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

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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" body force}{surface force} \rightarrow 0

Interfacial Forces Dominate in \mu g

\frac{dK}{dx} = \frac{U}{R^2} = \text{Capillary Number}

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 (σK) for all thicknesses + disjoining pressure (A/δ^n) for thickness < 100 nm]

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

VISUAL

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**
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
  - g
  - Non-Symmetric
- Isothermal
  - g
  - Symmetric Bubble
- Heated
  - g
  - Curvature Gradient

Liquid at top
Heated end
Evaporating Meniscus
Fluid Flow in Meniscus & Condensation
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 – \( \mu g \) at \( 10x \)

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

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

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 \( \mu g \)

- Using temperature data, zones in the CVB and local heat transfer fluxes were determined.

- Phenomena in \( \mu g \) 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.
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References

