Newport News Shipbuilding
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PARAMETRIC ANALYSIS OF SCO2 POWER CYCLES OPERATING AT MODERATE TEMPERATURES

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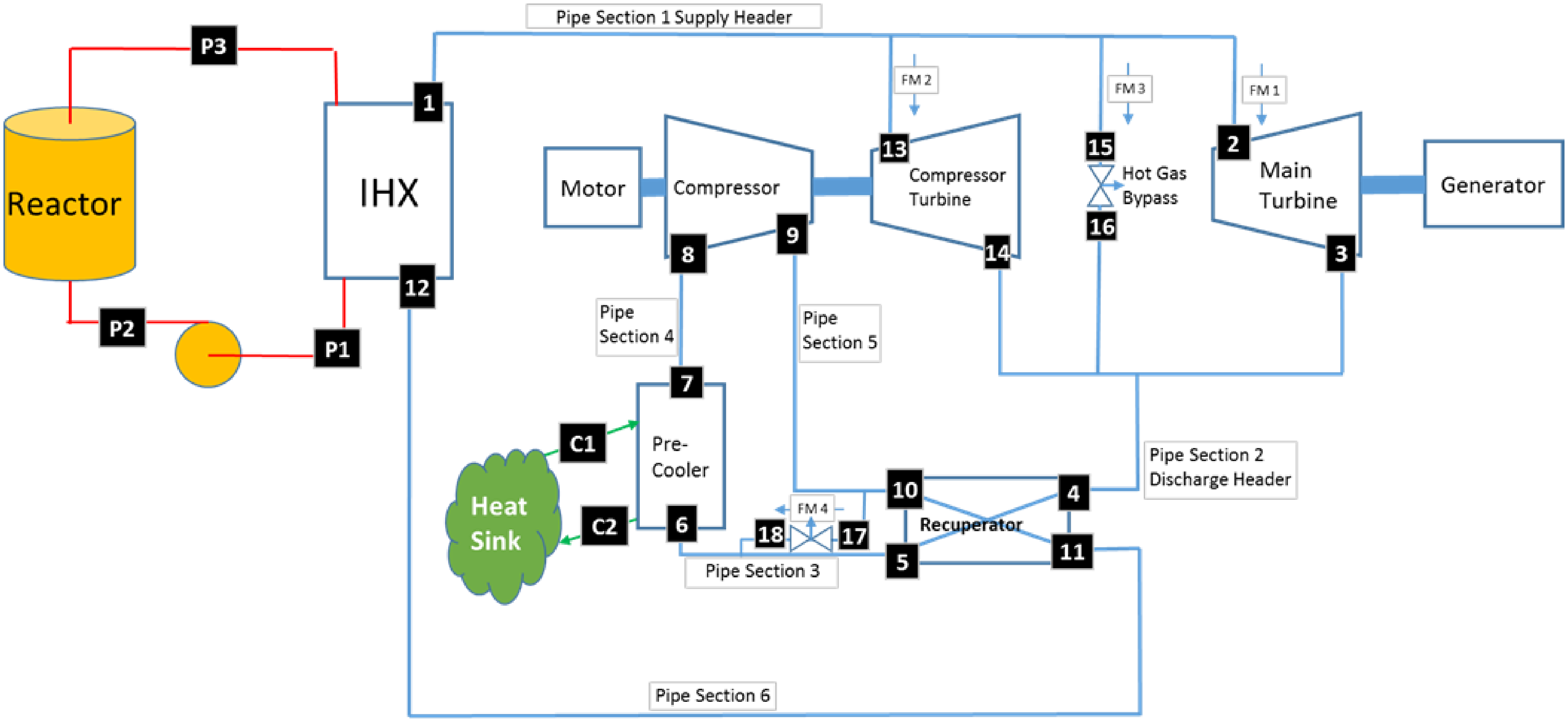
Background

- Considerable effort has focused on sCO2 performance at relatively high cycle temperatures.
- Prior research has shown that at moderate temperatures, sCO2 cycles provide little efficiency gain from traditional Rankine cycles.
- However, sCO2 offers a number of other operational advantages over steam at moderate temperatures where efficiency gains are not realized.
- This presentation summarizes parametric analysis results of sCO2 cycles at moderate peak cycle temperatures

Analysis Plant Arrangement



Base Case

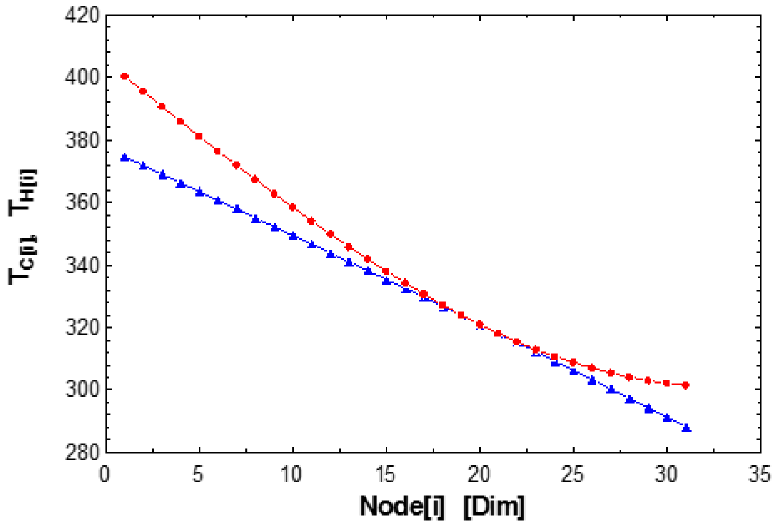
- Heat source:
  - 100MW Small Modular Pressurized Water Reactor
- IHX outlet conditions:
  - Cycle high temperature: 550K, Cycle high pressure: 30MPa
- Recuperator
  - Effectiveness: 92.5%
- Adiabatic components
- Turbomachinery
  - Turbine efficiency: 90%, Compressor efficiency: 85%
- Component pressure drops: 330kPa
  - Pre-cooler 100kPa, IHX 150kPa, Recuperator cold side 30kPa, Recuperator hot side 50kPa
- Piping pressure drops total: 370kPa
  - 1→2: 80kPa, 3→4: 10kPa, 5→6: 5kPa, 7→8: 40 kPa, 9→ 10: 35kPa, 11→12: 200kPa

Governing Relationships

See paper for Thermodynamic, Heat Transfer and Fluid Dynamic relationships

Computational Methods

- Engineering Equation Solver (EES) from F-Chart Software ®
- 400 equations
  - Pressurized water reactor (PWR)
  - Secondary sCO_2 plant
  - Tertiary heat sink cooling system

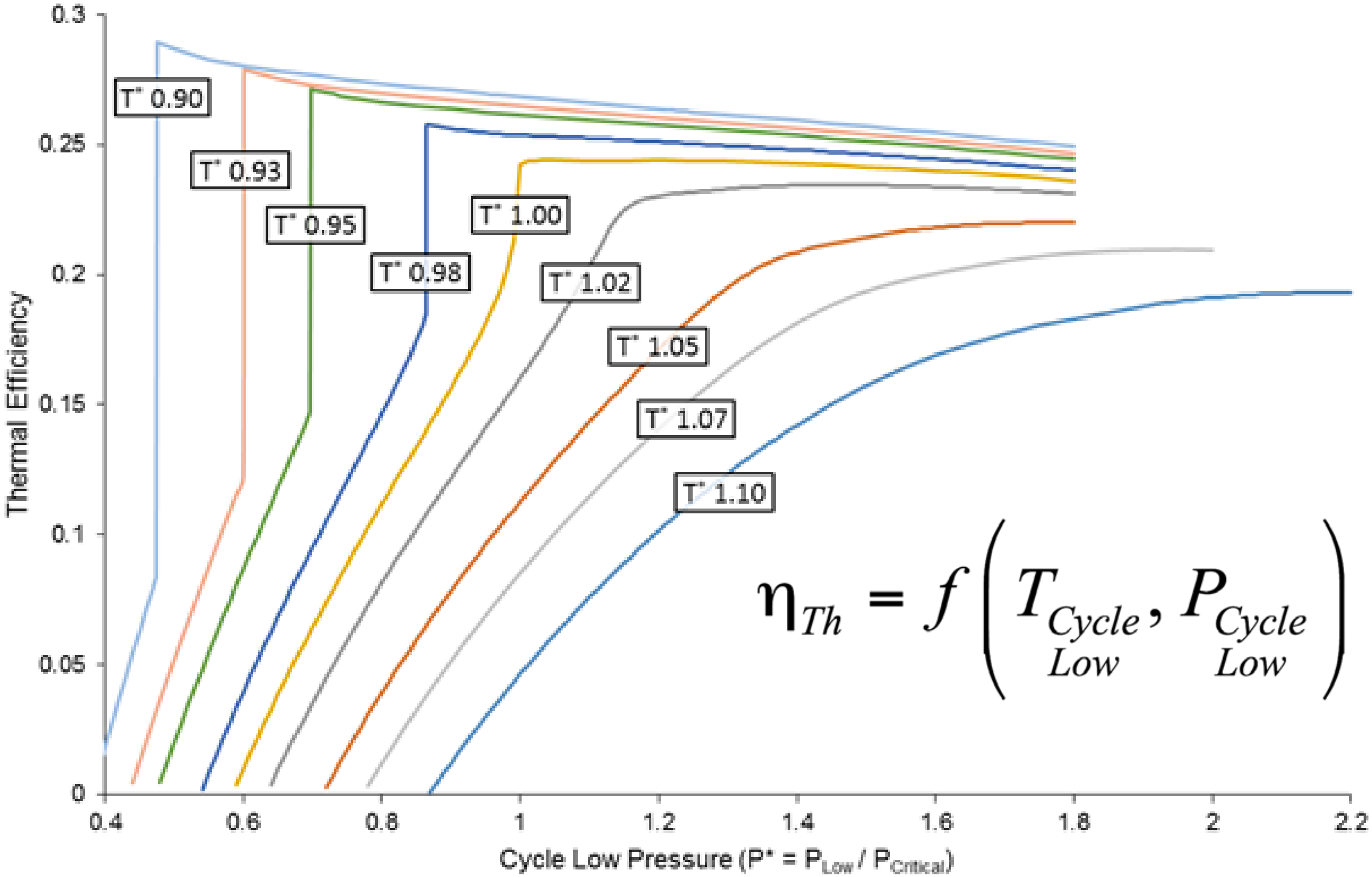


- Recuperator procedure segmented the unit into 30 sections to determine the internal pinch point
- IHX subprogram segmented the unit into 10 sections
- Pre-cooler subprogram segmented the unit into 20 sections

Computational Methods

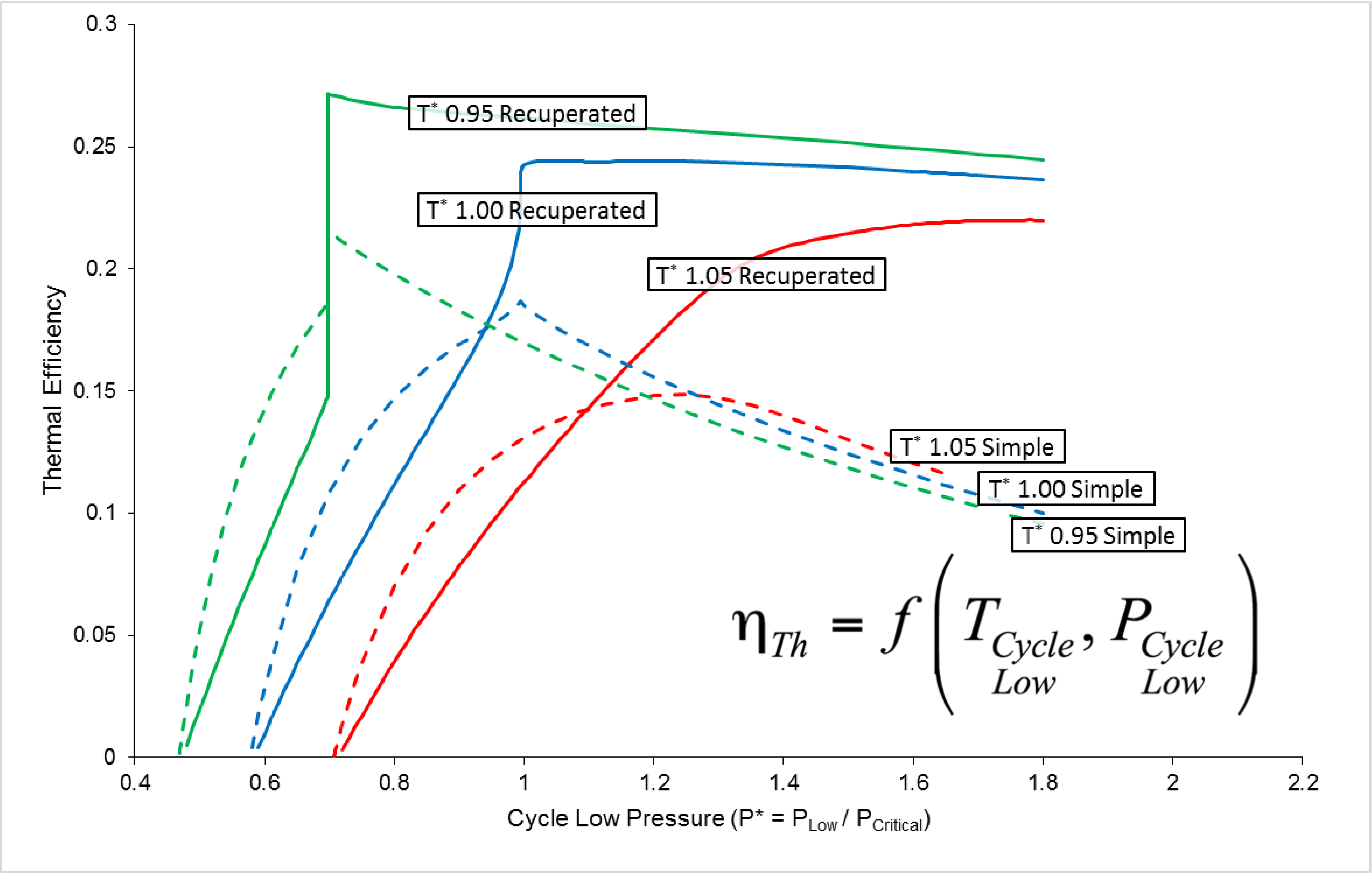
- Engineering Equation Solver (EES) Internal property library:
  - In most cases, EES library values were within 0.003% of REFPROP values.
  - Near the critical point errors approached 1% in enthalpy and 0.8% in entropy.
  - Values for thermal conductivity and viscosity approached 15% and 20% respectively at the critical point, although these values were not used in the current model.

Results – Base Case



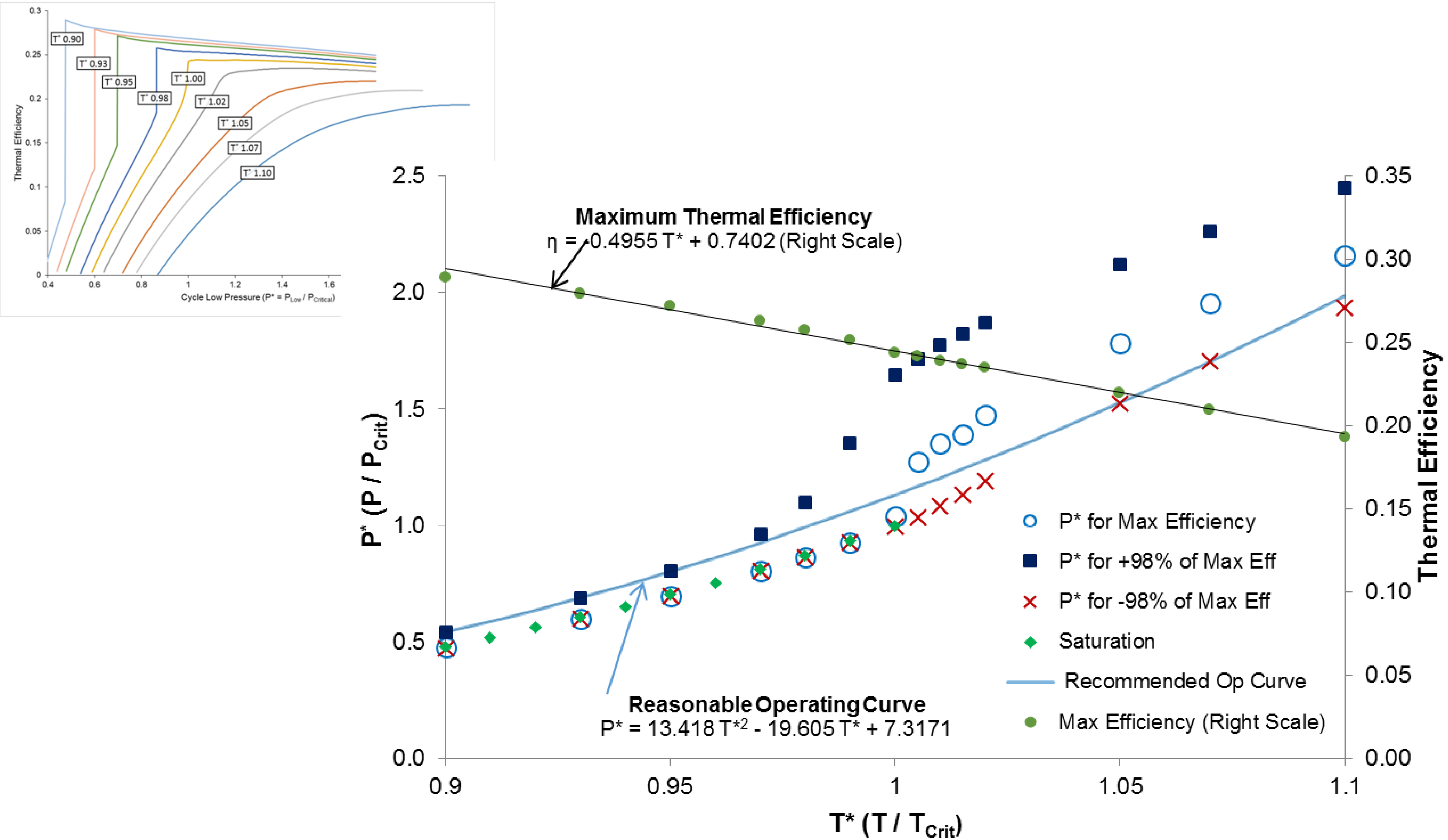
$$\eta_{Th} = f\left(T_{\substack{Cycle \\ Low}}, P_{\substack{Cycle \\ Low}}\right)$$

Base Case Results – Effect of Recuperation



$$\eta_{Th} = f\left(T_{\substack{Cycle\\Low}}, P_{\substack{Cycle\\Low}}\right)$$

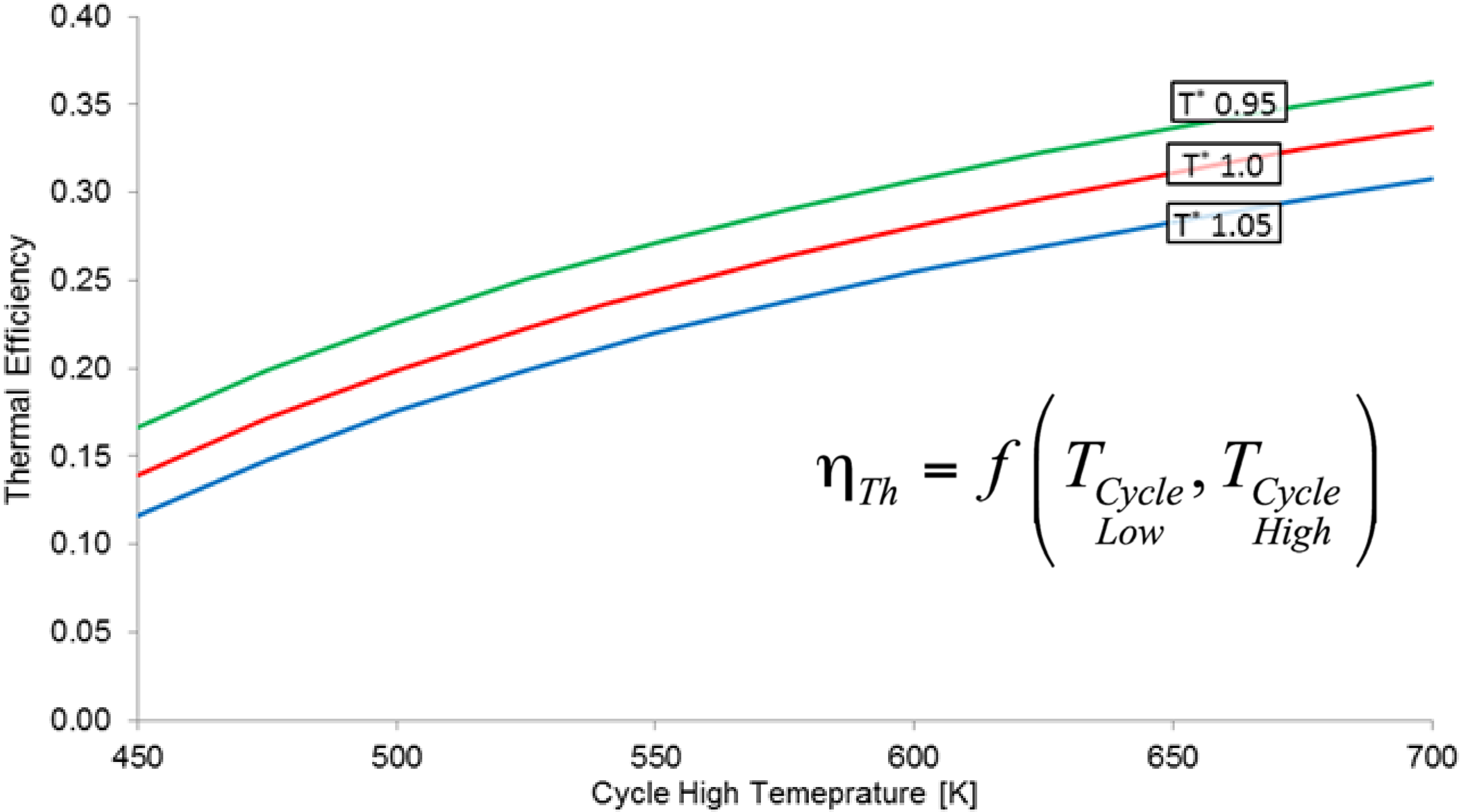
Base Case Results – Effect of Cycle Low Temperature



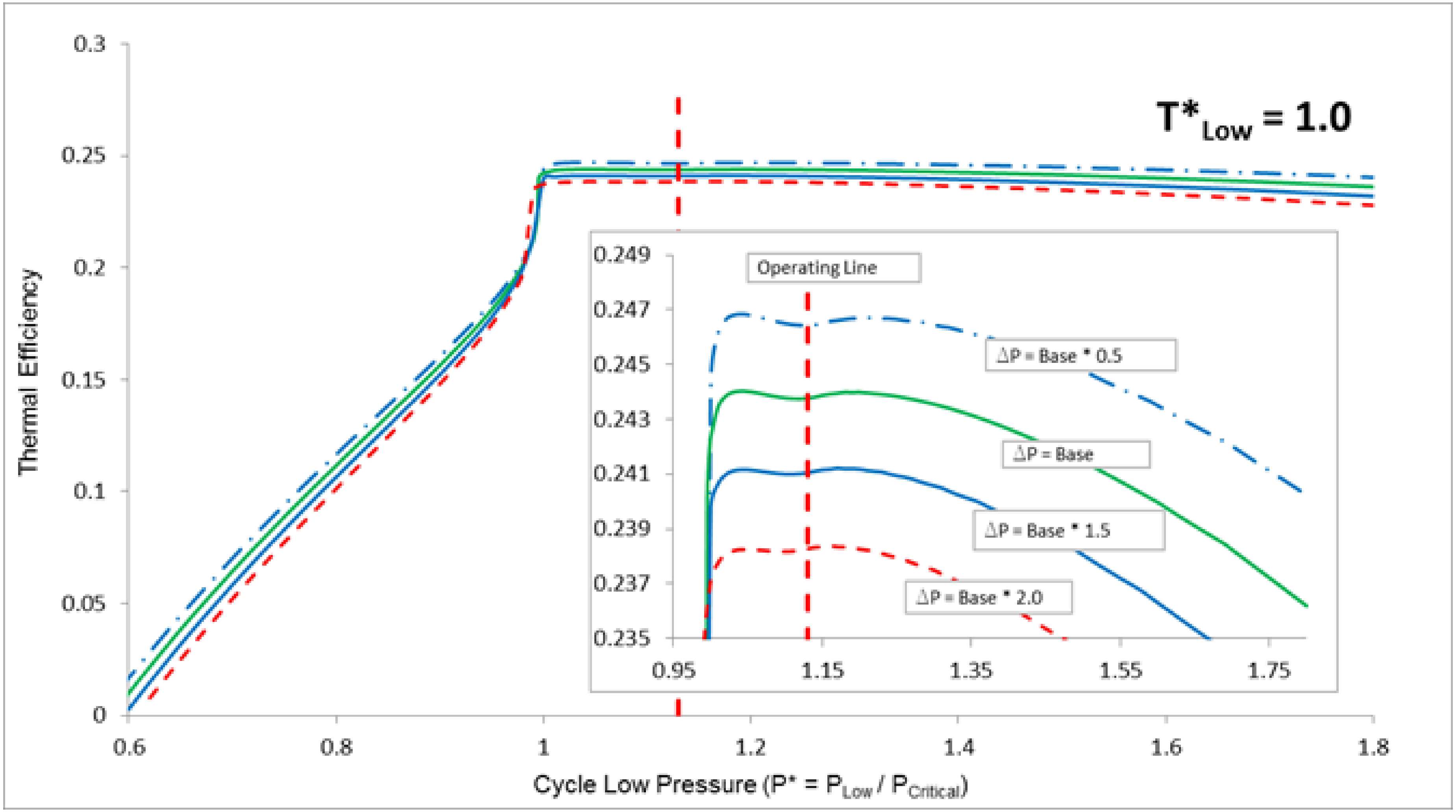
Parametric Analysis

		Sensitivity Analysis Cases				
	Base Case	1 T_H	2 P_H	3 Component Efficiency	4 Recuperator Effectiveness	5 Pressure Drops
Point 1 Temperature (K)	550	450 - 700				
Point 1 Pressure (MPa)	30		25 - 40			
Efficiency						
Turbine	90%			80% - 95%		
Compressor	85%			70% - 92.5%		
Recuperator Effectiveness	92.5%				85% - 100%	
Component pressure drops (kPa)						
Pre-cooler	100					50-200
IHX	150					75-300
Recuperator (cold)	30					15-60
Recuperator (hot)	50					25-100
Piping pressure drops (kPa)	---	-------	-------	-------	-------	----
Section 1-2	80					40-160
3-4	10					5-20
5-6	5					2.5-10
7-8	40					20-80
9-10	35					17.5-70
11-12	200					100-400

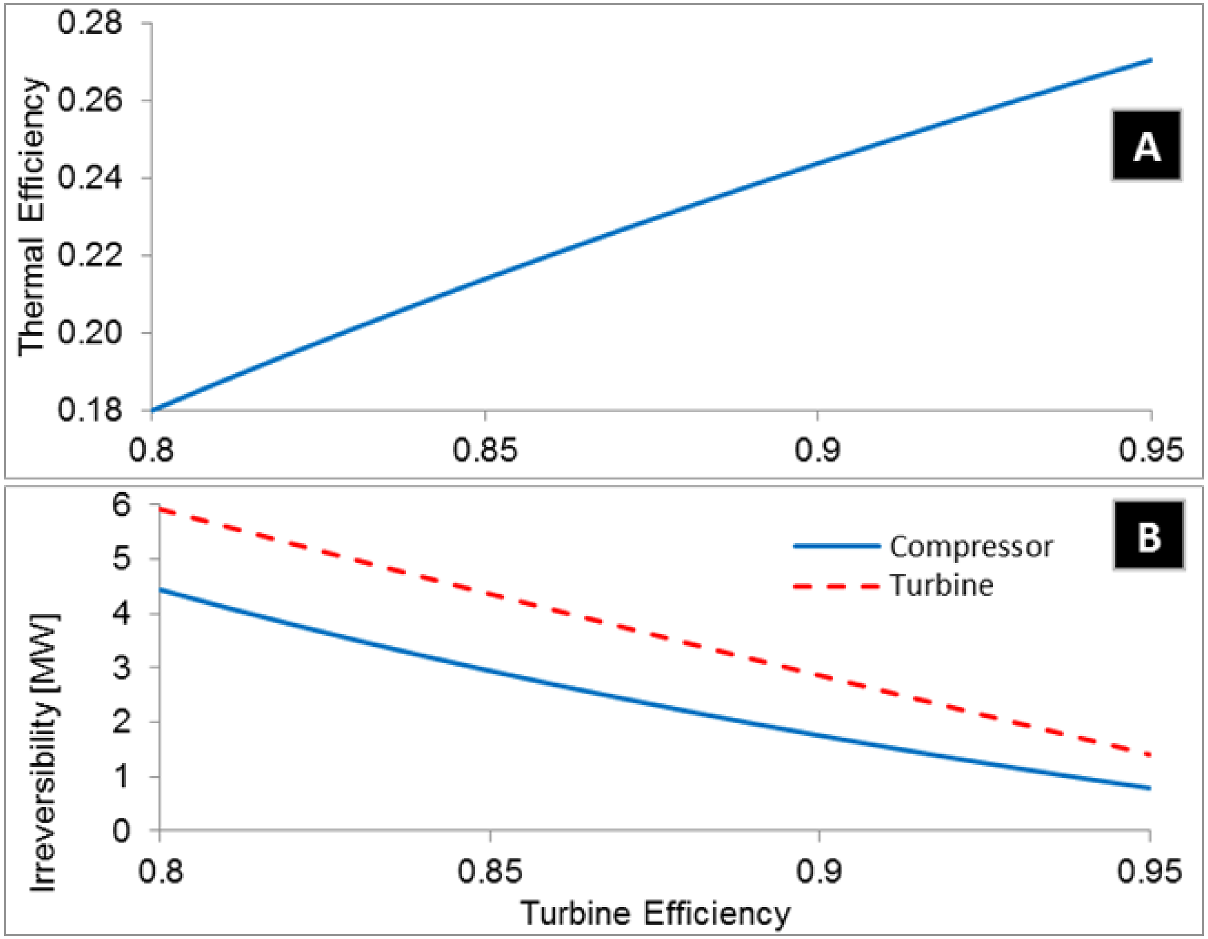
Parametric Analysis – Effect of Cycle High Temperature



Parametric Analysis – Effect of System Pressure Drops

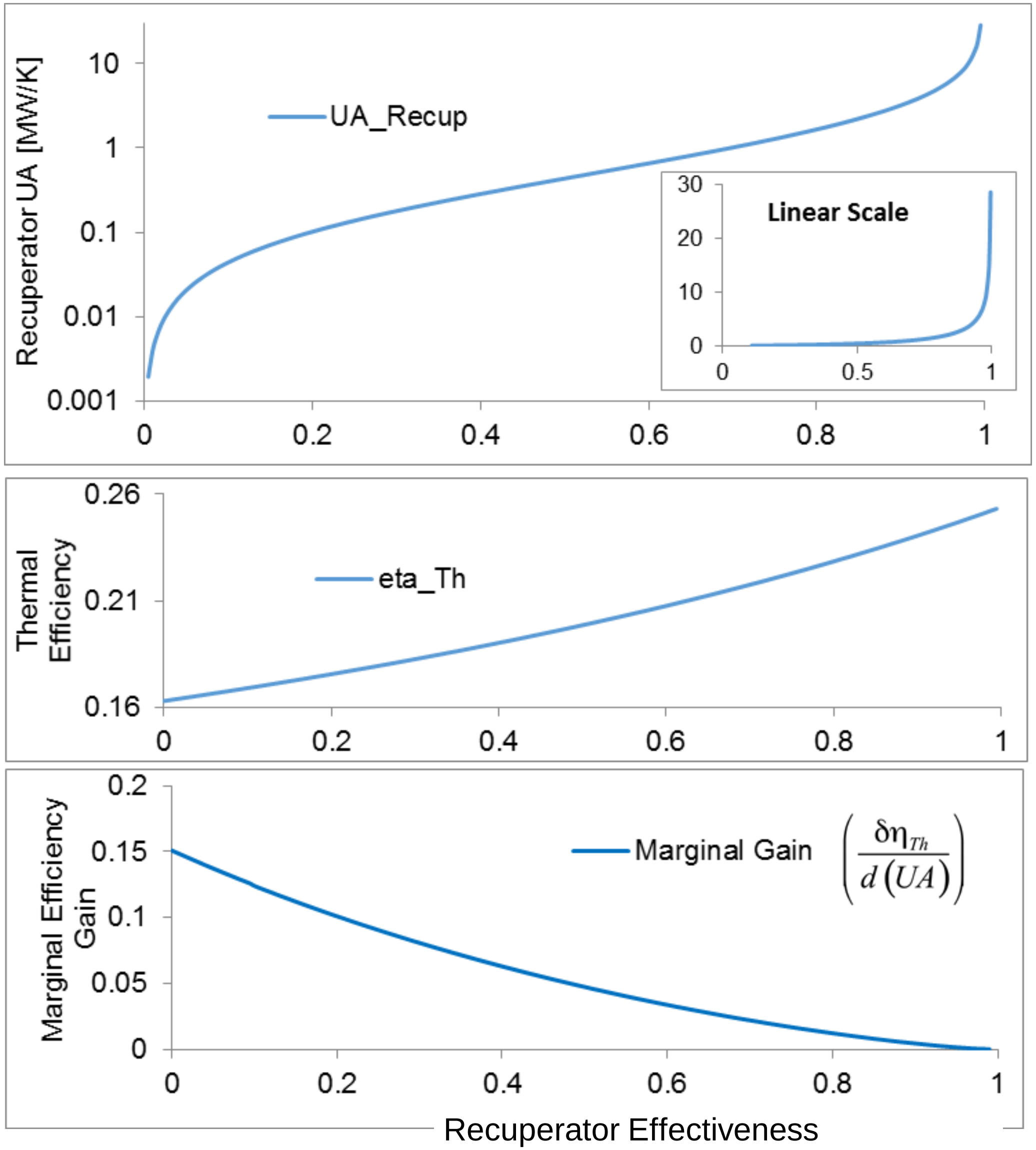


Parametric Analysis – Effect of Turbomachinery Efficiency

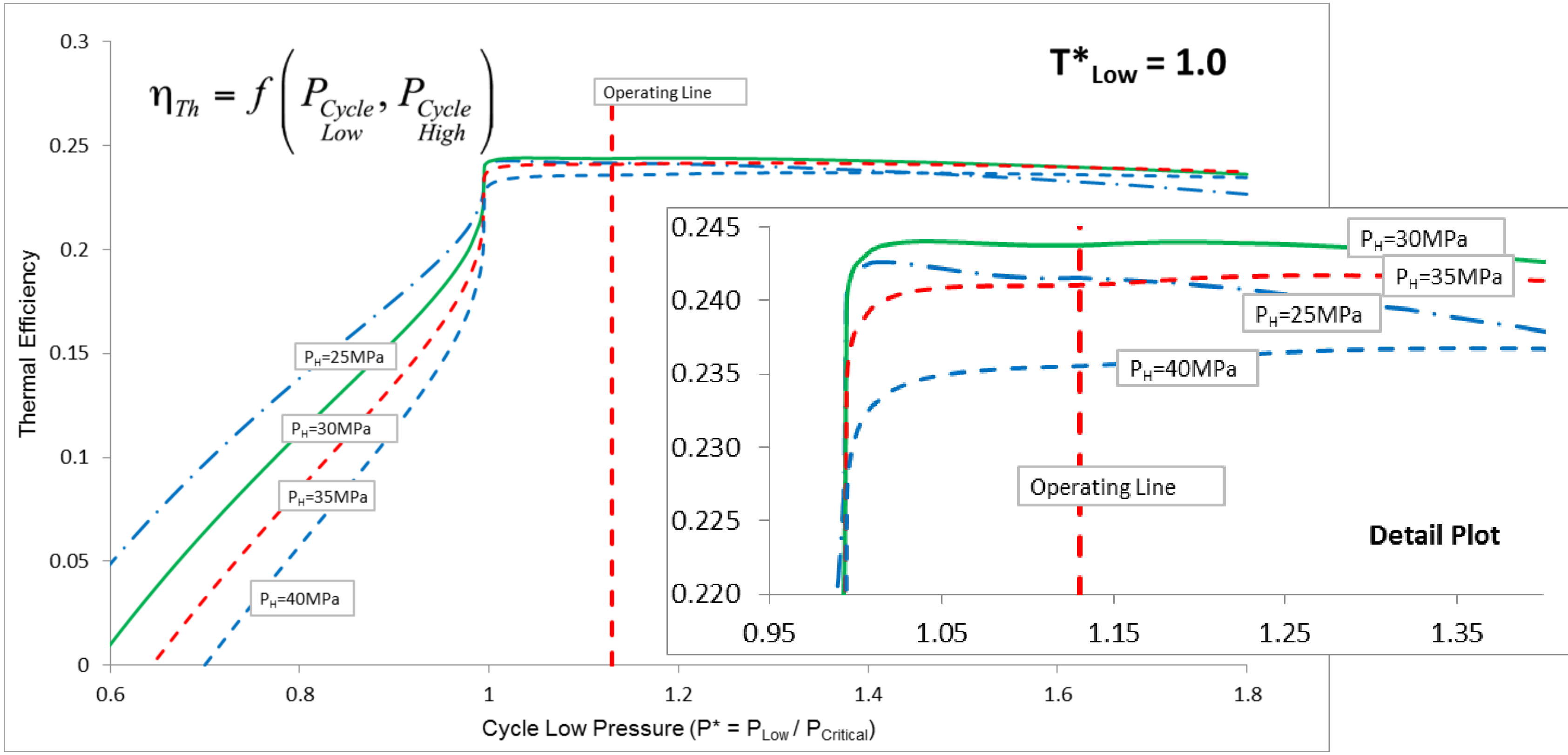


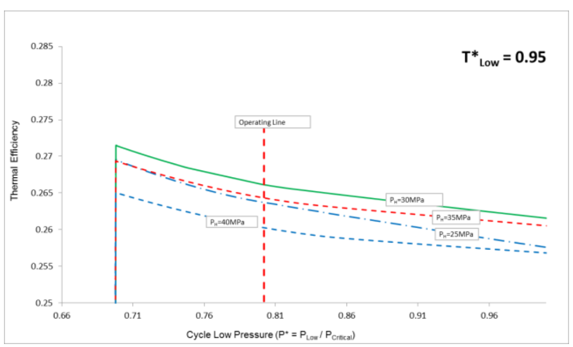
Note: $(1-\eta_C) = 1.5(1-\eta_T)$

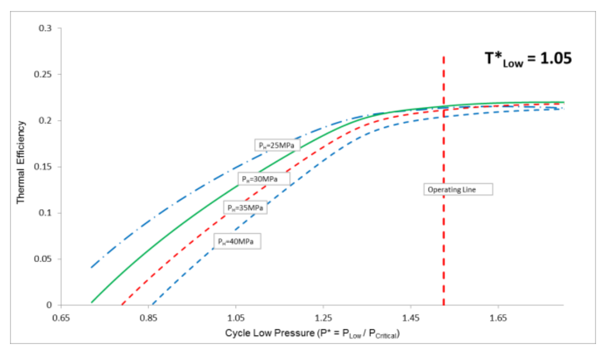
Parametric Analysis – Effect of Recuperator Effectiveness



Parametric Analysis – Effect of Cycle High Pressure

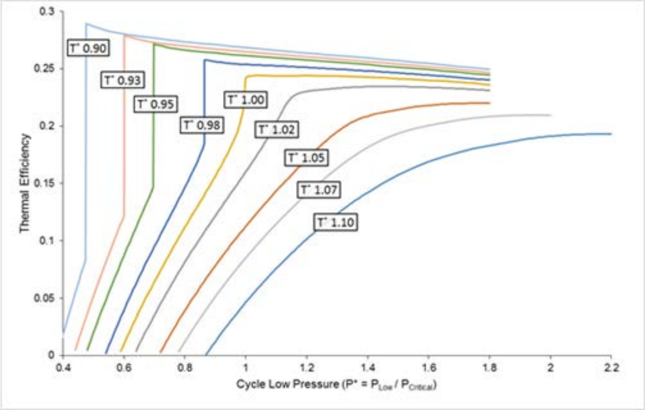


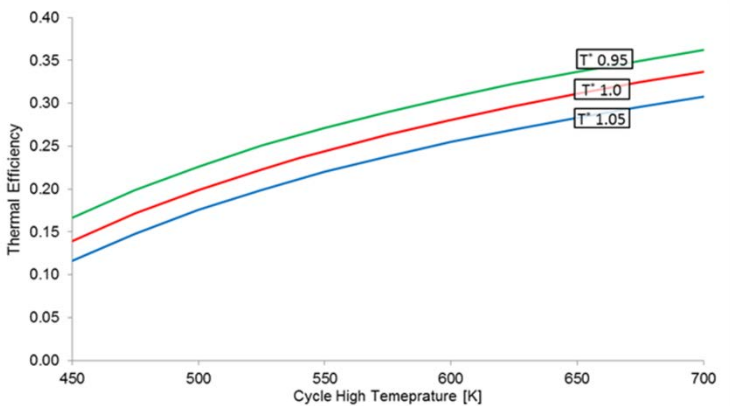




Conclusions

- Over the parametric range tested, the thermal efficiency of real recuperated cycles is strongly dependent on the cycle high and low temperatures.
  - Efficiency of the cycle increases as the compressor suction temperature is decreased.
  - The efficiency increases smoothly as turbine inlet temperature increases. The increase shows that the efficiency roughly doubles as the turbine inlet temperature increases from 450K to 700K.





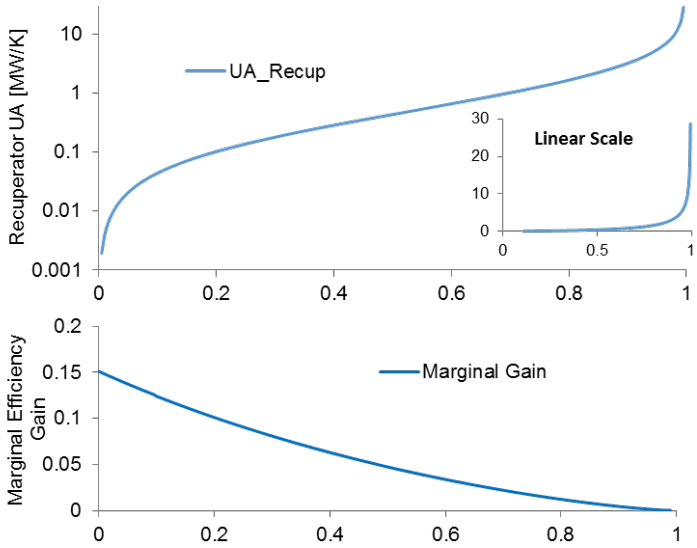
Conclusions

- Thermal efficiency is strongly dependent on cycle low pressure.
- For subcritical cycle low temperatures,
  - Maximum efficiency occurs when the cycle low pressure equals the saturation pressure
  - Efficiency drops in a step change if the pressure drops below the saturation pressure.
  - Efficiency drops gradually and smoothly if cycle low pressure is increased above saturation pressure.
- For cycles operating above the critical temperature, efficiency decreases smoothly and gradually if pressure deviates from the ideal.
- A suitable suction low pressure provides a reasonable safety margin with less than a 2% reduction in efficiency.
  - The recommended curve achieves 98% of the maximum efficiency at subcritical temperatures (by maintaining pressure slightly above saturation) and limits mechanical stresses at supercritical temperatures (by operating at pressures below the maximum efficiency).

Conclusions

- Cycle irreversibilities reduce the thermal efficiency as expected.
  - System pressure drops over the range of parameters tested have a relatively small influence on cycle efficiency.
  - Because of the magnitude of the back work, turbomachinery efficiencies have a large influence on cycle efficiencies.

- Increasing recuperator area increases efficiency, but at a diminishing rate as area increases.



Questions

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