ENHANCEMENT OF CRYOGENIC POOL BOILING BY SURFACE MODIFICATION

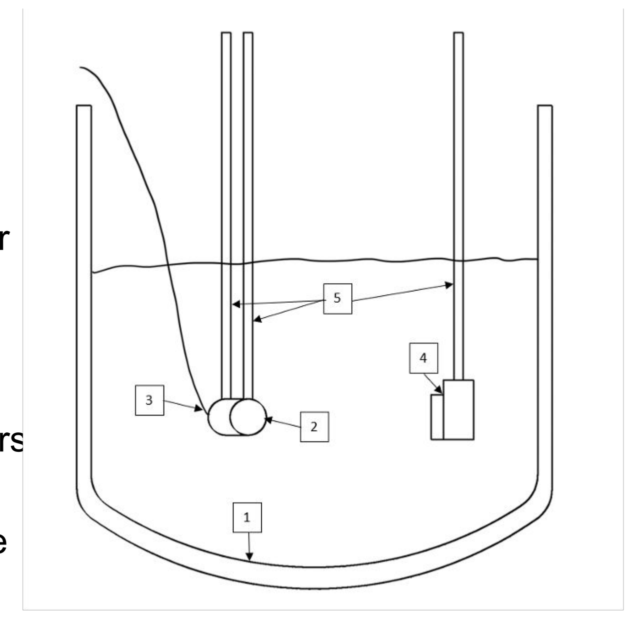
ANDREW JACOB, SHUBA MURTHY AND JIM HERMANSON
GARY GRAYSON AND MICHAEL FRIEDMAN, BLUE ORIGIN, KENT, WA

Introduction

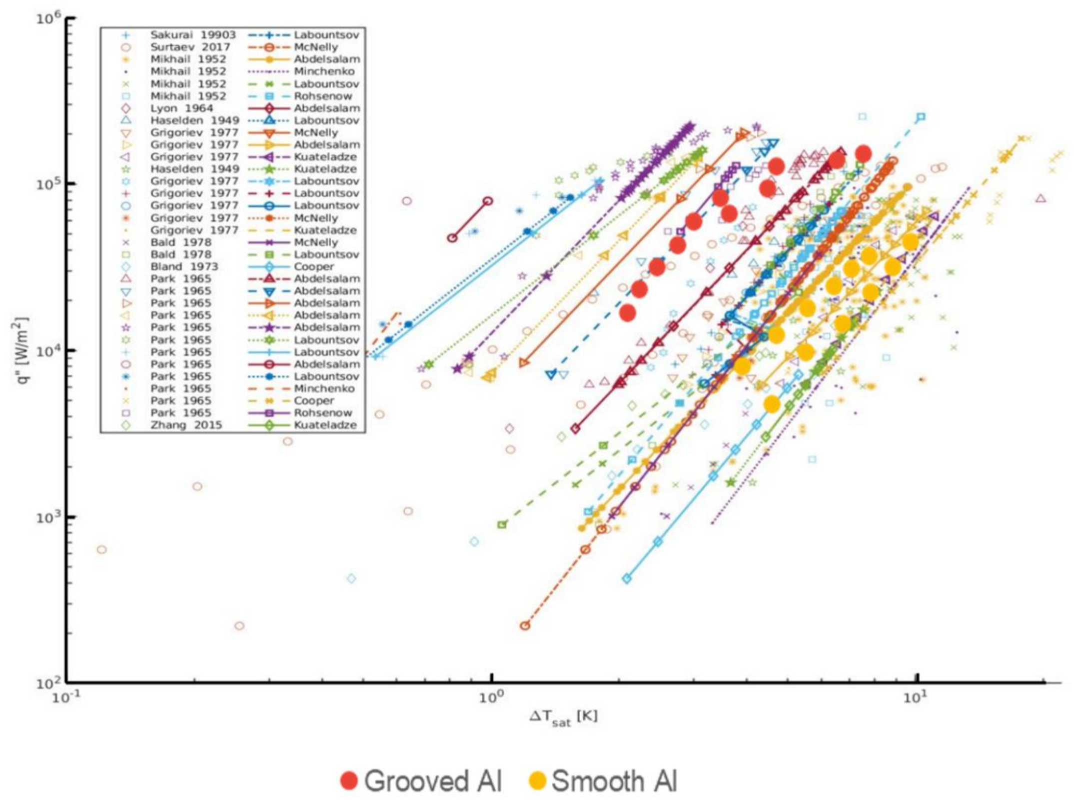
- Cryogenic liquids are used for propulsion and other space-based applications
- Pool boiling is known to be a stable and efficient method of producing vapor and transferring large quantities of heat
- In spite of the many studies of cryogenic boiling conducted to date, considerable experimental uncertainty in the results persists
- Altering the texture of the surface is used to increase the rates of boiling and heat transfer

Experimental Test Setup

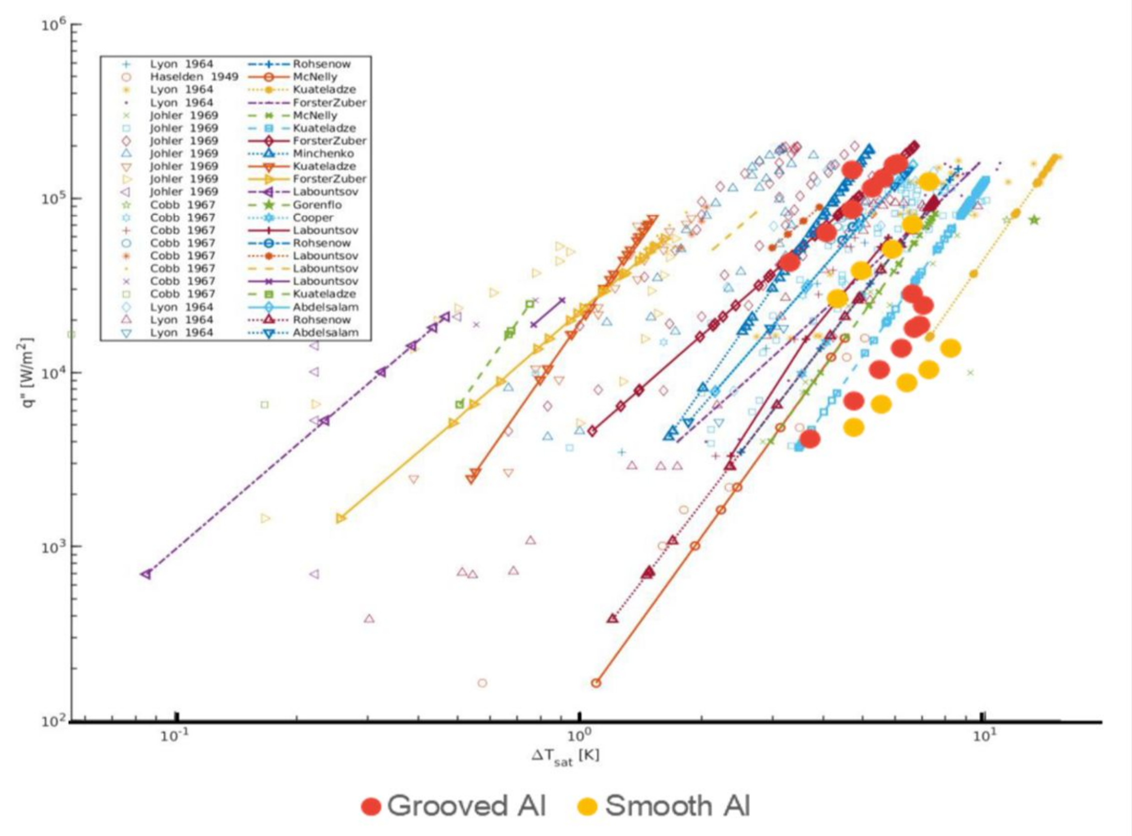
- Liquid nitrogen is employed given its similarity to liquid oxygen and the large database of existing results
- The experimental configuration consists of an insulated vessel 13.5 inches (34.3 cm) in diameter fitted with horizontal or vertical test specimens
- The test specimens are cylinders with smooth surfaces and regular grooves
- Heating is provided by embedded electrical heaters
- Temperatures are measured using copper-constantan thermocouples mounted inside and near surface



Comparison with Previous Studies of LN_2 Nucleate Boiling



Horizontal Cylinder Test result

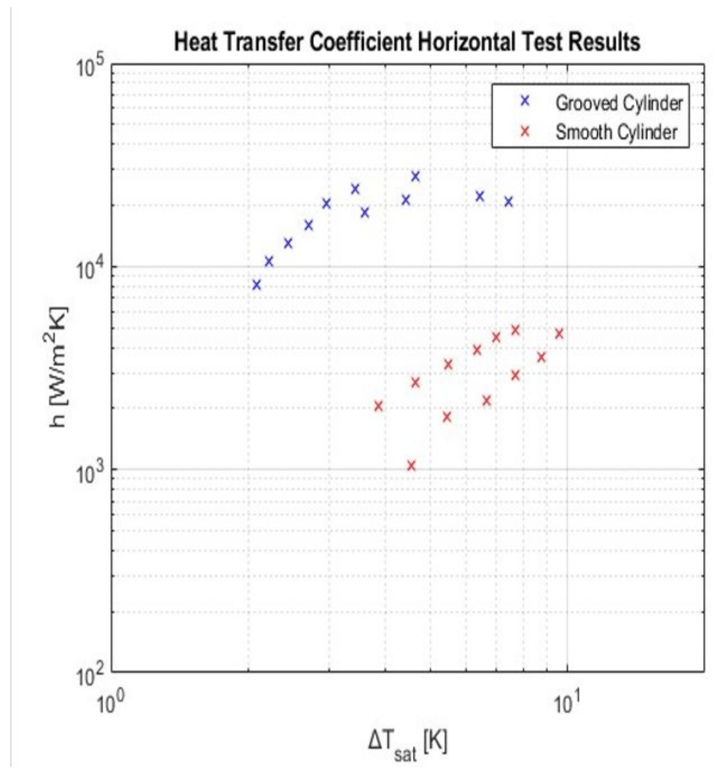


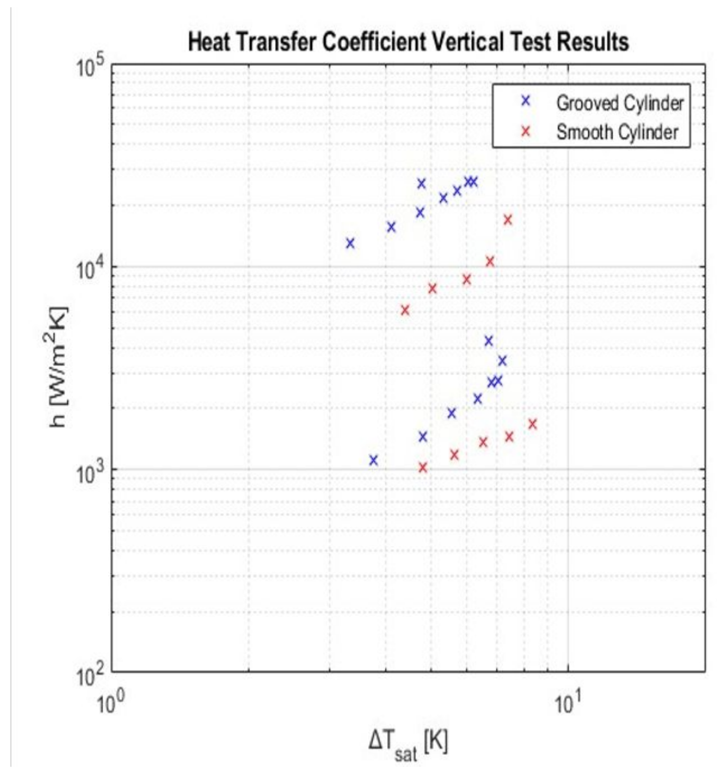
Vertical Cylinder Test Result

Nucleate Boiling Results

- **Heat Transfer Coefficient:**

$$h = q/\,(T_s - T_\infty)$$



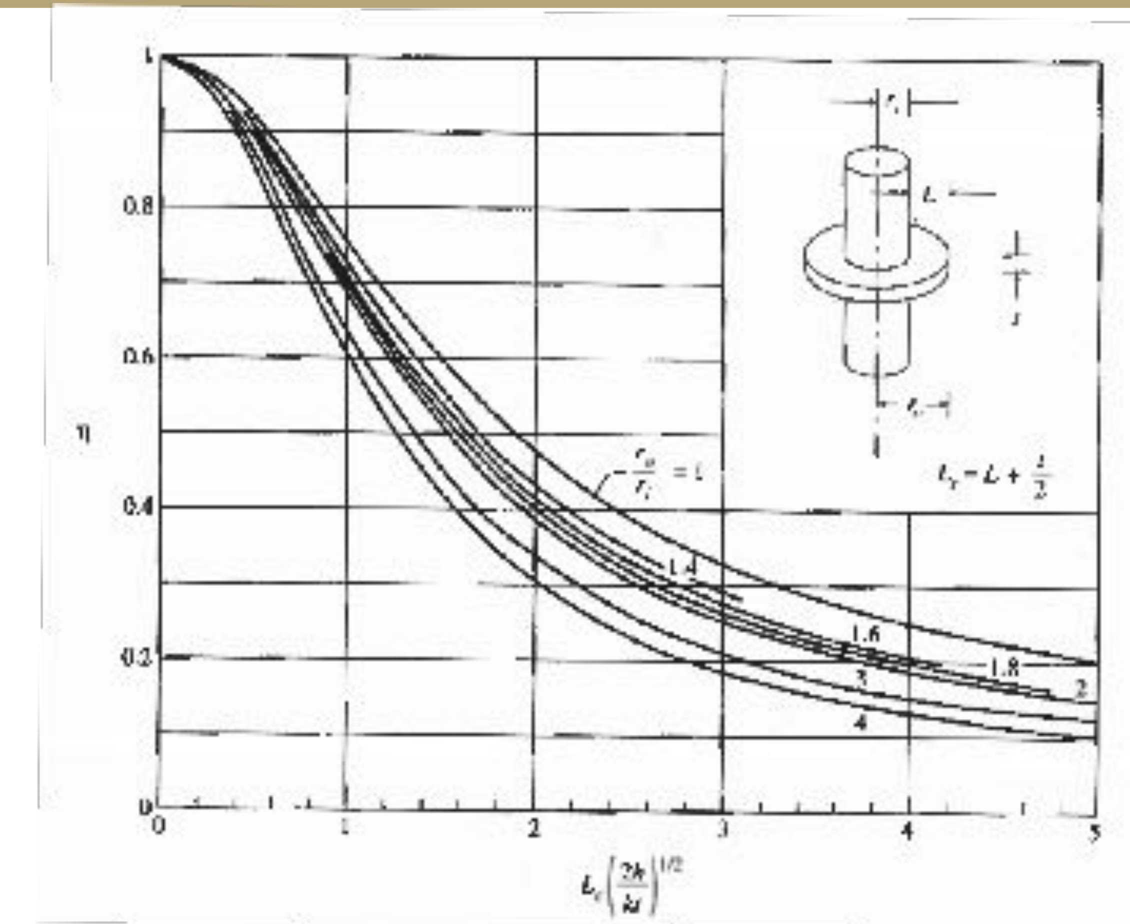


Approximate enhancement in heat transfer due to grooves:

5.5 – 15 x

2.6 – 2.9 x (mid-cylinder)
1.5 – 2.3x (lower-cylinder)

Corrected results



Heat Transfer Correction for Fin Effectiveness 2

Gardner, K. A., "Efficiency of extended surfaces," *Transactions of the American Society of Mechanical Engineers*, Vol. 67, No. 8, 1945, pp. 621–628.

$$Q_{fins} = h_{fins}\,(T_b - T_\infty)[\eta A_{fin} + A_{base}]$$

$$Q_{fins} = h_{fins}\,(T_b - T_\infty)[\eta A_{fin} + A_{base}]$$

Fin Efficiency

$$\eta = \frac{Q_{fin}}{h A_{fin}(T_b - T_\infty)}$$

Summary and Conclusions [2]

- Experiments were conducted to evaluate the effects of surface modifications on the nucleate pool boiling of liquid nitrogen.
- Temperature probes, combined with the variable thermal conductivity of the solid, were used to calculate the heat flux at the surface.
- A grooved surface provided an increase on heat flux, as indicated by the heat transfer coefficient, of as much as a factor of roughly 16.
- A greater enhancement in heat transfer was seen for the case of horizontal cylinders than vertical ones.
- For the vertical cylinder, both the rate of heat transfer and the augmentation due to surface modification were larger at the higher vs. lower measurement location.
- Applying a correction for fin effectiveness suggests a slighter greater enhancement in heat flux than indicated by the temperature measurements alone.

Reference:
Zhang,X.,Chen,J.,Xiong,W.,andJin,T.,"Visualization study of nucleate pool boiling of iquid nitrogen with quasi-steady heat input," *Cryogenics*, Vol. 72, 2015, pp. 14–21.

Faculty:Prof Jim Hermanson
Graduate Students:Andrew Jacob, Shuba Murthy
Undergraduate Students:Natalie Coats

WILLIAM E. BOEING
DEPARTMENT OF AERONAUTICS & ASTRONAUTICS

ADVISERS: JIM HERMANSON
SPONSOR: BLUE ORIGIN