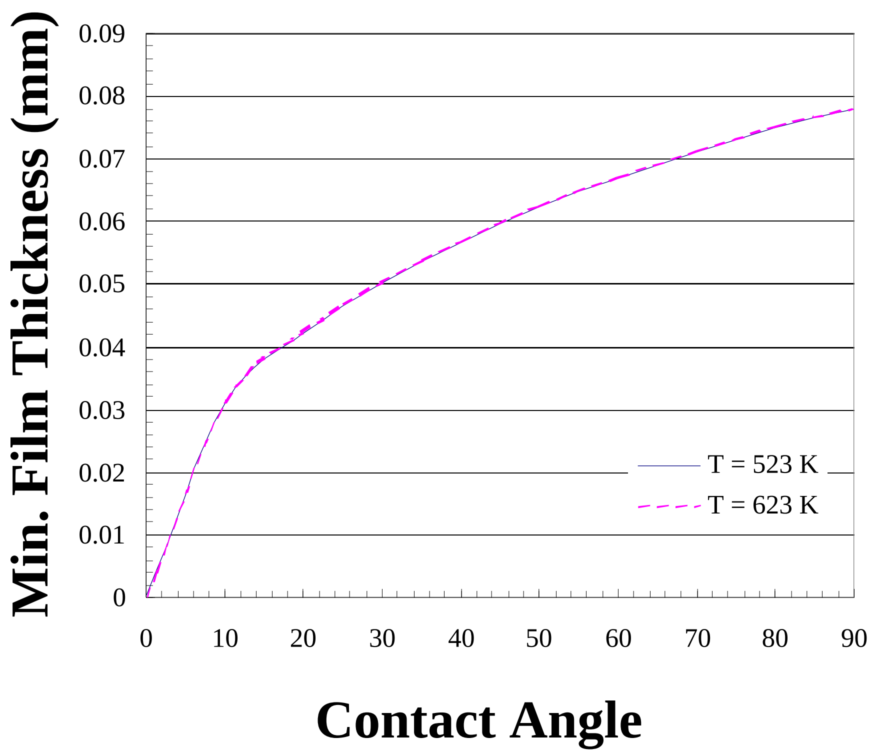


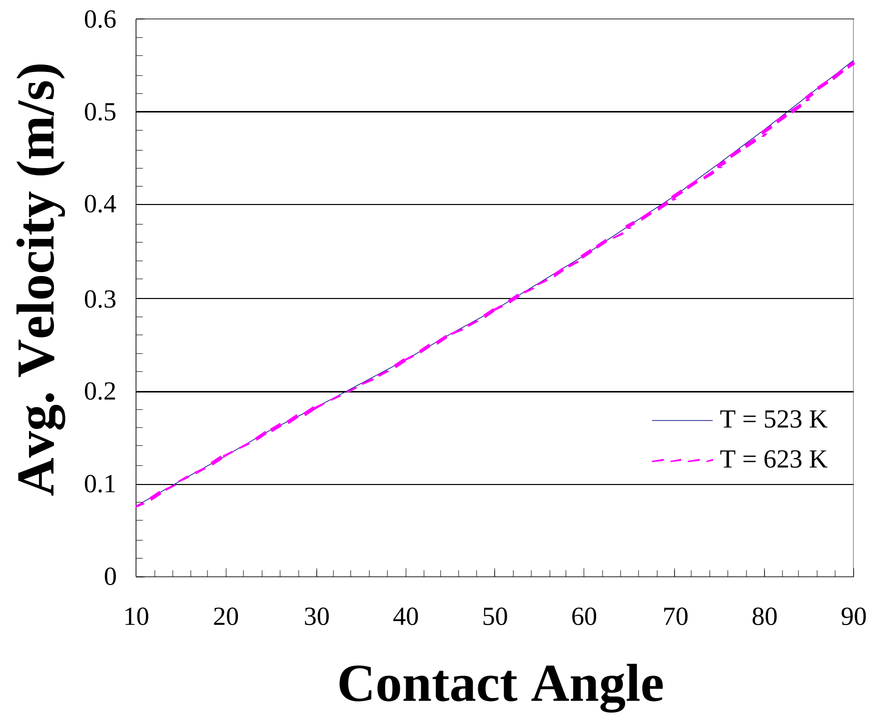
Minimum Film Thickness δ_{min} & Average Velocity U: Lithium



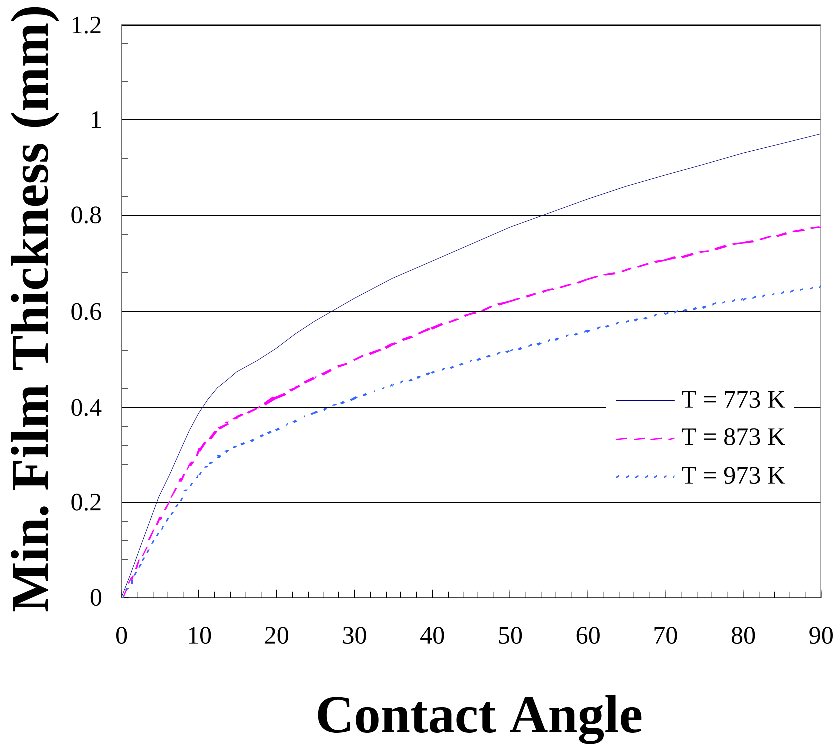


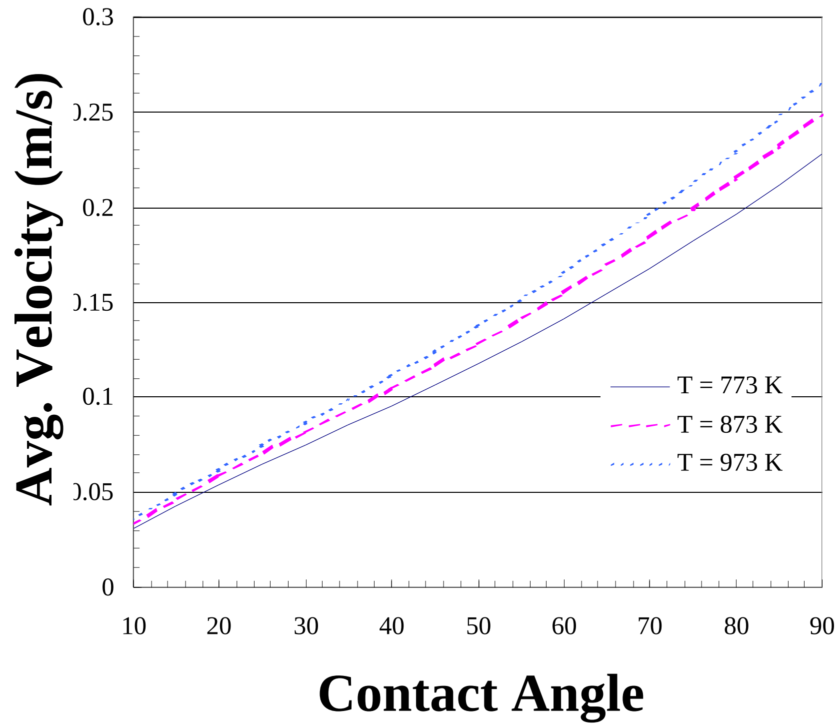
Minimum Film Thickness & Average Velocity: Lithium-Lead





Minimum Film Thickness & Average Velocity: Flibe 66/34%





Conclusion

- **For fluids of interest, a film thickness of ~ 1 mm and an average film velocity of ~ 1 m/s exceed the values required for a stable dry patch in isothermal films on vertical adiabatic surfaces.**

The Path Forward

- **Hydrodynamics of Thin Liquid films**
  - **Surface orientation (downward facing)**
  - **Chamber geometry (injection locations; beam ports protection)**
- **Response of liquid film/solid wall system to microexplosions**
  - **Thermal & hydrodynamic response of liquid**
  - **Thermal & mechanical response of wall**