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Comparison of Measured and Analytical Performance of Shell-and-tube Heat Exchangers Cooling and Heating Supercritical Carbon Dioxide

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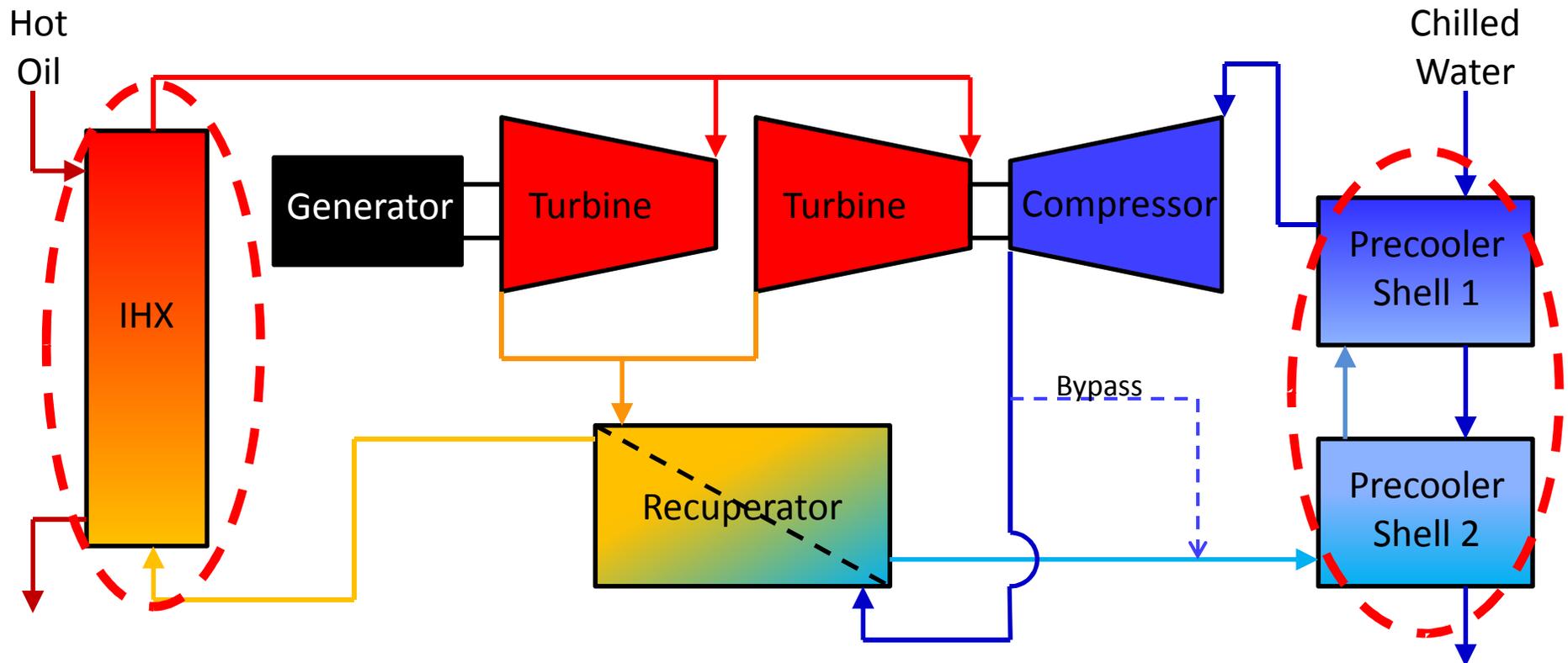
Purpose

- Evaluate whether commonly used design tools are applicable to Supercritical Carbon Dioxide (S-CO₂)
 - Conventional shell and tube heat exchangers are well understood
 - First operational data available with S-CO₂
 - Shell side and tube side
 - Heating and cooling applications



IST Overview

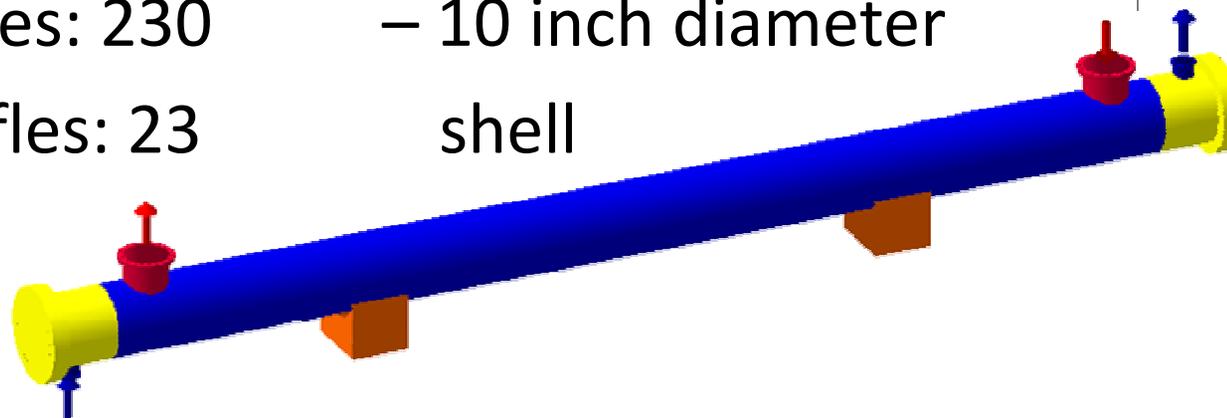
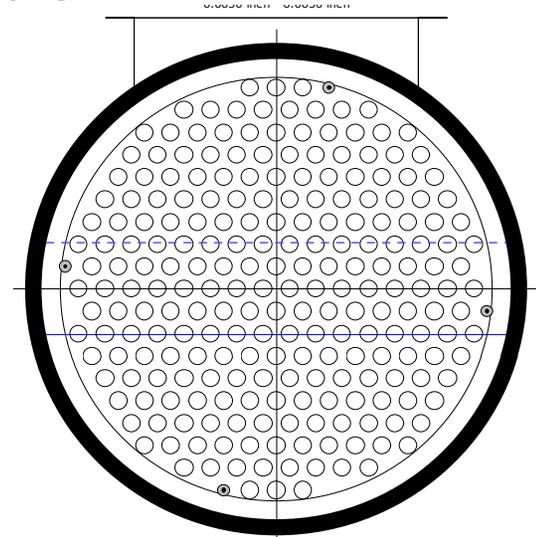
- 100 kWe Brayton Cycle, 1MW Heat Source
- Two Shell and Tube Heat Exchangers





Intermediate Heat Exchanger

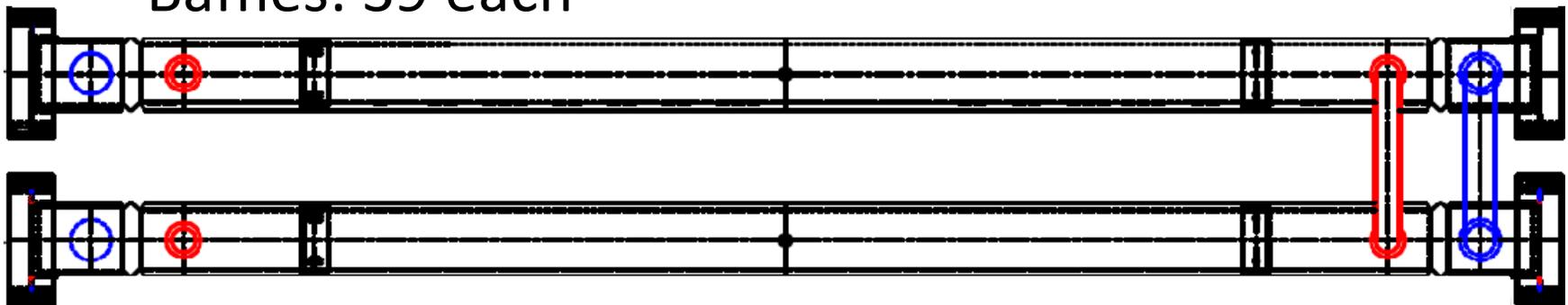
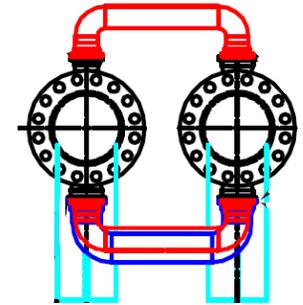
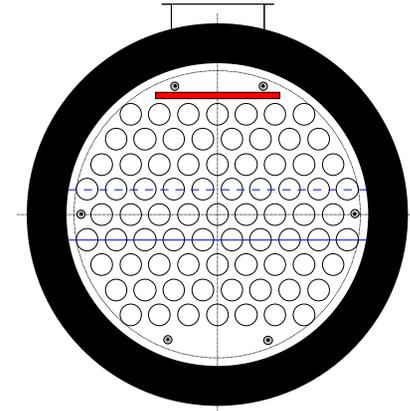
- Mineral oil on the shell (hot) side
- S-CO₂ on the tube (cold) side
- Design duty 857 kW
- Geometry
 - Overall Length: 17 ft.
 - Tubes: 230 – 10 inch diameter
 - Baffles: 23 shell





Precooler

- Chilled water in the tubes
- S-CO₂ on the shell side
- Design duty 936 kW
- Geometry – Two identical units
 - Length: 19 ft. each
 - Tubes: 77 each
 - Baffles: 39 each
 - 10 inch diameter shell





Heat Exchanger Analysis

- Xist[®] Shell and Tube Heat Exchanger Design Software from the Heat Transfer Research Institute (HTRI)
- Nodalized Method – important for the widely varying fluid properties of S-CO₂
- Fluid Properties:
 - VMGThermo included with Xist[®]
 - Can be linked with NIST's REFPROP
 - Oil properties entered via grid input

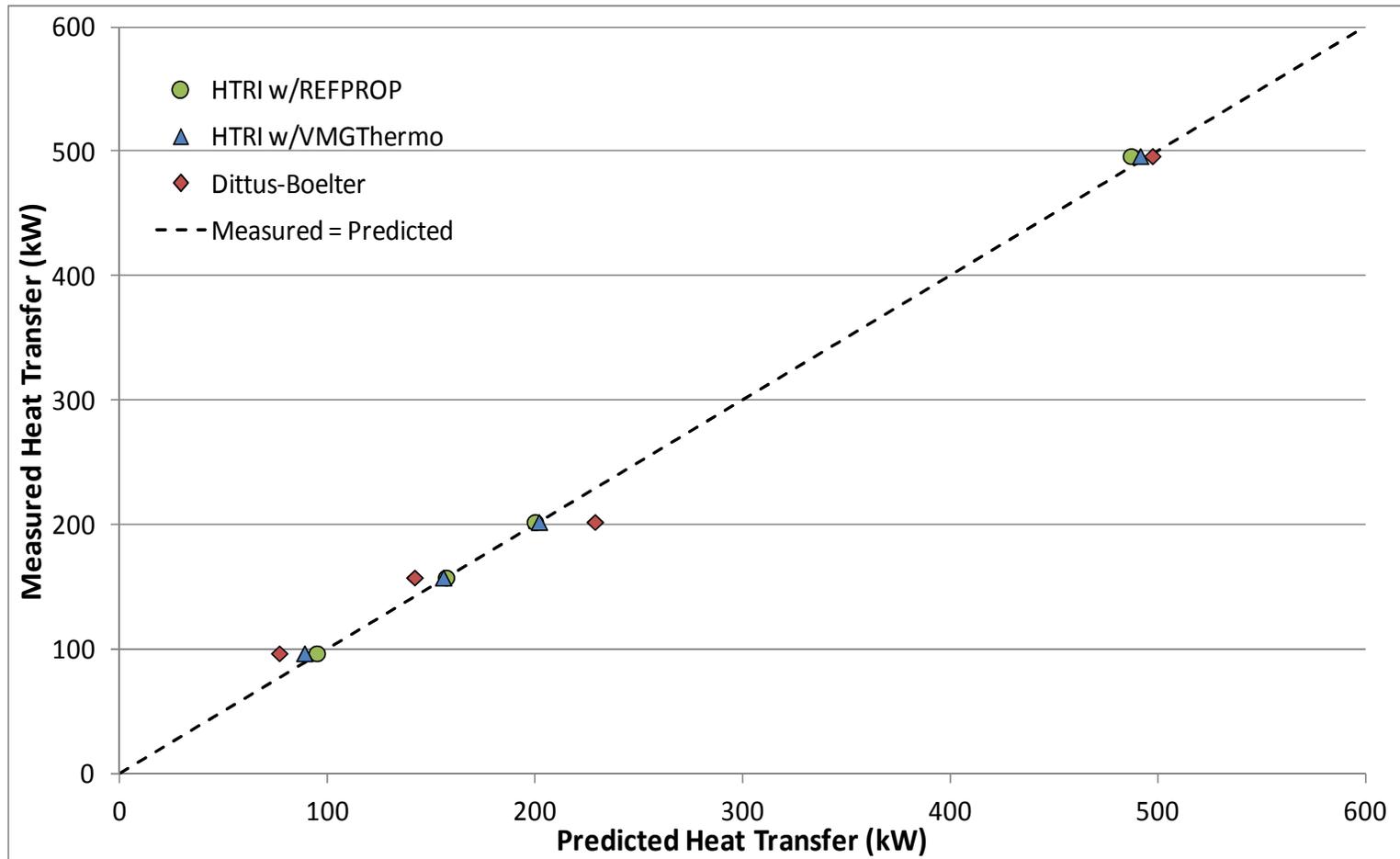


Steady-State Operating Data Points

| Case | IHX | | | | Precooler (Series) | | | |
|------------|---|---------------------------------------|-----------------------------|-------------------------|---|--|-------------------------------|---------------------------|
| | \dot{m} S-CO ₂ (lbm/s) | T_{in} S-CO ₂ (°F) | \dot{m} Oil (lbm/s) | T_{in} Oil (°F) | \dot{m} S-CO ₂ (lbm/s) | T_{out} S-CO ₂ (°F) | \dot{m} Water (lbm/s) | T_{in} Water (°F) |
| Cold Idle | 3.5 | 129.2 | 16.7 | 176.5 | 5.6 | 101.2 | 6.9 | 89.5 |
| 300°F Hold | 4.8 | 201.6 | 16.7 | 299.5 | 7.2 | 101.0 | 9.5 | 89.5 |
| Hot Idle | 4.8 | 429.3 | 50 | 571.3 | 7.6 | 96.8 | 7.1 | 81.5 |
| Full Power | 8.9 | 361.6 | 50 | 548.0 | 11.2 | 97.1 | 15.8 | 81.0 |

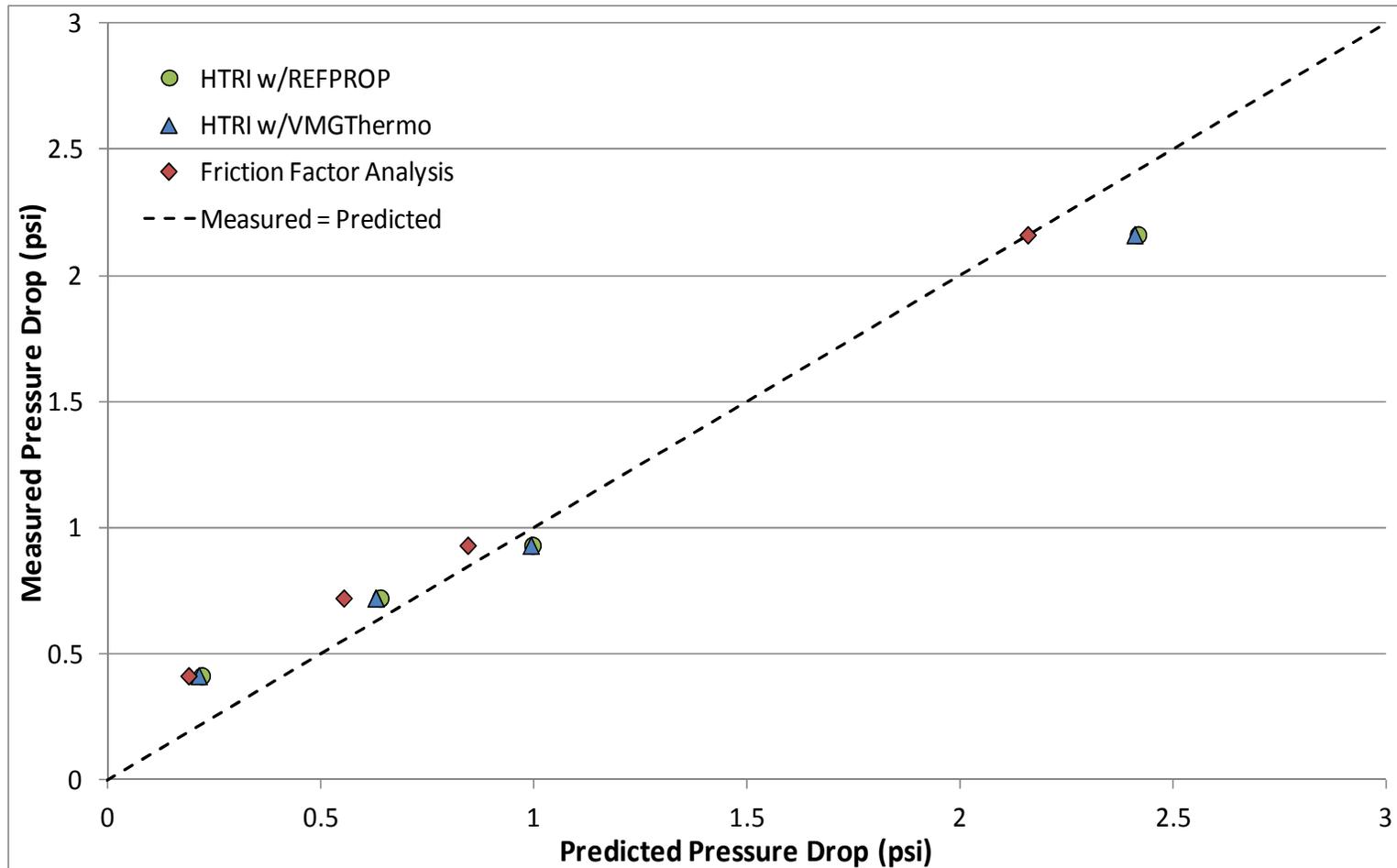


IHX Heat Transfer



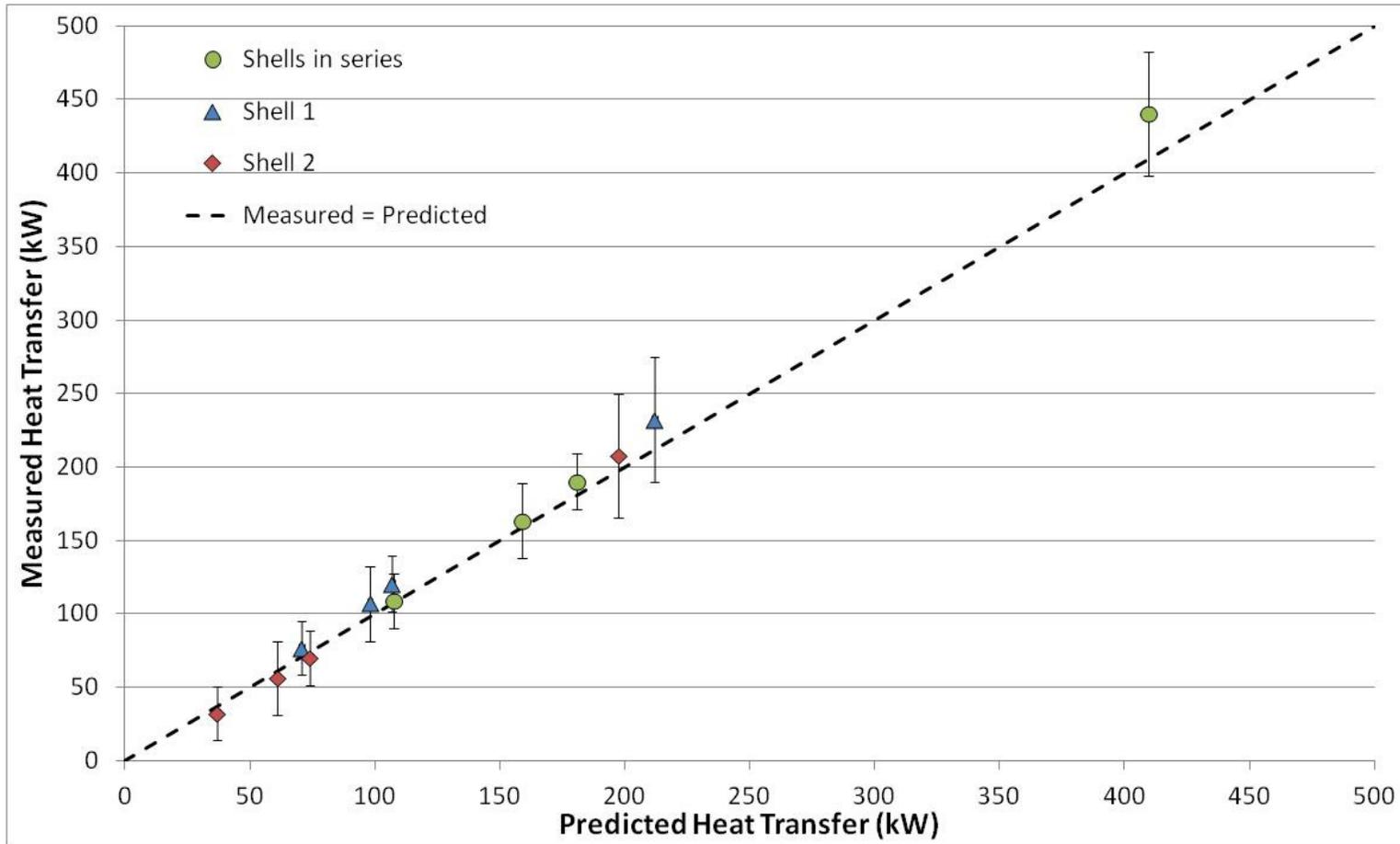


IHX Pressure Drop



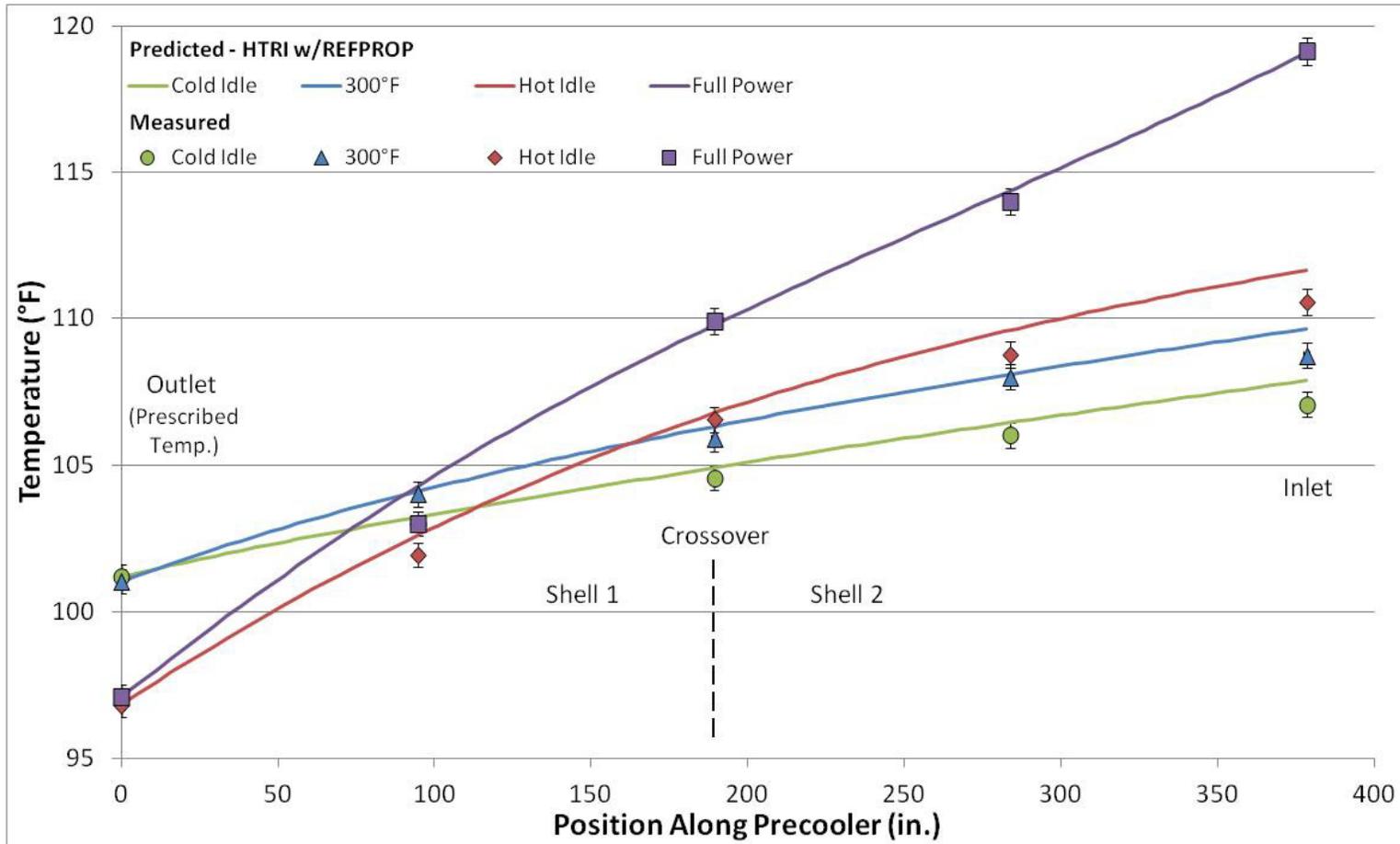


Precooler Heat Transfer



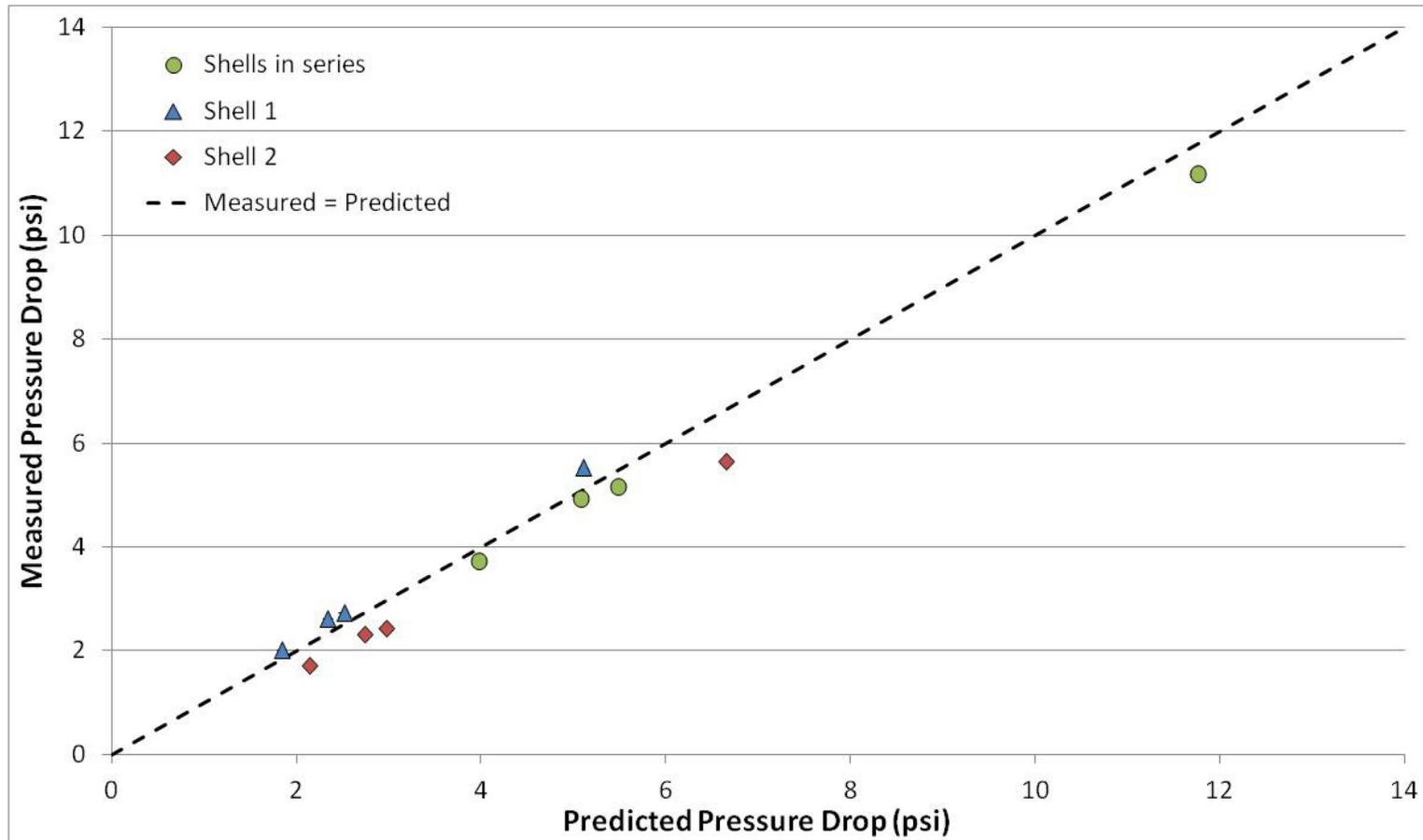


Precooler Temperature Profile





Precooler Pressure Drop





Difference Between Single Node LMTD Method Predicted Heat Transfer and Measured Test Data using both Cold Idle and Full Power Cases as Baselines

$$Q = UA \Delta T_{LM}$$

| | IHX | | Precooler (Series) | |
|------------|------------------------|-------------------------|------------------------|-------------------------|
| Case | Cold Idle <i>UA</i> | Full Power <i>UA</i> | Cold Idle <i>UA</i> | Full Power <i>UA</i> |
| Cold Idle | ----- | 77.3% | ----- | 73.3% |
| 300°F Hold | 3.8% | 83.9% | -29.0% | 23.1% |
| Hot Idle | -35.4% | 14.6% | -23.0% | 33.5% |
| Full Power | 77.5% | ----- | -42.3% | ----- |



Summary

- HTRI's Xist[®] Software does a good job at predicting the heat transfer and pressure drop performance of S-CO₂ in shell and tube heat exchangers.
- Methods using average properties such as LMTD should be avoided, especially at temperatures and pressures near the critical point.