
Experimental Verification of Gas-Cooled T-Tube Divertor Performance

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Overview

- **2D and 3D analyses have been performed to assess the thermal performance of helium-cooled T-Tube divertors.**
- **Numerical results indicate that:**
 - Heat fluxes up to 10 MW/m² can be accommodated
 - Design is “robust” with respect to manufacturing tolerances, and/or mal-distribution of flow
 - Extremely high heat transfer coefficients (> 40 kW/m² K) are predicted near the stagnation point. These values are “outside the experience base” for gas-cooled engineering systems

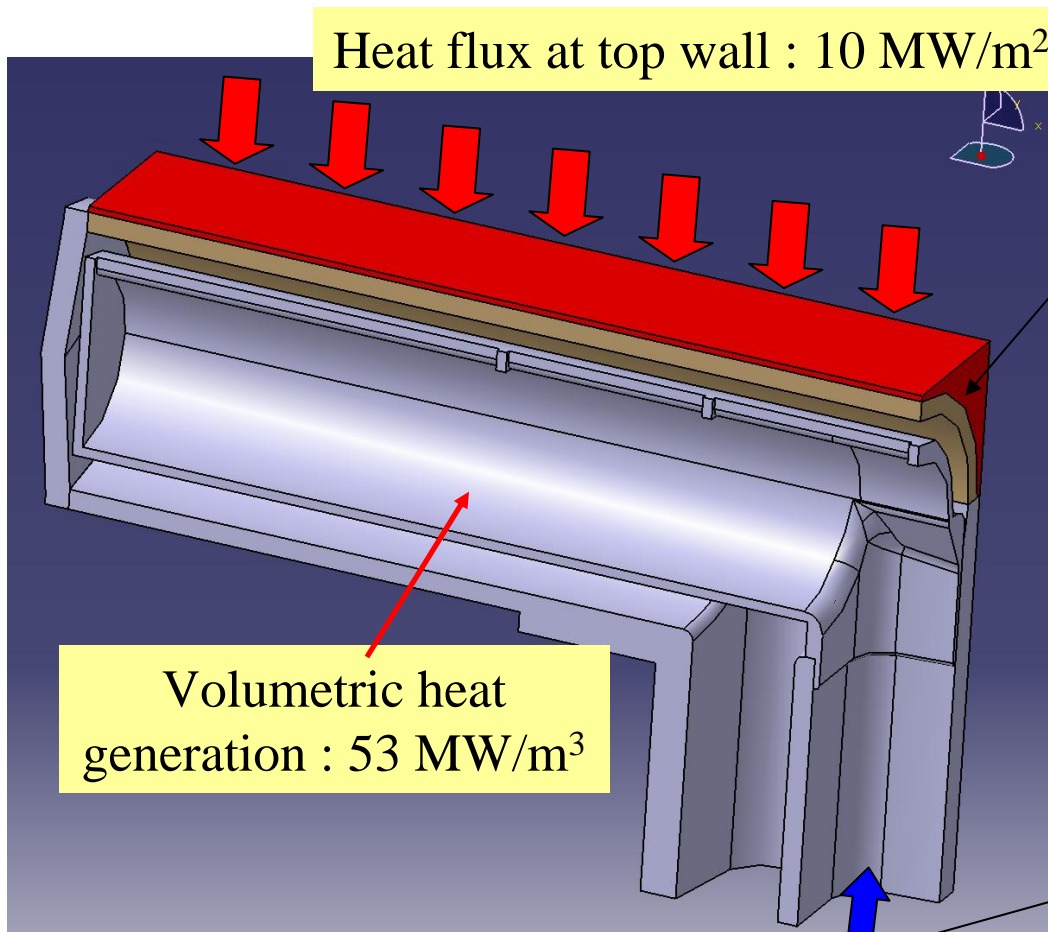


Objectives

- Design, construct, and instrument a test module which closely simulates the thermal-hydraulic behavior of the proposed helium-cooled T-Tube divertor
- Experimentally measure the axial and azimuthal variations of the local heat transfer coefficient in the test module over a wide range of operating conditions
- Perform “*a priori*” calculations to predict the wall temperature distribution and heat transfer coefficients for the test module using the same methodology used to analyze the actual T-Tube divertor performance
- Compare the measured heat transfer coefficients with predicted values
- Develop an experimentally-validated correlation for the local Nusselt Number for use in future design analyses of similarly-configured gas-cooled components



T-Tube Divertor Geometry



Heat flux at top wall : 10 MW/m²

Volumetric heat generation : 53 MW/m³

TUNGSTEN

Density : $\rho=19,254$ [kg/m³]

Conductivity :

$$k=115-0.012\times T$$
 [W/m·K]

Specific heat : $c_p=138$ [J/kg·K]

HELIUM

Mass flow rate : 8.5 g/s (= 0.2 kg/s.m)

Density : perfect gas law

Conductivity :

$$k=0.056+0.00031\times T$$
 [W/m·K]

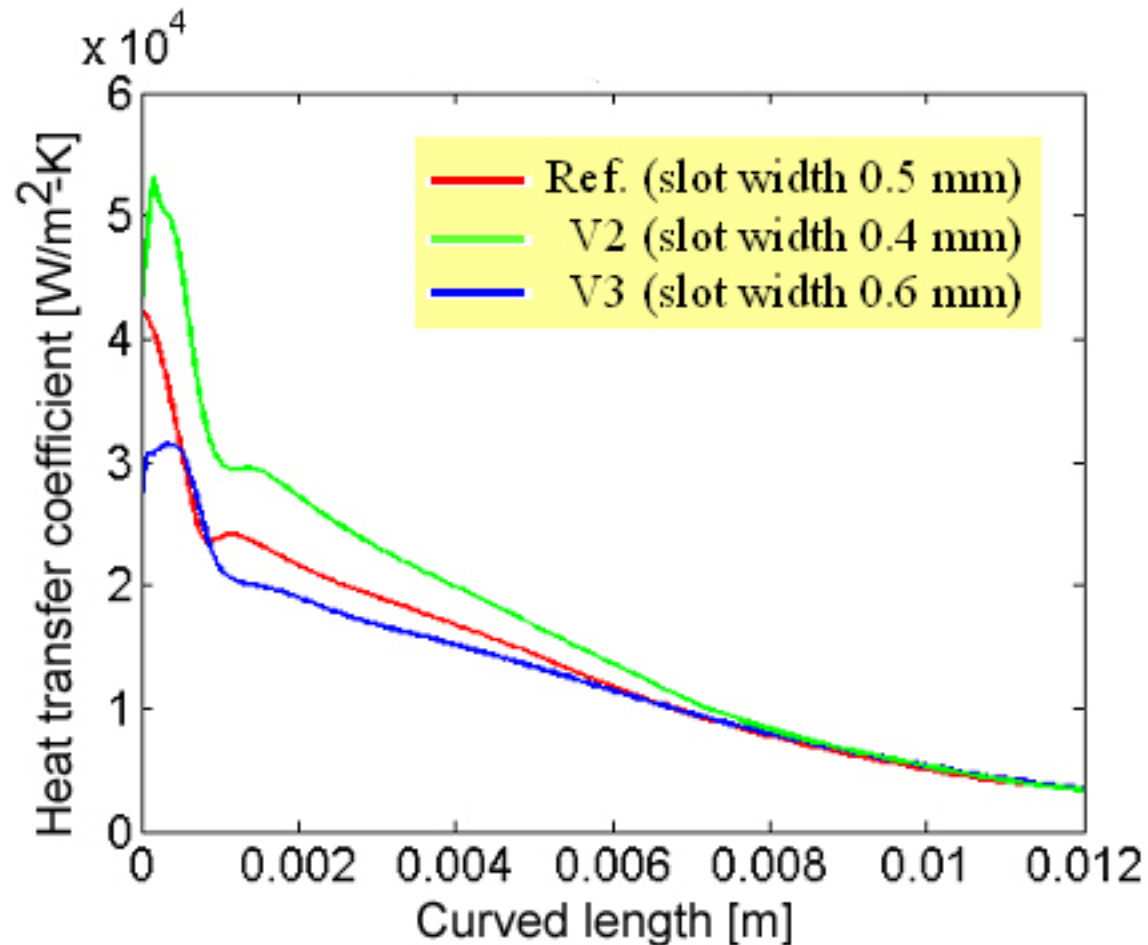
Specific heat : $c_p=5,193$ [J/kg·K]

Viscosity :

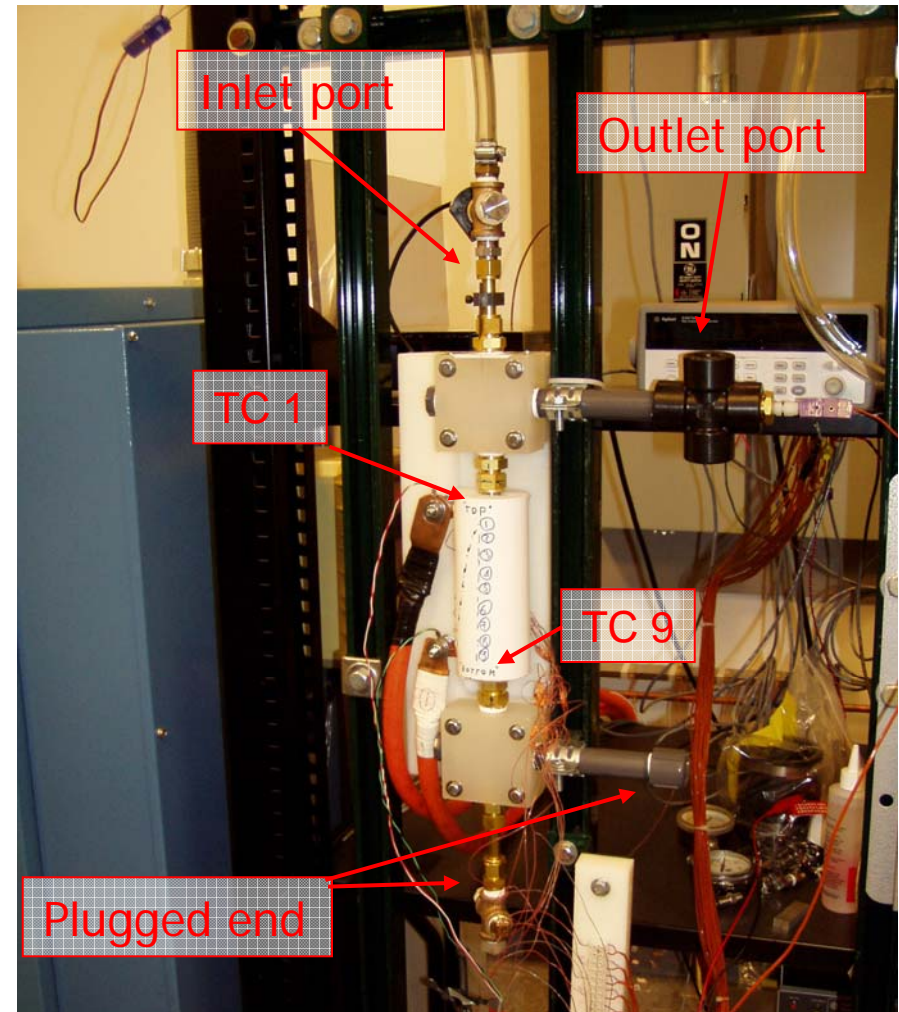
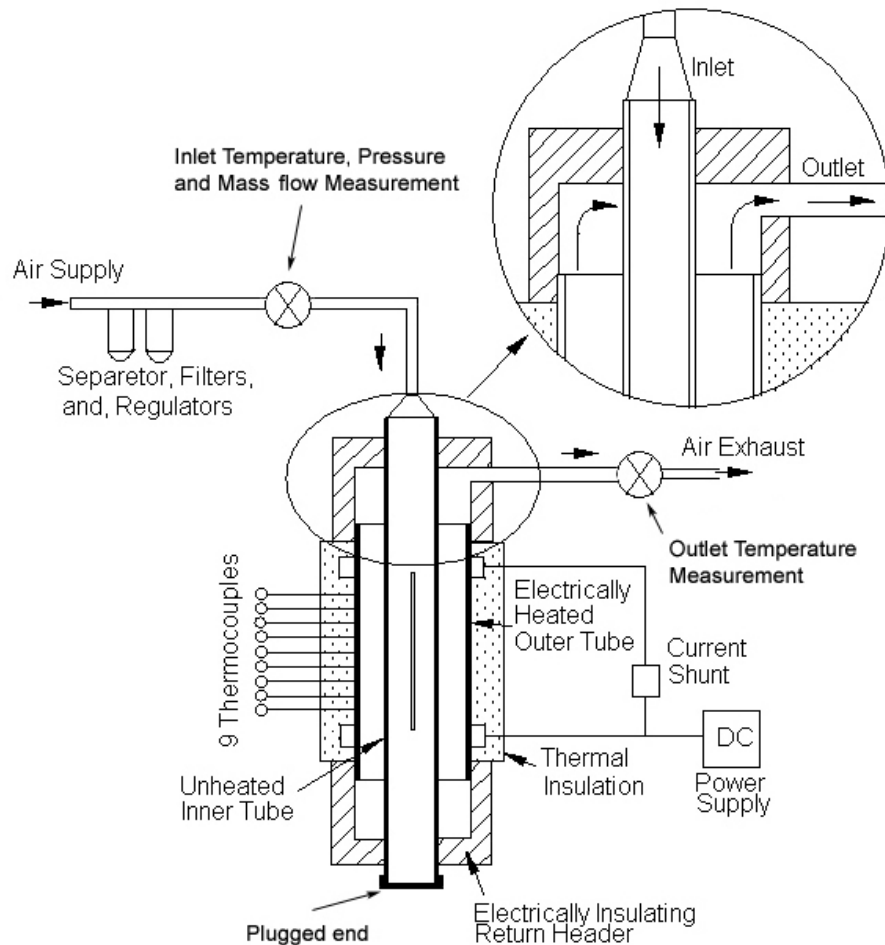
$$\mu=4.5\times 10^{-7}(T)^{0.67}$$
 [Pa·s]



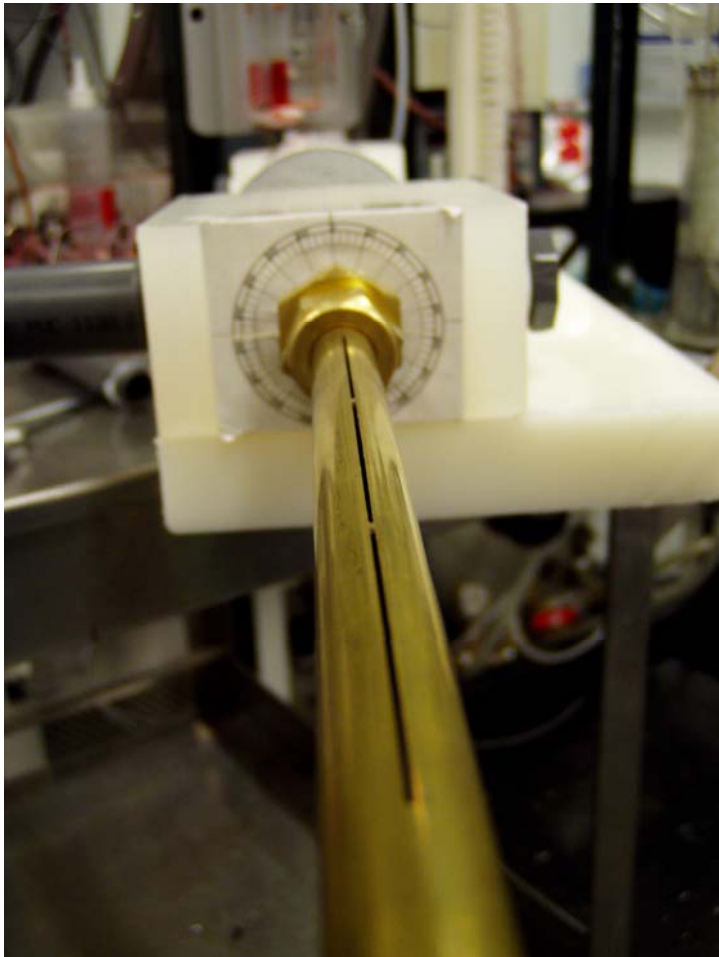
Calculated Heat transfer Coefficients (2D)



Experimental Flow Loop



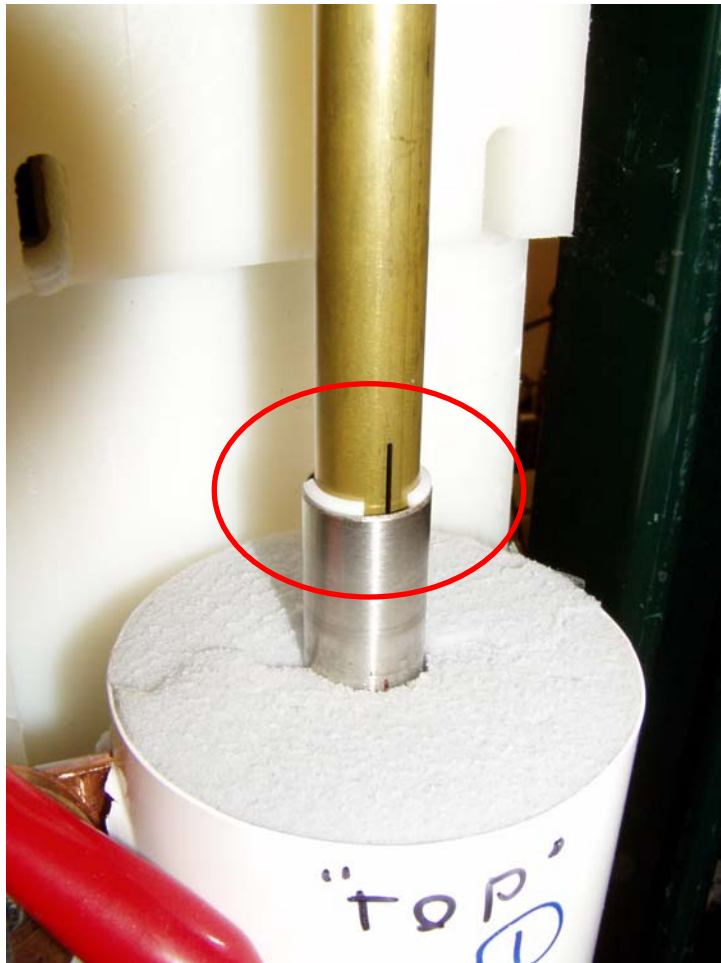
Slit Close-up



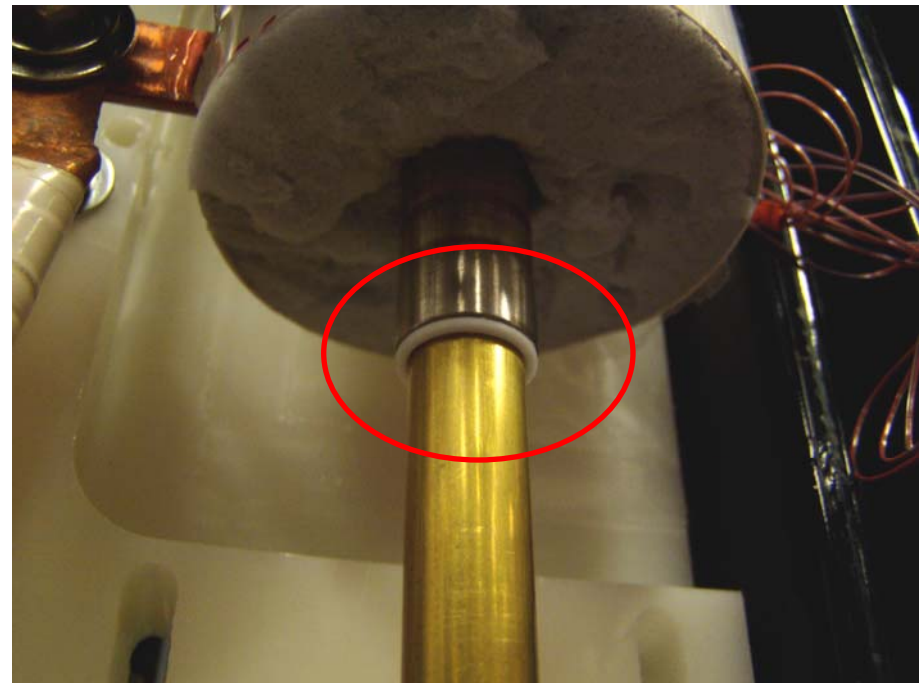
- Addition of two 1.2 mm wide “bridges” to preserve slit width uniformity after machining



Centering the tubes



- Addition of teflon ring on plugged end and teflon ring sectors on the discharge end to maintain concentricity of inner and outer tubes



Thermal-Hydraulic parameters

- Experimental parameter ranges selected to match the non-dimensional parameters for the proposed helium-cooled T-Tube divertor.

Parameter	Air (low pressure)	Air (high pressure)	Helium
Operating Pressure	101 kPa	689 kPa	10 MPa
Pressure Drop	22 kPa	68.9 kPa	0.1 MPa
Inlet Temp.	20° C	20° C	600° C
<i>Re</i>	2900	15600	10100
<i>Pr</i>	0.71	0.71	0.66

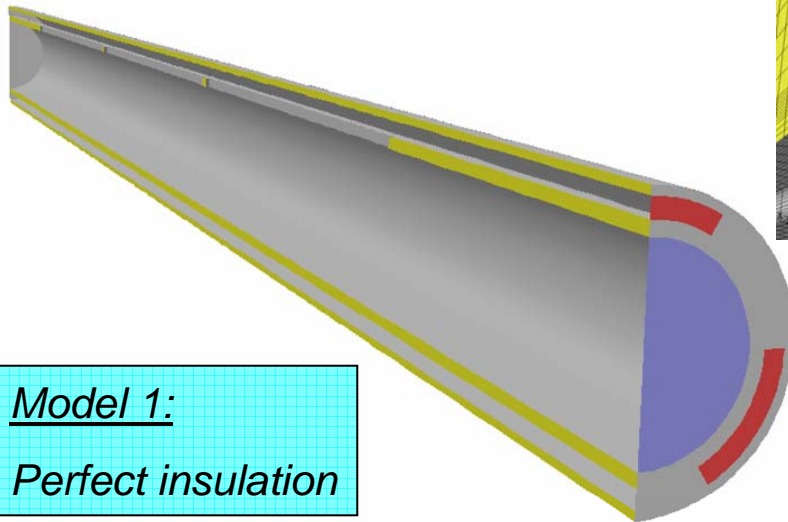


Predicted Performance - 3D Simulation

- FLUENT 6.2, Steady, turbulent (RNG k- ϵ) model with standard wall functions
- Grid size: 811,083 hexahedral/mixed cells (722,815 nodes)
- One symmetry plane
- Initial “coarse” mesh used
- Grid resolution studies will be conducted

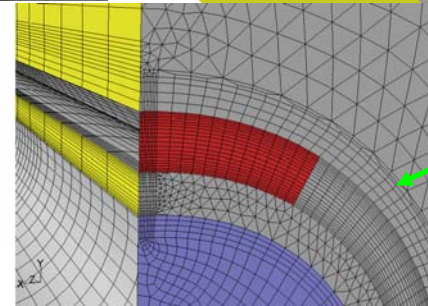
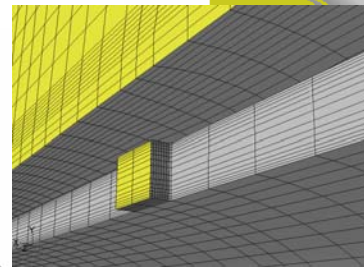
Model 2:

Insulation included with free convection on outer surface

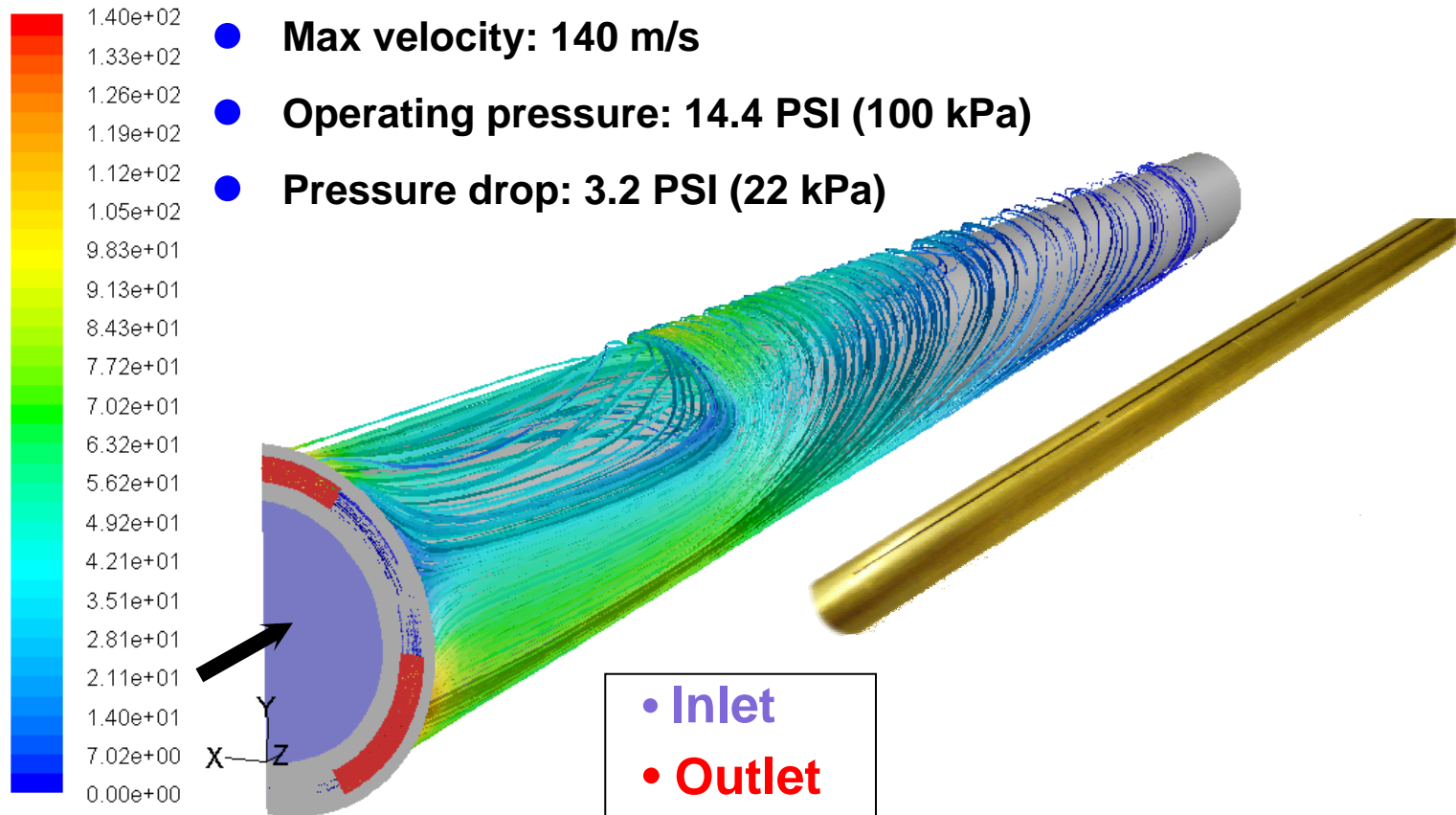


Model 1:

Perfect insulation



Predicted Performance – Flow field

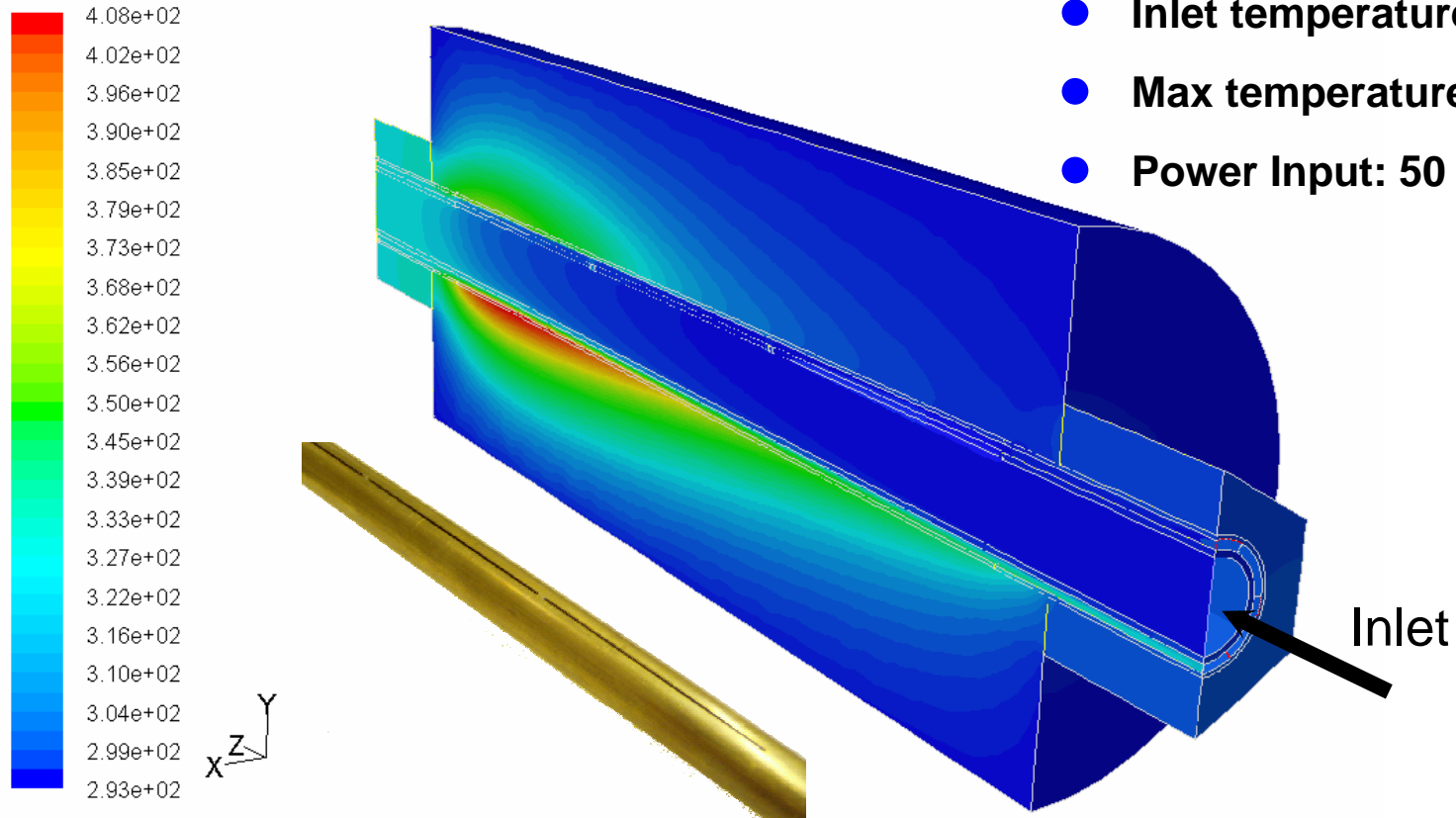


Path Lines Colored by Velocity Magnitude (m/s)

Apr 17, 2006
FLUENT 6.2 (3d, segregated, rngke)



Predicted Performance – Temperature

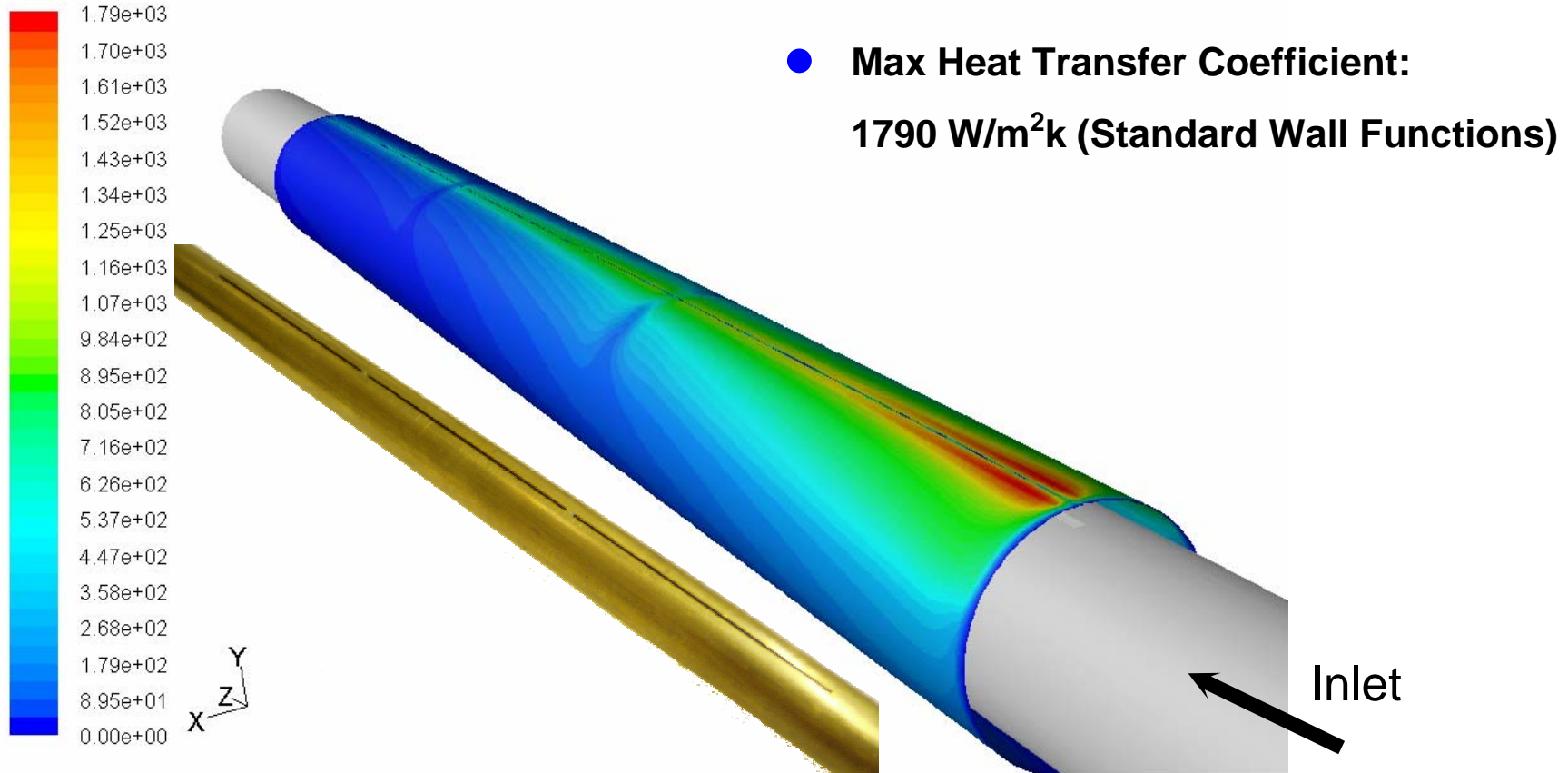


Contours of Static Temperature (k)

Apr 17, 2006
FLUENT 6.2 (3d, segregated, rngke)



Predicted Performance – Heat Transfer



Contours of Surface Heat Transfer Coef. (w/m2-k)

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FLUENT 6.2 (3d, segregated, rngke)

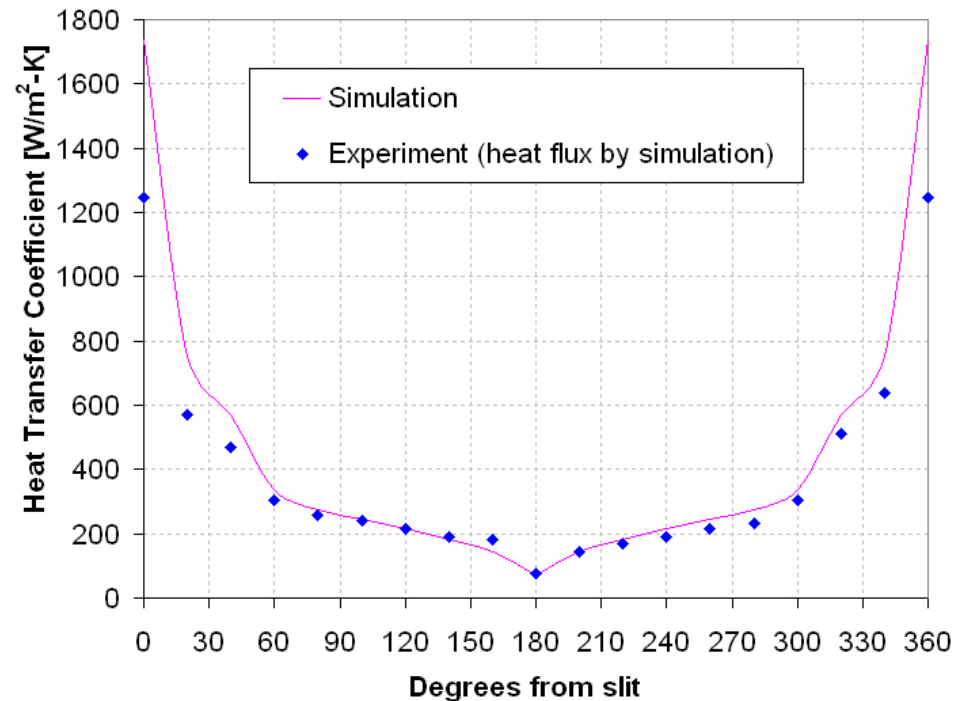
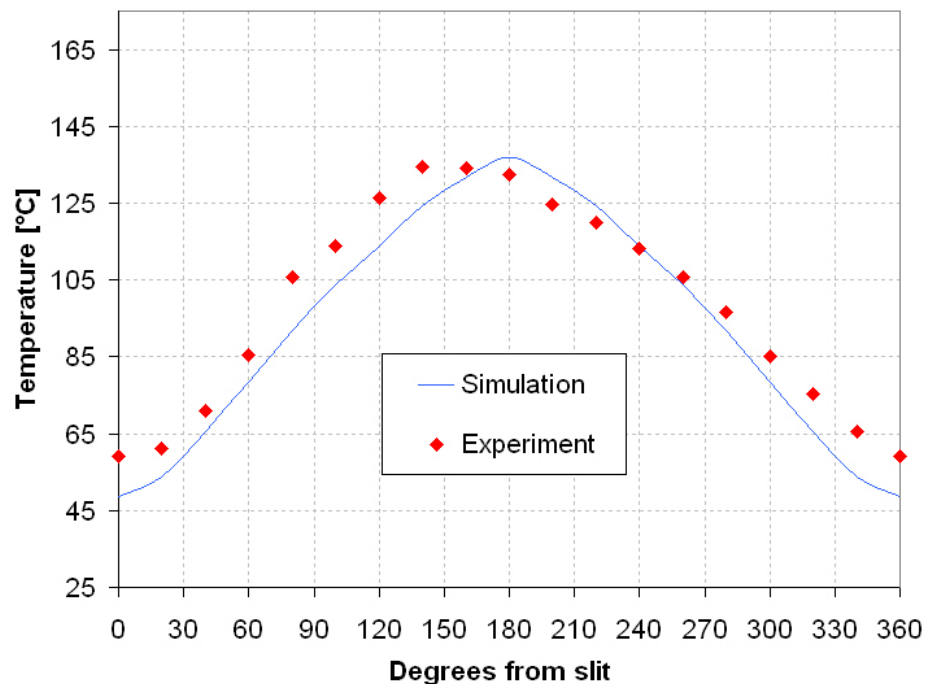


Experimental Results (two inlets)

Temperature & Heat Transfer Coefficient

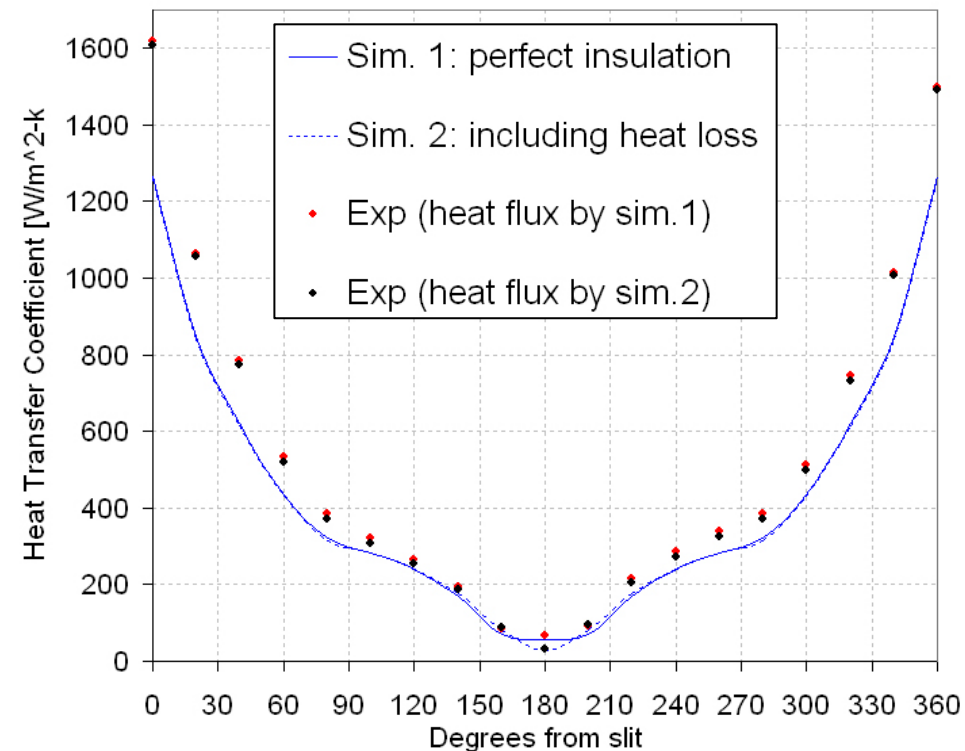
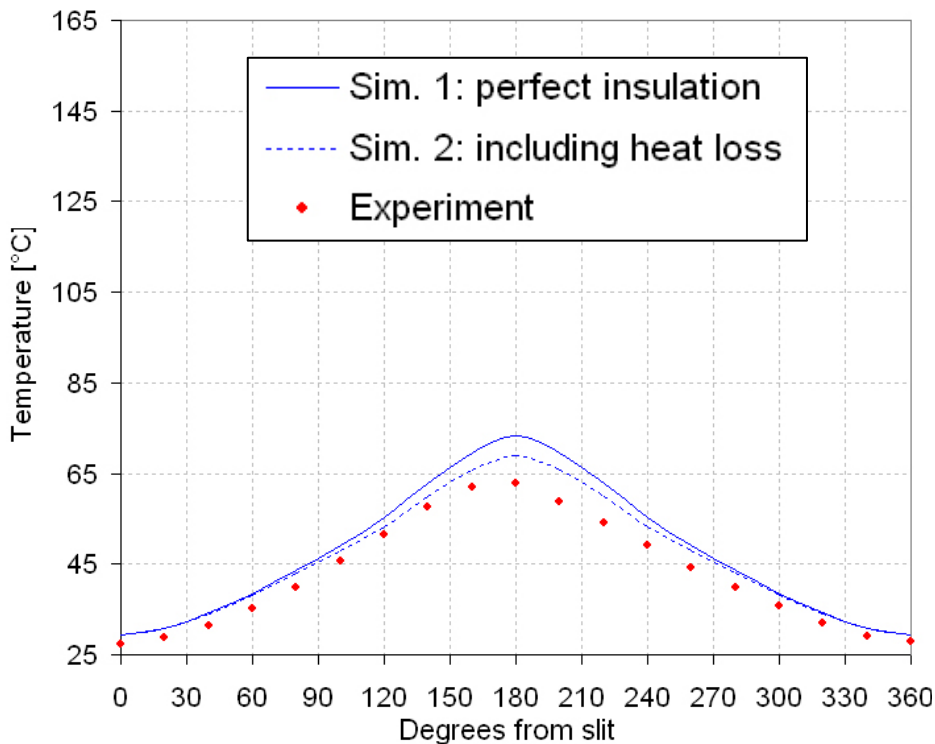
- Initial experiments with two inlets were affected by slit geometry, tube concentricity, and garolite tube deformation, resulting in non-symmetric profiles

Location 1



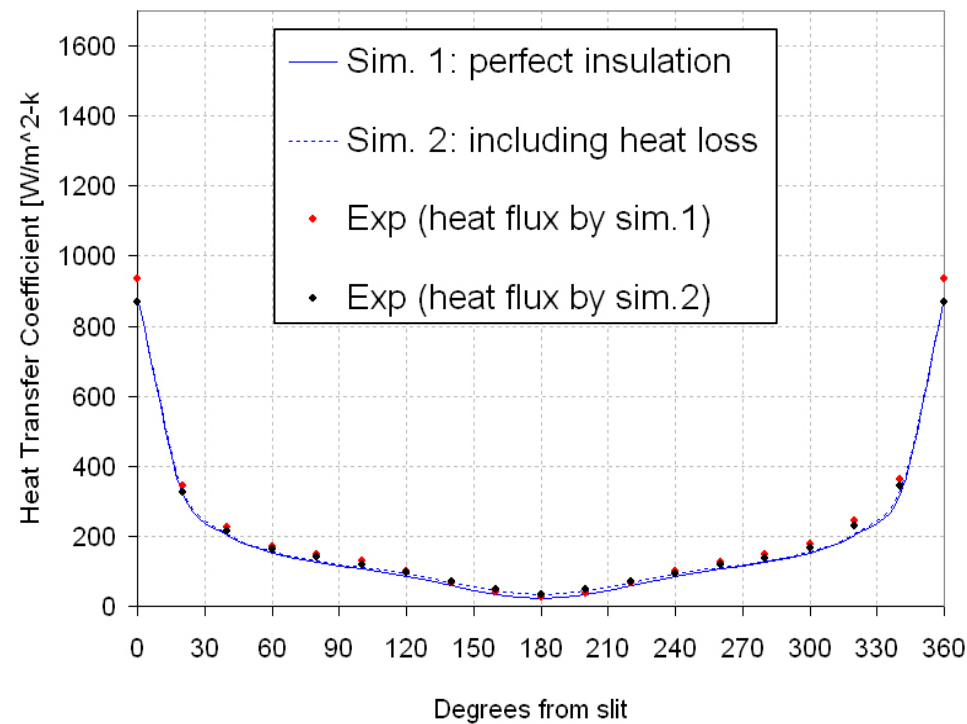
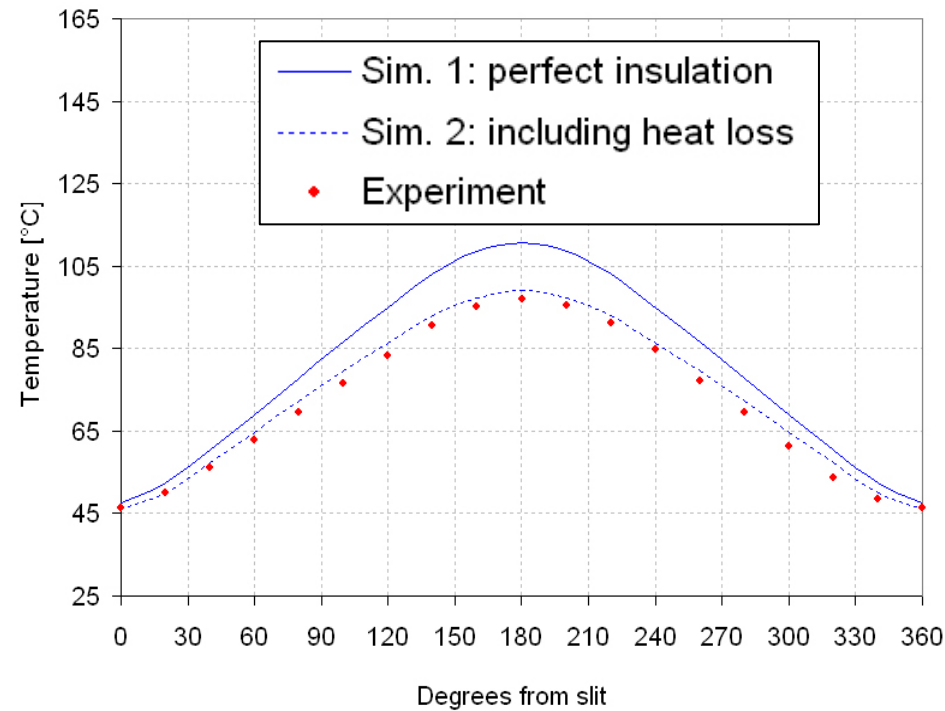
Experimental Results (single inlet): Temperature & Heat Transfer Coefficient

Location 1



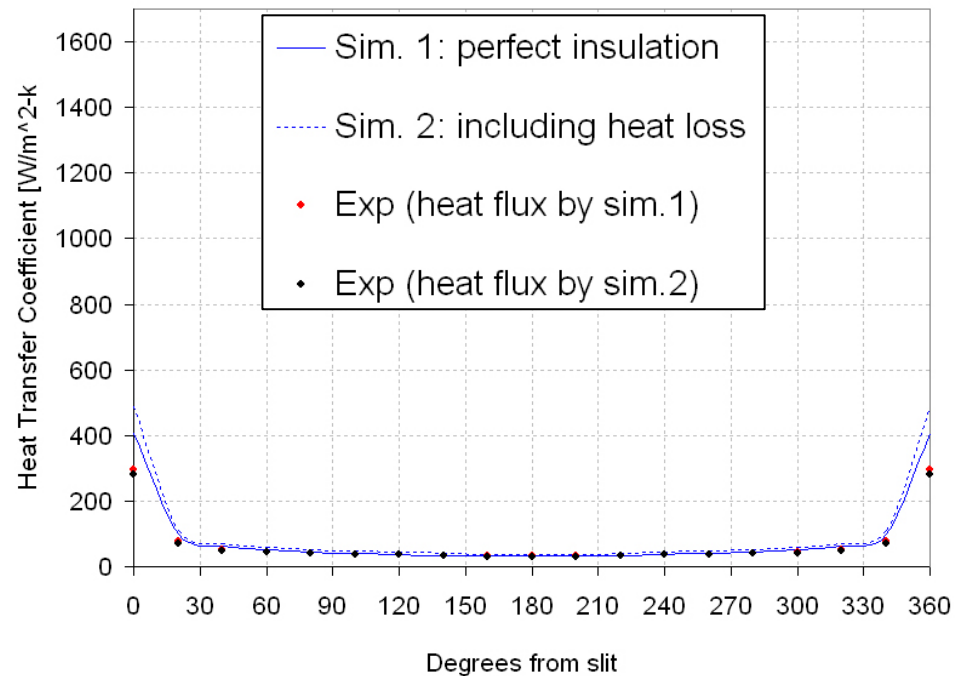
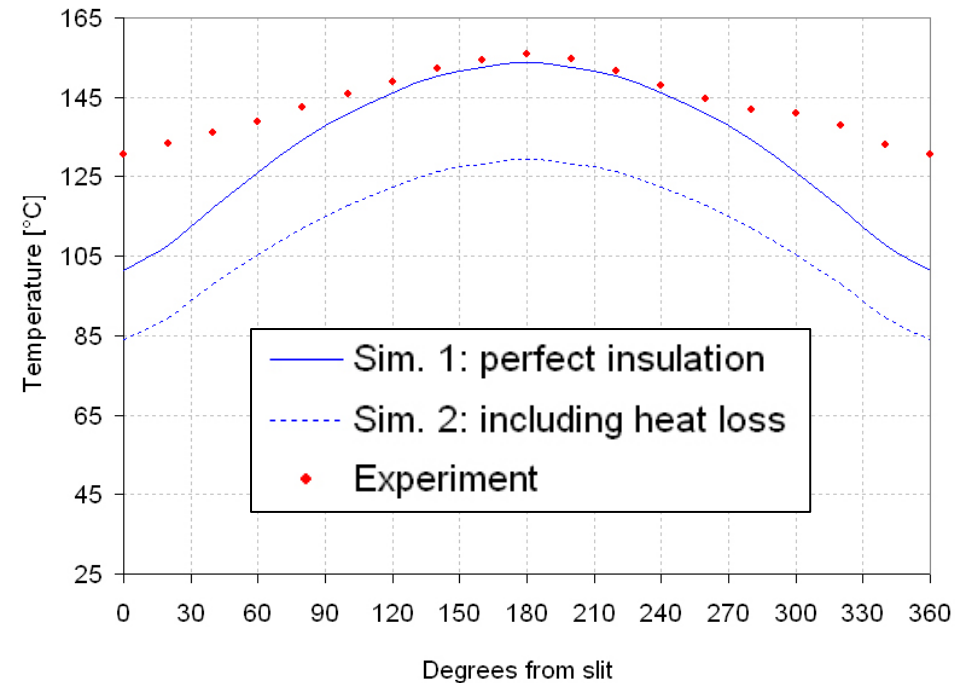
Experimental Results (single inlet): Temperature & Heat Transfer Coefficient

Location 5



Experimental Results (single inlet): Temperature & Heat Transfer Coefficient

Location 9



Summary

- **Issues associated with geometric variations of test section (slit uniformity and tube concentricity) have been successfully resolved**
- **Initial results for temperature distribution and local heat transfer coefficient show reasonably good agreement between experimental data and model predictions**



The Path Forward

- **Experiments will be conducted for different gas flow rates, exit pressures, and power input levels.**
 - **Test conditions will be selected to span the expected non-dimensional parameter ranges for the proposed helium-cooled T-Tube divertor**
 - **Data for axial and azimuthal variations of the heat transfer coefficient will be obtained for single and double inlet conditions**
 - **Test section will be modified to achieve desired conditions (i.e. uniform wall heating)**

