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Agenda

• Motivation for critical heat flux (CHF) modeling
• Background: pool boiling curve/flow boiling curve
• Availability of pool and flow boiling CHF data for LH₂, LCH₄, LO₂
• Results
• Ongoing/Future work
Motivation for CHF Modeling

1. Tank and line chilldown (pool and flow boiling)
2. Avoidance of CHF in “heated-tube” applications (flow boiling)

In-space tank-to-tank propellant transfer line

Application:
- Cryogenic fuel depots

Tank-to-pump propellant feedline

Application:
- Ascent and Descent Stages
- Nuclear Thermal Propulsion (NTP)

Credit: ULA

These lines could be on the order of tens of feet or higher in length

Informs insulation design and/or degree of propellant subcooling needed
Background: Pool Boiling

<table>
<thead>
<tr>
<th>Pre-CHF</th>
<th>Post-CHF</th>
</tr>
</thead>
<tbody>
<tr>
<td>Single-phase Free Convection</td>
<td>Nucleate Boiling</td>
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<td></td>
<td>Transition Boiling</td>
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<td></td>
<td>Film Boiling</td>
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</tbody>
</table>

- **q''**
- **T_w - T_sat**

- Red: Steady State Heated-Surface
- Black: Childown
Background: Flow Boiling

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<thead>
<tr>
<th>Pre-CHF</th>
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<tbody>
<tr>
<td>Single-phase Forced Convection</td>
<td>Nucleate Boiling</td>
</tr>
<tr>
<td>Pure Liquid</td>
<td>Bubble</td>
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</tbody>
</table>

$T_w - T_{sat}$

$q''$

Steady State Heated-Tube
Chilldown

[1]
• Critical heat flux is a vital point in the boiling curve
• If CHF occurs, heat transfer plummets and the structural integrity of the heated surface could be compromised
• In all propellant transfer applications where a heated-tube boiling situation is present, CHF is to be avoided at all cost.
State of available CHF data for $\text{H}_2$ [2-3]
State of available CHF data for CH$_4$ [2-3]

These data were not considered in the analysis.

Glickstein and Whitesides (1967) [3] is a valid source but was not found.
State of available CHF data for $\text{O}_2$ [2-3]
Correlations Considered

• Zuber (1961) or Kutateladze (1952)- seemingly identically derived correlations
• Lurie and Noyes (1964)
• Sun and Lienhard (1970)
• Kandlikar (2001)
• Von Glaun and Lewis (1960)- water and cryo data
• Katto and Ohno (1984)- R-12 data
• Shah (1987)- many fluids
• Mudawar and Maddox (1990)- FC-72 data
• Katto (1992)
• Hall and Mudawar (2000)- water data
Hydrogen CHF Recommendations

Pool Boiling: Sun and Reinhard (1970)

Methane and Oxygen **Pool**

CHF Recommendations

Methane: Lurie and Noyes (1964)

Oxygen: Sun and Lienhard (1970)
Methane and Oxygen Flow CHF Recommendations

(This chart was intentionally left blank)
Ongoing/Future Work

• Continuing to collect quality datasets (primarily flow CH₄ and O₂)
  • Ones we missed, e.g. Glickstein and Whitesides (1967) methane
  • Future data sets

• Please let us know if you are aware of any data sets we missed
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• A flow boiling O₂ experiment to capture pre-CHF HTC, post-CHF HTC, CHF data, and two-phase pressure drop data has been discussed and proposed as future work to be conducted at NASA MSFC or NASA GRC
References

