Thermodynamic study of SCO_2 Recompression Brayton Cycle with Intercooling and Reheating for Light Water Reactor

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Introduction

- **Contribution of SCO_2 Cycle to Light Water Reactor (LWR)**
  - ✓ Reduced turbomachinery and heat exchanger volume maintaining power conversion efficiency
  - ✓ high feasibility of dry cooling
- **Common idea of modifying power conversion efficiency: intercooling and reheating**
  - ✓ Intercooling: cooling the SCO_2 after compressor stages to reduce compression work of next stage.
  - ✓ Reheating: heating the SCO_2 after turbine stages.
- **Research Objective**
  - ✓ To investigate the effect of intercooling and reheating on power conversion efficiency of SCO_2 cycle with light water reactor.

Parameter classification

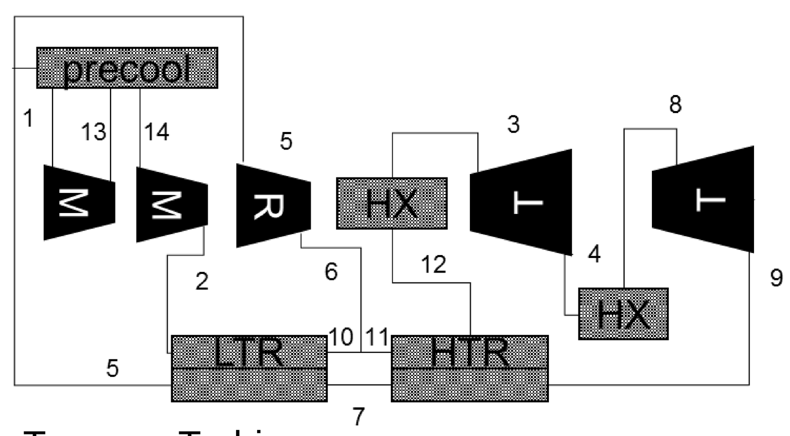
- **Operating conditions (fixed parameter)**

✓ HP turbine inlet pressure	25MPa
✓ HP turbine inlet Temperature	310°C
✓ Main compressor inlet Temperature	32°C
✓ Isentropic efficiency of turbine	0.90
✓ Isentropic efficiency of compressor	0.89
✓ Maximum effectiveness of heat exchanger	0.90

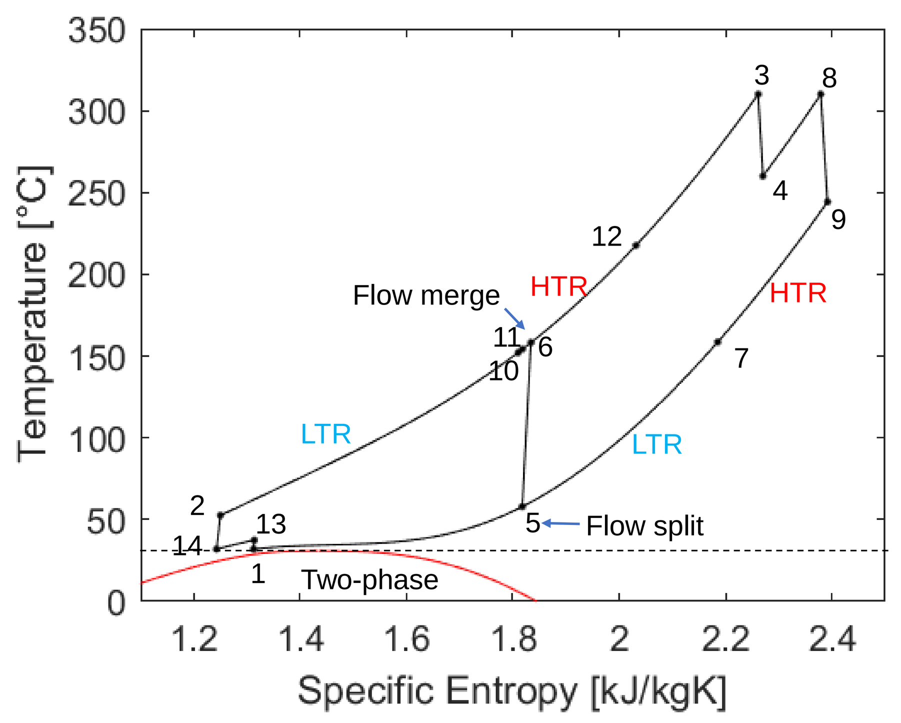
- **Optimization parameters**
  - ✓ Parameters that determine recuperated heat: pressure ratio, mass split ratio
  - ✓ Intermediate pressure for intercooling/reheating stage

Analysis model development

- **Assumptions for modeling**
  - ✓ Pressure drop and heat loss terms in all flow paths and heat exchangers are negligible.
  - ✓ Each compressor has the same isentropic efficiency.
  - ✓ Each turbine has the same isentropic efficiency.
  - ✓ All heat exchangers have the same maximum effectiveness regardless of the inlet conditions.
- **Software**
  - ✓ Refprop 9.0v (NIST) : Evaluation of thermodynamic property of SCO_2
  - ✓ MATLAB(Mathworks): Programming and calculation
- **Mathematical models for components**
  - ✓ For Turbines : $h_{outlet} = h_{inlet} - \left(h_{inlet} - h_{(s_{inlet},P_{outlet})}\right) * \eta_{turbine}$
  - ✓ For Compressors : $h_{outlet} = h_{inlet} + \frac{\left(h_{(s_{inlet},P_{outlet})} - h_{inlet}\right)}{\eta_{compressor}}$
  - ✓ For heat exchangers : $\Delta h = \epsilon * \min\left(\left|h_{in,2} - h\left(T_{in,1}\right)\right|, \left|h_{in,1} - h\left(T_{in,2}\right)\right|\right)$
- **Cycle layout and T-s diagram**



T	Turbine
M	Main compressor
R	Re-compressor
LTR	Low temperature recuperator
HTR	High temperature recuperator
HX	Heat exchanger



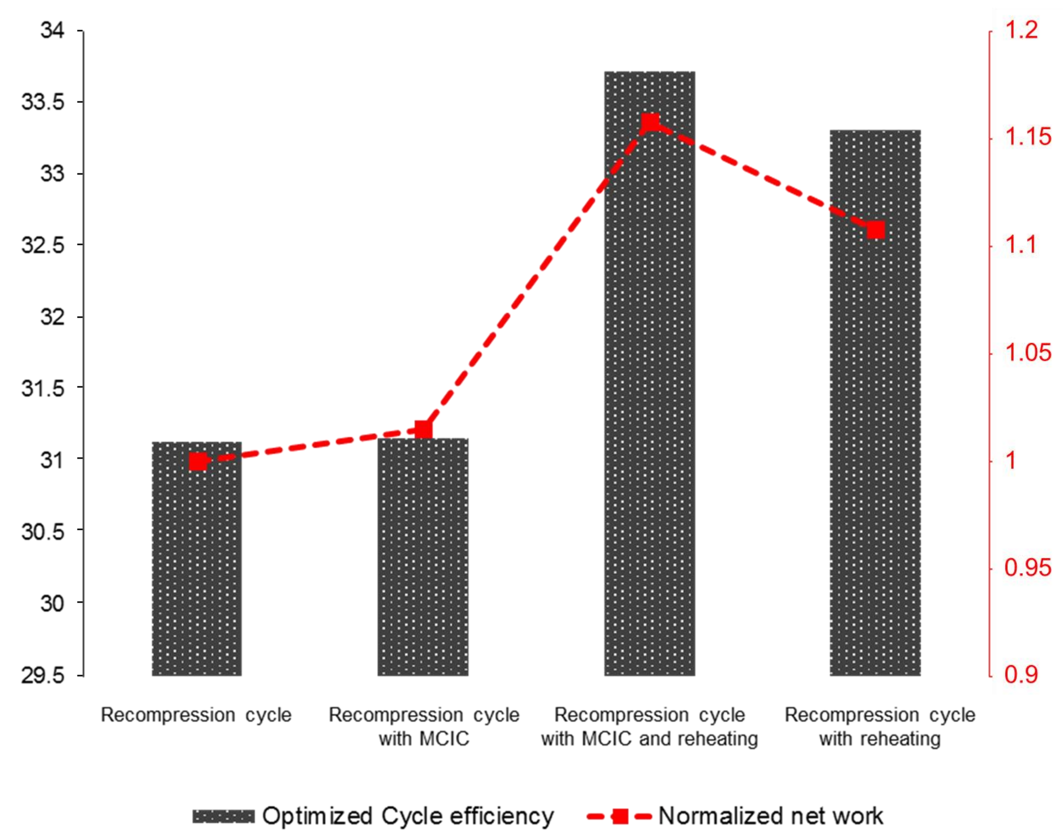
- **Model validation**

Operating Conditions					Cycle efficiency		Error
T_{min}	T_{max}	P_{max}	Split ratio	P_{max}/P_{min}	Ref. data*	Code	
32°C	550°C	20MPa	0.666	2.64	41.18%	41.92%	1.79%
32°C	550°C	30MPa	0.645	3.86	43.32%	42.41%	2.09%
50°C	550°C	20MPa	0.816	2.40	36.71%	37.10%	1.07%
50°C	550°C	30MPa	0.746	2.80	38.93%	39.81%	0.65%

*J. Sarkar, Souvik Bhattacharyya,Optimization of recompression S-CO2 power cycle with reheating,Energy Conversion and Management,Volume 50, Issue 8,2009,Pages 1939-1945

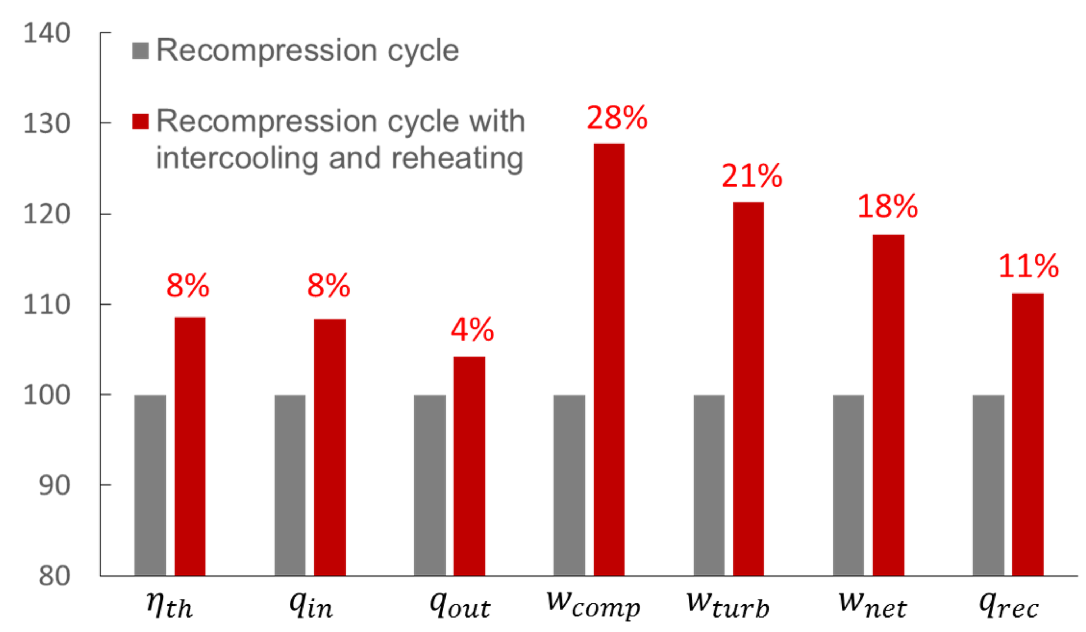
Optimization result

- **Optimization result**



- ✓ 8% more efficiency at recompression cycle with intercooling and reheating.
- ✓ 7% more efficiency at recompression cycle with reheating.

- **Cycle parameter comparison**



- ✓ Efficiency increase factor: improved turbine work and recuparated heat.
- ✓ The negative effect of compression work was insignificant to efficiency.

Conclusion

- ✓ **Reheating**, like the typical power cycle, could be effective strategy to improve cycle efficiency.
- ✓ **Intercooling** itself is **not** an efficient strategy due to the relatively low compression work of SCO_2 cycle.
- ✓ Because of the assumptions to maximize the intercooling and reheating effect, the increase in efficiency might be diminished in real situations. **Nevertheless**, this study could **suggest** the maximum effect of intercooling and reheating strategies for LWR application.

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