CONJUGATE HEAT TRANSFER MEASUREMENTS IN A SINGLE-SIDE HEATED CIRCULAR FLOW CHANNEL UNDER TURBULENT, SUBCOOLED FLOW BOILING CONDITIONS

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ABSTRACT

High Heat flux removal (HHFR) from plasma-facing components and electronic heat sinks involves conjugate heat transfer analysis of the applicable substrate and flowing fluid. The present conjugate measurements include both three-D developing turbulent flow and subcooled water flow boiling. The results form a 3-D conjugate data set which includes all of the above noted complexity and provides a basis for increased understanding of this conjugate heat transfer phenomena. The recommended approach for quasi-steady-state identification included steady local wall temperature selection before subsequent changes in the heat flux.

INTRODUCTION

The optimized design of single-side heated (SSH) plasma-facing components (PFC) and electronic heat sinks (EHS) is dependent on using conjugate heat transfer to find the local distribution of inside wall heat flux in the flow channels of the cooling substrate of the component or heat sink. The local inside wall heat flux can be obtain from selectively chosen local PFC wall temperatures close to the inside boundary of the flow channel. To this end, three-dimensional thermal measurements for a one-side heated cylindrical-like test section were made.

TEST SECTION (TS)

- The TS was fabricated from Type AL-15 Glidcop Grade Copper.
- Cylindrical-like test section with half (-90 to +90 degrees) of its outside boundary was subjected to a uniform heat flux and the remaining half insulated.
- The outside diameter and length of the test section were 30.0 mm and 200.0 mm, respectively.
- The actual directly heated length (L) was 180.0 mm.
- The inside diameter of the flow channel was 10.0 mm.

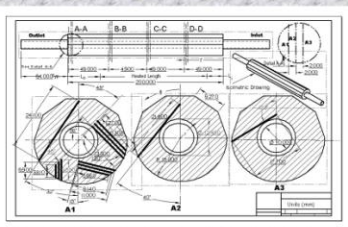

Figure 1. Test Section used for Local Temperature and Heat Transfer Measurements. Water Flows Through the 10.0 mm Diameter Channel. The Thermocouple Wells are the Solid Black Lines with Specified Lengths and Angles. The Outer Concentric Annulus (the 10.0 mm Inner Diameter Channel Thread into Aluminum Block) Is Not Shown. Insulation Has Been Added to Show the Outside Diameter of the Channel Where the Internal Bore Ends. Note: 4 +/- degrees, the single TC shown in plane A3 should be resolved with the corresponding TC in plane A1.

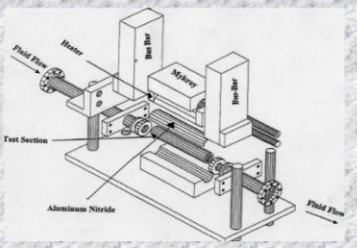

Figure 2. High Heat Flux Test Section Conceptual Assembly. The Actual Test Section has Five Parts of Bus Bar Connecting to Two Heater Segments.

THERMOCOUPLE PLACEMENT

- Shown in Fig. 1 are four axial stations labeled A-A, B-B, C-C, and D-D, which are axial locations where thermocouple (TC) wells exist for local in-depth wall temperature measurements.
- Typical TCs at station A-A result in both radial and circumferential distributions of the local wall temperature.
- Hence, combination of all axial stations will produce a three-dimensional distribution of the TS local wall temperature as a function of the applied heat flux.

TEST CONDITIONS

- Water was the coolant.
- Thermocouples were placed at forty-eight test section locations.
- The mass velocity, exit pressure, and inlet water temperature used for the present case were 0.59 Mg m^{2}s, 0.207 MPa (T_{sat} = 121.3 ^{0}C) and near 26.0 ^{0}C, respectively.
- The basic fluid flow is a turbulent (Re = 6,900) and highly developing flow with a reciprocal Graetz number (Gz^{-1}) of 4.5 x 10^{-4}.

RESULTS

Conjugate heat transfer analysis of complex geometries and boundary conditions is highly dependent on having two- and three-dimensional data which show the relationship between the local channel wall temperatures and the SSH channel heat flux. Examples of such data is presented and provide a unique turbulent, developing flow boiling data base for single-side heated flow channels which can be used for comparisons with future computational fluid dynamic and heat transfer predictions.

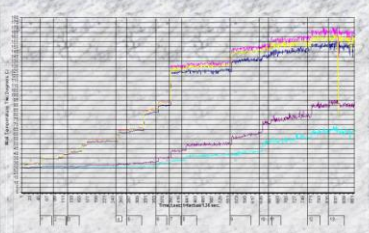

Figure 3. Experimental History: (1) Local Wall Temperature (top two curves), and, (2) Inlet and Outlet Water Temperatures (bottom two curves).

DEFINITON OF QUASI-STEADY STATES

- Fig. 3 shows typical TS wall temperature history measurements (top and second curve from the top) at 0.0 degrees and an axial coordinate of 145.1 mm (and radial coordinates of 9.08 and 8.06 mm, respectively).
- Alternative definition: inspection of extrema in a plot of net incident heat flux versus the local TS wall temperature.

OUTSIDE NET HEAT FLUX/WALL TEMPERATURE

Results are presented which show the relationship, at different radii, between the outside net heat flux ($q_{o,n}$) and the local wall temperature (T_w). Although not identical, this relationship between q_o and T_w would be directly related to the 2-D local boiling curve if the radius at which this relationship was considered was equal to the inside radius of the flow channel. This work will eventually lead to the latter. The relationship between the steady state, net incident outside wall heat flux and the locally measured test section wall temperature is presented in Fig. 4.

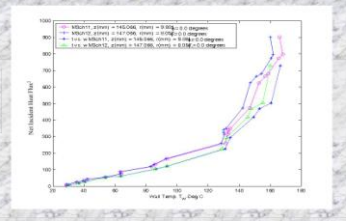

Figure 4. Net, Outside, Single-Side Heat Flux as a Function of the Local Temperature.

OBSERVATIONS

- An apparent excursion occurred as the heat flux was increased above the highest level shown by the curves represented by the dotted lines in Fig. 4.
- As the heat flux was increased, a loud hammer-like sound began.
- The normal temperature escalation, which accompanies CHF in uniformly heated tubes, was absent due to the three-dimensional conjugate heat transfer effects.

CONCLUSIONS

A first HHFR measurement step has been completed for a SSH circular TS in that 3-D data has been produced which describes the relationship between the net outside heat flux and the local wall flow channel temperature. The data include all of the above noted conjugate heat transfer complexity, namely--highly developing axial turbulent flow of a fluid (water) with phase changes radically, axially, and circumferentially.

FUTURE WORK

The results form the basis for:

- The examination of inside flow channel heat flux and heat transfer coefficient distributions;
- Future computational fluid dynamic and conjugate heat transfer comparisons; and
- The assessment and comparison of existing subcooled boiling curve (BC) correlations with two-dimensional boiling curves, after the data has been transformed to BC-Form.

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