CVB: The Constrained Vapor Bubble
40 mm Capillary Experiment on the ISS

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ASGRA Annual Meeting 2013
**THE CVB HEAT TRANSFER SYSTEM**

- The CVB is a Constrained Vapor Bubble inside a quartz cuvette with a working fluid like pentane.
- Inside 3mm x 3mm ~ 40 mm long.
- Liquid rises along the sharp corners and across the flat surfaces due to interfacial forces.
- Heat source at one end.
- Inside Radiation and Radiation to the surroundings Important
- Evaporation from the hotter regions; condensation in the cooler regions;
- Important visual observation through the cuvette gives unprecedented insight into transport processes.
- Emissivity = 0.775 for thermal radiation frequencies.

A transparent “heat pipe” – ideal for studying basic fluid flow and heat transfer due to interfacial forces inside.
Micro-gravity Attributes

Bond Number = \[ \frac{"gravitational" \hspace{1pt} body \hspace{1pt} force}{surface \hspace{1pt} force} \rightarrow 0 \]

Interfacial Forces Dominate in \( \mu g \)

Interfacial Curvature \( (K = 1/R) \) Gradient is Less in Large \( (R) \) Systems [i.e. more flow]; Simpler system without natural convection.
Use of pressure gradient due to interfacial forces that control fluid flow is optimized in μg

[ capillarity ($\sigma K$) for all thicknesses + disjoining pressure ($A/\delta^n$) for thickness < 100 nm ]

\[
(P_l - P_v)' = K + \frac{A}{\delta^n}
\]

Reflectivity profile gives liquid film thickness profile & pressure gradient in liquid
Objectives

• Basic *science* study of transport processes due to interfacial phenomena.

• Basic *engineering* study of the CVB extended surface fin ("wickless heat pipe") for cooling hot surfaces.

• Generic study of phase-change heat transfer processes in a non-isothermal *constrained vapor bubble sub-system*.
Recorded Multi-Scale Data

The macroscopic view – flow and heat transfer in the axial direction
Dimensions ~ mm

The microscopic view – interfacial phenomenon at the contact line
Dimensions ~ μm

Engineering (10x) Scale

Axial Corner Curvature Gradient

Science (50x) Scale
RECORDED EXTENSIVE DATA

- **(MACRO) Temperature field** from thermocouples gives information on the details of heat transfer.
- **(MACRO) Vapor pressure** data gives vapor purity and temperature.
- **(MACRO) Surveillance video** gives bubble location, stability, boiling.
- **(MICRO) Liquid film thickness profile** from microscopic reflectivity gives local pressure gradient for fluid flow.
- **(MICRO) Transient Reflectivity Profile** from video camera on microscope gives transient data on microscopic details of pressure gradient and fluid flow.

**WHICH SCALE DO WE ANALYZE FIRST?**
Surveillance Camera Images: MACROSCOPIC VIEW

Isothermal
- Symmetric Bubble
- Curvature Gradient

Isothermal
- Non-Symmetric
- Heated End
- Evaporating Meniscus
- Fluid Flow in Meniscus & Condensation

Liquid at top
Thermo-couples
Surveillance Camera Image:
40 mm higher flux

Visual Observations Support Experimental Heat Transfer Results Based on the Temperature Profile
Note: Excess fluid at hot end.
0.2 W  30 mm Cell – μg at **10x**

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Evaporation  Condensation

Corner meniscus

Film on flat side surface

**FRINGES SHOW THE DETAILS OF MANY DIFFERENT LOCAL ZONES**

? HOW AND WHERE TO MODEL FIRST?
ENGINEERING SCALE DATA

(SIMPLE 1D MODEL EASIER TO ANALYZE WHICH GIVES OVERALL VIEW OF TRANSPORT PROCESSES)
SIMPLE ONE DIMENSIONAL HEAT BALANCE

\[ q_{in\Delta x} = \square k A_c \left( \frac{d^2 T}{dx^2} \right) + P_o \square\square\left( T^4 \square T_{\square}^4 \right) \]

MEASUREMENTS: TEMPERATURE DATA GIVES OUTSIDE HEAT TRANSFER RATE PER UNIT LENGTH & CONDUCTION GRADIENT IN WALL

1 UNKNOWN: \( q_{in\Delta x} \), LOCAL INSIDE HEAT TRANSFER RATE PER UNIT LENGTH INCLUDES RADIATION & PHASE CHANGE
TEMPERATURE GIVES OBVIOUS CHANGE IN AXIAL CONDUCTION GRADIENT PER UNIT LENGTH, EXTERNAL RADIATION AND INSIDE HEAT TRANSFER
Inside heat transfer per unit length for 2 W in $\mu$g. Only radiation present on inside and outside for the dry case. Net inside radiation field is thereby known.
Conclusions from μg

- Using temperature data, zones in the CVB and local heat transfer fluxes were determined.
- Phenomena in μg are very different –
  - because of low effective gravity, there is more fluid flow.
  - because of no natural convection, there is a change in the heat transfer profile.
- Surface of the CVB runs “hotter” in space due to lack of convective cooling.
- Macroscopic model shows expected trend – enhanced liquid flow and heat transfer coefficient for evaporative heat transfer.
- More microscopic models describing the details of the transport processes and stability are being evaluated.
- Visual Observation are Essential for Understanding.
- Loop Configuration Design Using the CVB Concept is Anticipated.
Acknowledgements
A Team Effort

- Astronauts Connected CVB and LMM Modules, and Fluids Integrated Rack
- NASA Glenn Coordinated Study (Fred Kohl, Brian Motil, David Chao, Ronald Sicker)
- Zin Tech Constructed Equipment (Tibor Lorik, Louis Chestney, John Eustace, Raymond Margie, John Zoldak)
- Arya Chatterjee, Akshay Kundan (Graduate Students)
- Prof. Joel L. Plawsky (CoPI) Co-directed Program
- NASA Provided Financial Support
- Prof. Peter Wayner (PI) Co-directed Program
References

