Design Curves for the Plate Divertor and Status of the GT Helium Test Facility

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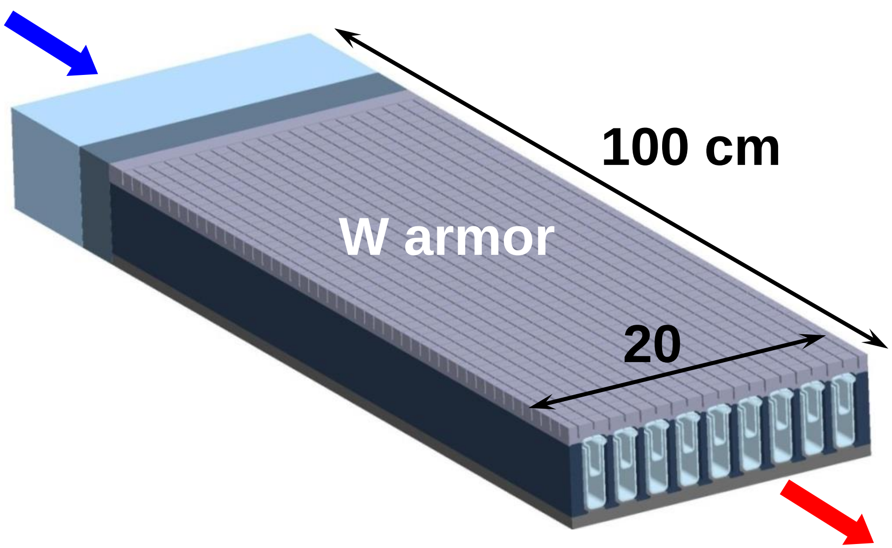
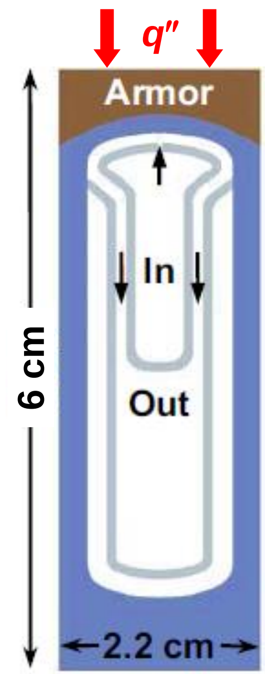
Outline

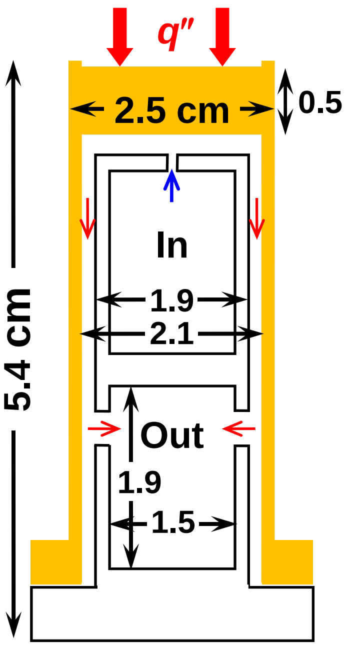
- Thermal performance of helium-cooled flat-plate (HCFP) divertor
  - Estimate maximum heat flux that can be accommodated by divertor $q''_{\max}$ and coolant pumping power requirements as a fraction of incident thermal power β
  - Provide design guidance and develop correlations that can be used in system codes: $q''_{\max}(Re)$ and $\beta(q''_{\max})$ subject to maximum temperature constraints due to materials considerations
- Initial results with tungsten-alloy HEMJ test section in GT helium loop
  - Inlet temperatures $T_i \leq 295$ °C, inlet pressures $p_i \approx 10$ MPa

Plate-Type Divertor

- Cools large areas: ~500 modules to cover the $O(100\ \mathrm{m}^2)$ divertor
  - Accommodates heat fluxes up to 10 MW/m^2 without exceeding $T_{max} \approx$ 1300 °C, $\tau_{max} \approx$ 400 MPa [Wang *et al.* 09]
  - Experiments on single HCFP module with air [Hageman *et al.* 11]



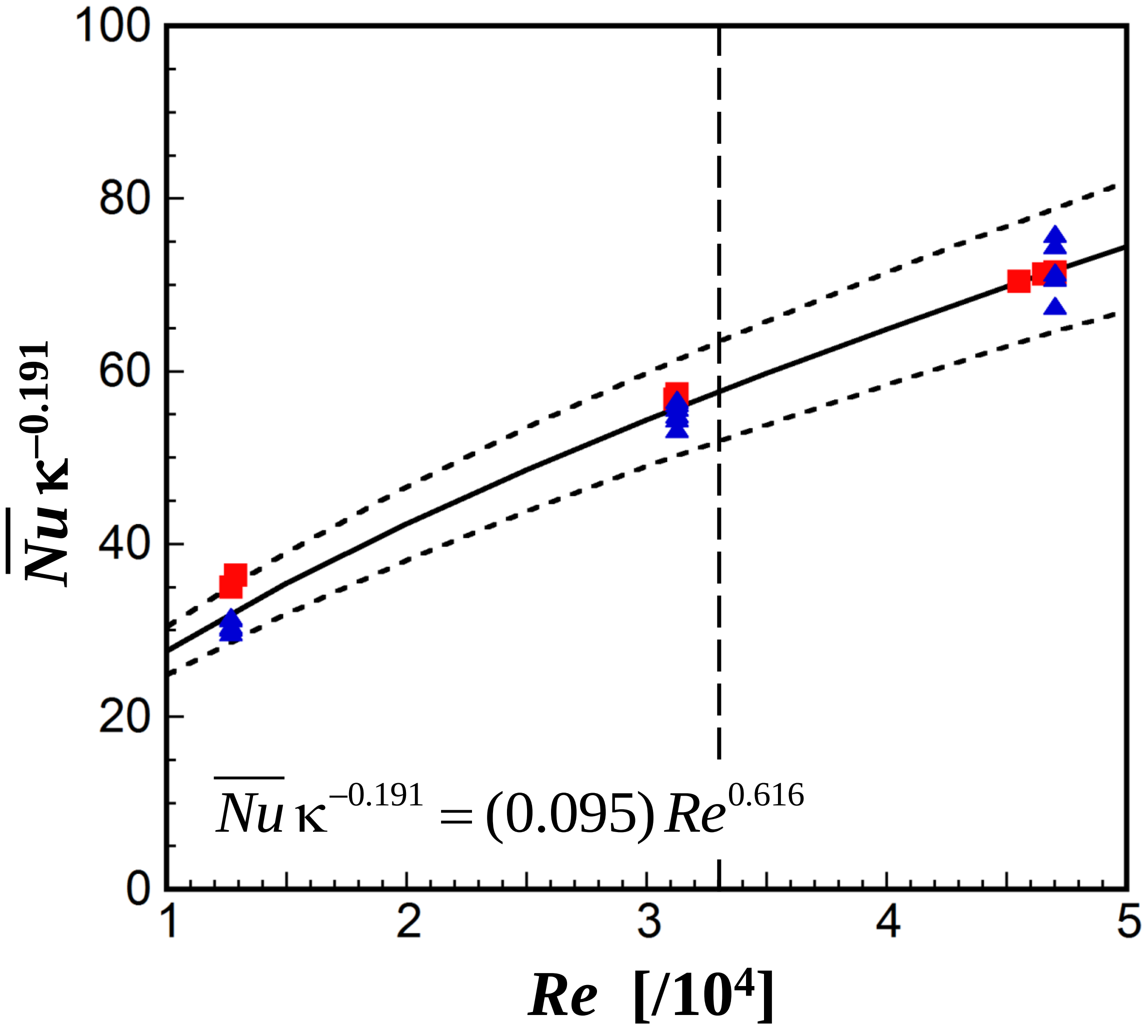




HCFP Studies

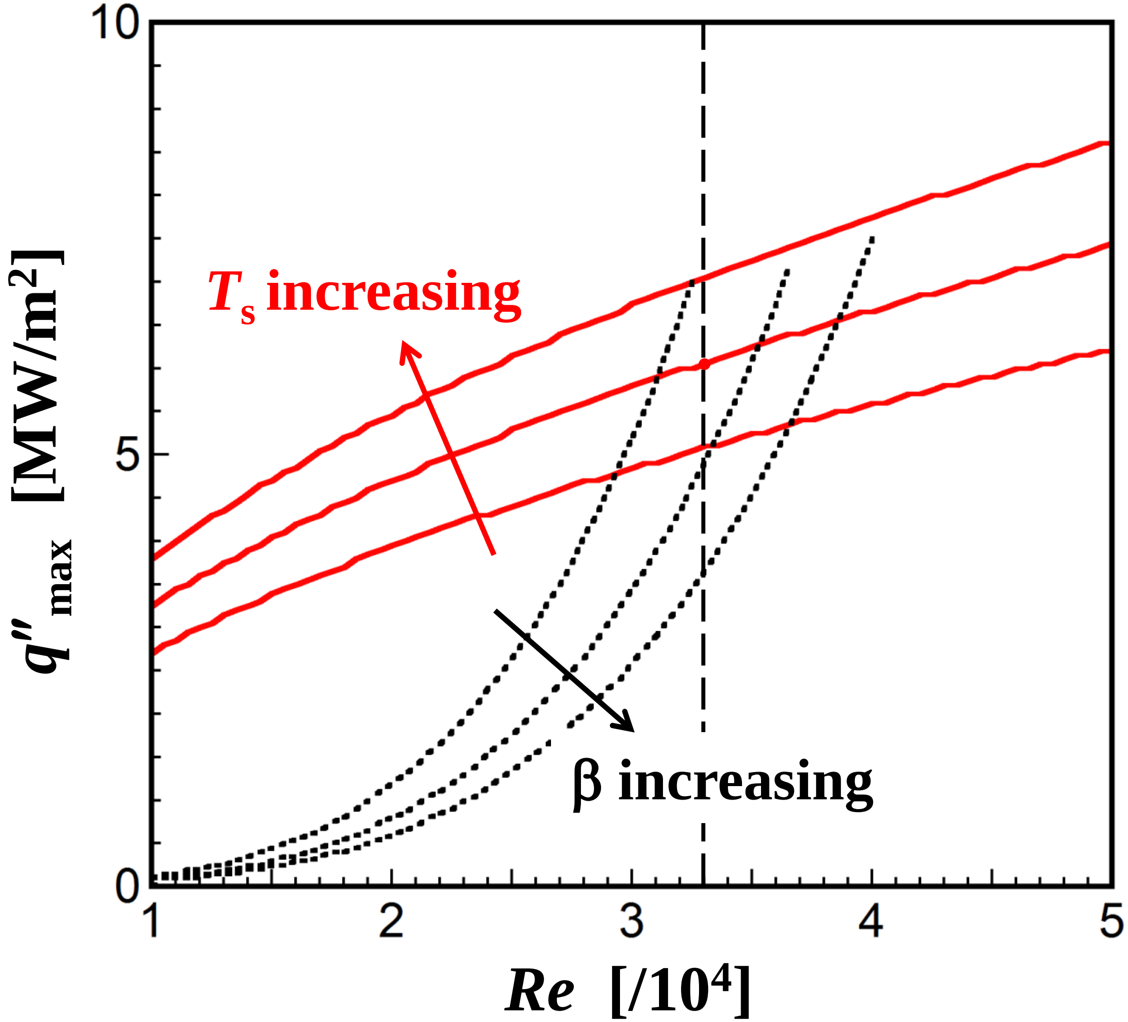
- Experimental data
  - Air with brass-alloy test section (thermal conductivity ratio $\kappa \equiv k_s / k \approx 5000$ at Reynolds numbers $Re \approx 1.2\times10^4$, 3.0×10^4, 4.5×10^4 (*vs*. prototypical $Re_p = 3.3\times10^4$): incident heat flux $q'' \leq 0.5$ MW/m^2
- Numerical simulations
  - Half-model with ~3×10^6 cells using ANSYS v14: realizable k-ε turbulence model with standard wall functions
  - Air, He cooling brass, steel test sections: $\kappa \approx 340$, 750, 7000 at same Re as the experiments: $q'' \leq 2.0$ MW/m^2
- Update design curves and correlations for plate-type divertor to include effect of κ

Nu Correlation



- Use multilinear regression to fit numerical predictions (▲) and experimental data (●) to power-law correlation
  - κ = 340–7000
  - Correlation within 10% of experimental and numerical data

Max. Heat Flux



- Maximum heat flux q''_{max} *vs.* Reynolds number *Re*
  - Max. avg. pressure boundary temperature T_s = 1100 °C, 1200 °C, 1300 °C
  - Pumping power β = 10%, 15%, 20% of incident thermal power
  - At $Re_p = 3.3\times10^4$, $q''_{max} = 6.1$ MW/m², β ≈ 12% for T_s = 1200 °C

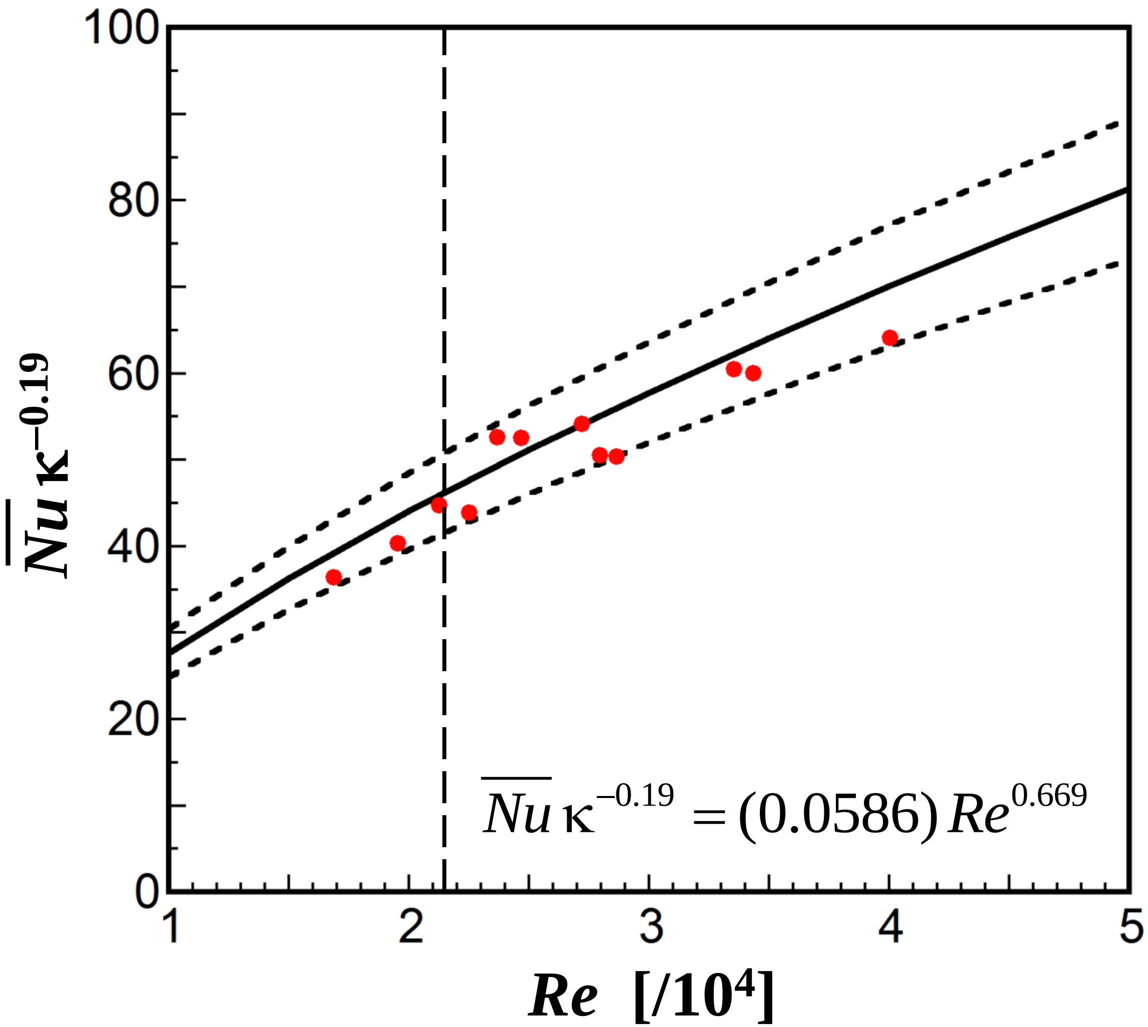
New HCFP Correlations

- For HCFP with 2D jet issuing from 2 mm slot, pumping power fraction as a function of q''_{max} [MW/m^2]
  - For T_s = 1100 °C: $\beta = (3.011\times10^{-4})\exp\{1.213\, q''_{max}\}$
  - For T_s = 1200 °C: $\beta = (2.427\times10^{-4})\exp\{1.022\, q''_{max}\}$
  - For T_s = 1300 °C: $\beta = (2.065\times10^{-4})\exp\{8.811\, q''_{max}\}$
  - At $Re = 2.3\times10^4$: $\beta = 0.192(q''_{max})^{-0.999} + 1.09\times10^{-3}$
  - At $Re_p = 3.3\times10^4$: $\beta = 0.716(q''_{max})^{-0.999} + 2.84\times10^{-3}$
  - At $Re = 4.3\times10^4$: $\beta = 1.904(q''_{max})^{-0.998} + 5.75\times10^{-3}$
- Future work
  - Obtain experimental data with air at more *Re* and different κ this summer using a 304 stainless-steel test section: $\kappa \approx 700$

HEMJ Experiments

- Evaluate thermal performance of helium-cooled divertor with multiple-jet cooling (HEMJ) at prototypical conditions
  - Test 97% W-2.1% Ni-0.9% Fe alloy (Densimet D185) test section in helium loop
  - Experiments at inlet temperatures $T_i \leq 295$ °C, inlet pressures $p_i = 10$ MPa for $Re \approx 1.7\times10^4 - 4\times10^4$ (*vs.* $Re_p = 2.14\times10^4$)
  - Incident heat fluxes $q'' \leq 2.2$ MW/m^2 with oxy-acetylene torch
  - No oxidation of W surface (at maximum temperatures $T_s > 700$ °C) observed: flowing argon around test section appears to successfully suppress oxidation

Nu Correlation: HEMJ



- Experimental data in good agreement with previous correlation based on data at non-prototypical materials
  - Assumes thermal conductivity of W-alloy k_s = 83 W/(m ·K) [for 20 °C – 500 °C]
  - Working with ORNL to measure k_s (T)

Future Work

- Continue studies of tungsten-alloy HEMJ test section
  - Increase T_i to ~400 °C and incident heat flux q''
- Study effect of varying gap between jet exit and cooled surface using finger-type divertor in GT helium loop
  - 1 mm, *vs*. 2 mm
- Further experimental verification of HCFP correlations