Methodology of Modeling and Comparing the Use of Direct Air-Cooling for a Supercritical Carbon Dioxide Brayton Cycle and a Steam Rankine Cycle

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Outline

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- Economic Considerations
- Life Cycle Earnings Optimization
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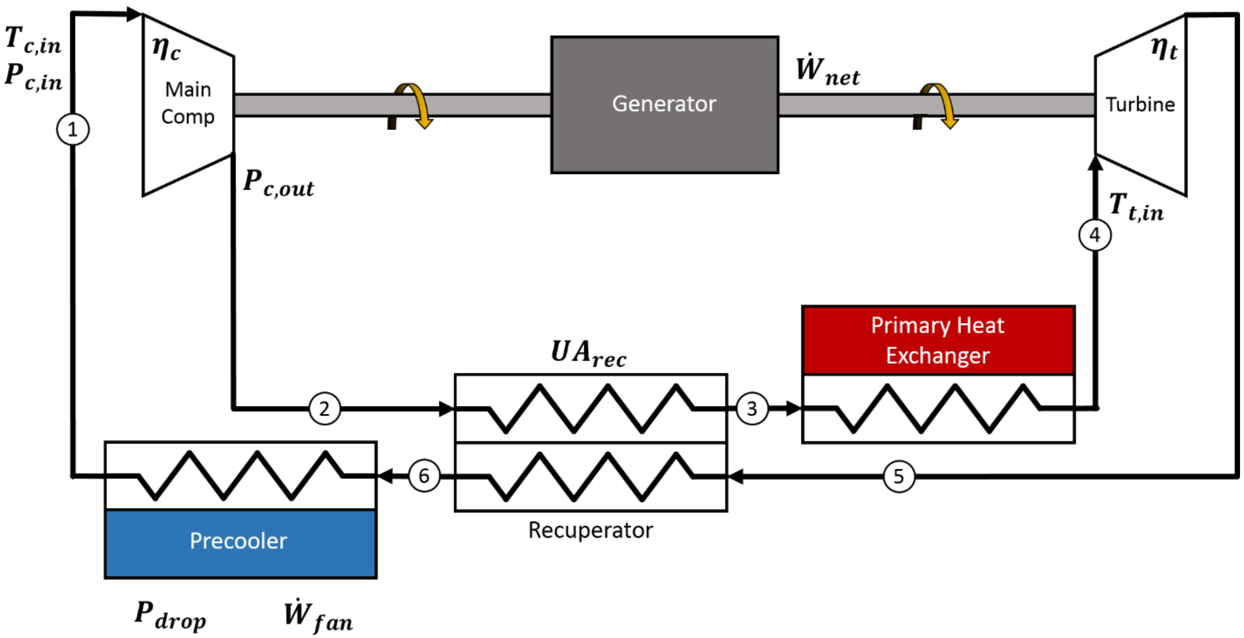
Introduction

- Dry air-cooling has become increasingly important for power generation cycles, especially those located in arid regions with restricted water resources
- Compare feasibility of dry air-cooling with S-CO2 precooler to traditional steam condenser
- Complete cycle and heat exchanger models allow for a proper comparison
- Economic analysis developed to predict the cost of the heat rejection unit based on material costs and actual quoted heat exchangers

Power Generation Cycles

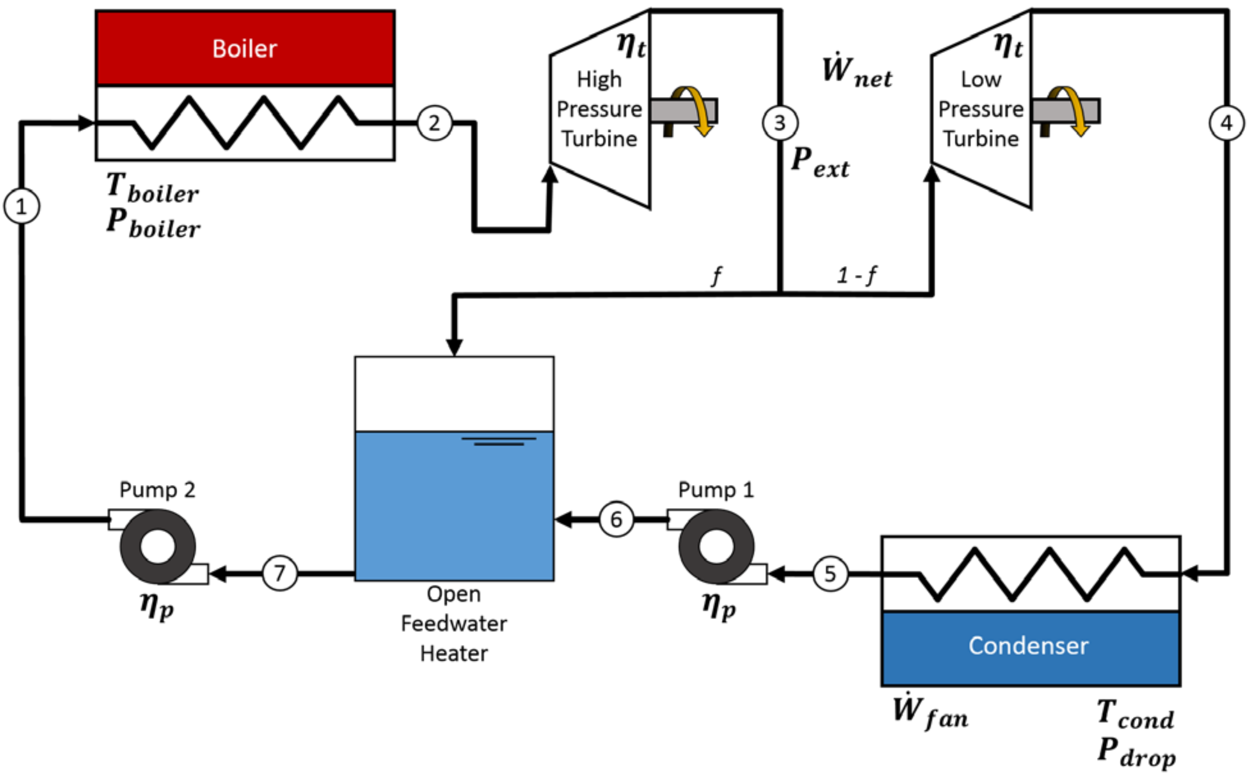
- S-CO2 Brayton Cycle vs. Steam Rankine Cycle
- Single source of regeneration
- Pressure drop only considered in the heat rejection units
- Cycles are defined in order to determine the required performance for the heat rejection units

Supercritical Carbon Dioxide Brayton Cycle



Input	Description
$T_{c,in}$	Compressor Inlet Temperature
$P_{c,in}$	Compressor Inlet Pressure
η_c	Compressor Isentropic Efficiency
$P_{c,out}$	Compressor Outlet Pressure
UA_{rec}	Recuperator Conductance
$T_{t,in}$	Turbine Inlet Temperature
η_t	Turbine Isentropic Efficiency
P_{drop}	Precooler Pressure Drop
$\dot{W}_{fan}$	Required Fan Power
$\dot{W}_{net}$	Total Net Power

Steam Rankine Cycle



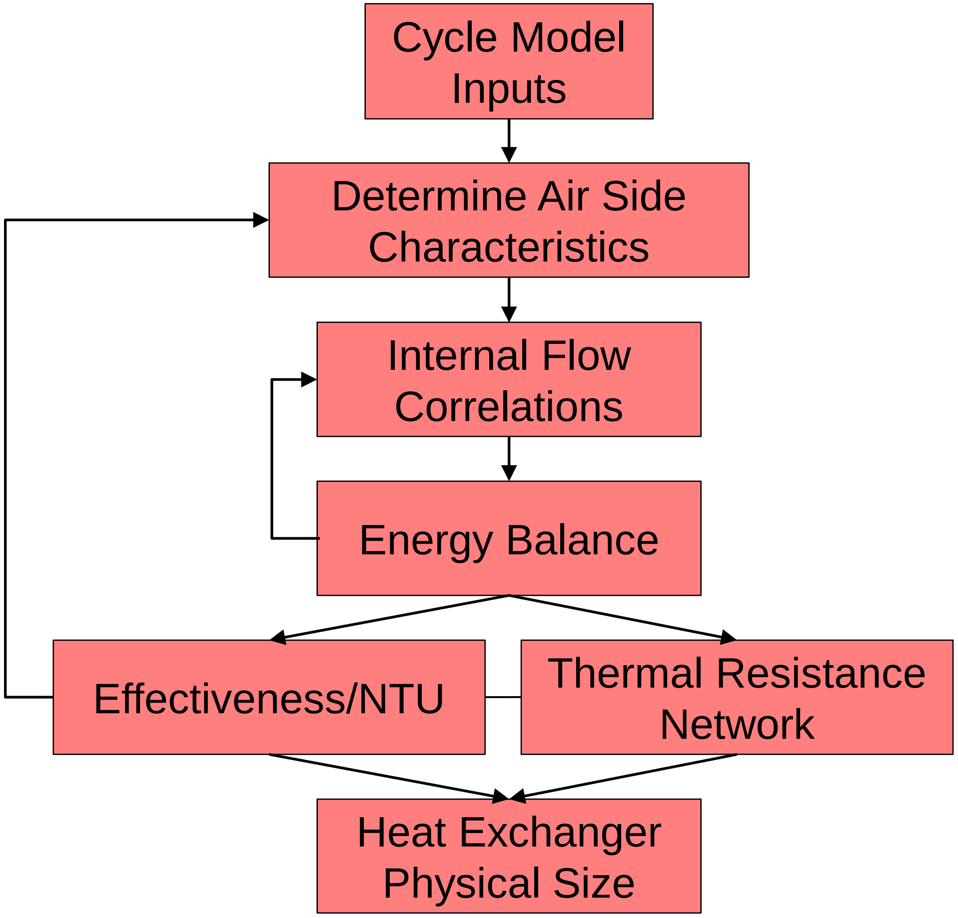
Input	Description
T_{boiler}	Boiler Temperature
P_{boiler}	Boiler Pressure
η_t	Turbine Isentropic Efficiency
P_{ext}	Feedwater Heater Extraction Pressure
T_{cond}	Condensing Temperature
P_{drop}	Condenser Pressure Drop
η_p	Pump Isentropic Efficiency
$\dot{W}_{fan}$	Required Fan Power
$\dot{W}_{net}$	Total Net Power

Air-Cooled Heat Exchanger Model

- S-CO2 Precooler vs. Steam Condenser
- Modeled as finned tube heat exchanger using Engineering Equation Solver (EES) software
- Equate physical size of cooling unit to required performance from cycle model
- Heat exchanger is directly integrated with cycle models
- Investigate the effect of size of cooling unit and the required fan power on the efficiency of the cycles and the cost of these units

Modeling Methodology

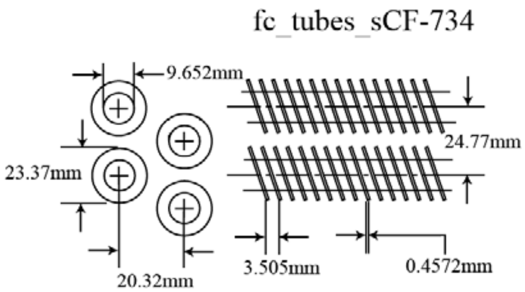
Heat Exchanger Model Inputs
Ambient Air Temperature
Ambient Pressure
Fan Power
Fan Efficiency
Air Side Pressure Drop
Compact Heat Exchanger Geometry
Minimum Tube Thickness
Allowable Pressure Drop
Working Fluid Mass Flow Rate
Working Fluid Inlet Temperature
Cooling Capacity
Working Fluid Outlet Temperature
S-CO2 Inlet Pressure



Economic Considerations

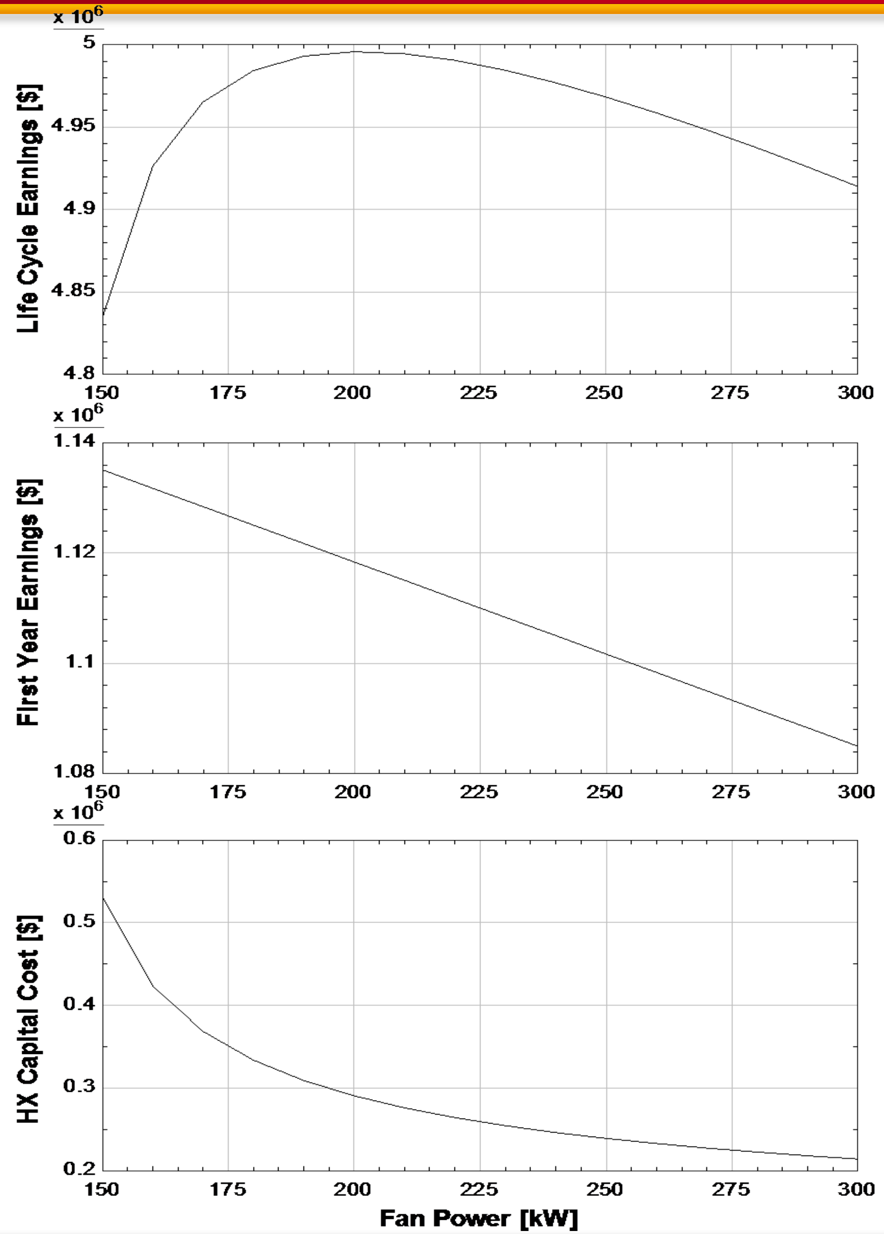
- Analysis includes earnings from generating electricity, cost of providing thermal energy to the cycle, and capital cost of the cooling heat exchanger
- Calculate life cycle earnings from P1-P2 methodology
- Heat exchanger costing model created from predicting overall cost from tubing and fin material costs
- Estimated cost of heat exchanger is calculated using a power law model developed from obtaining two quotes for air-cooled heat exchangers

Life Cycle Earnings Optimization Parameters

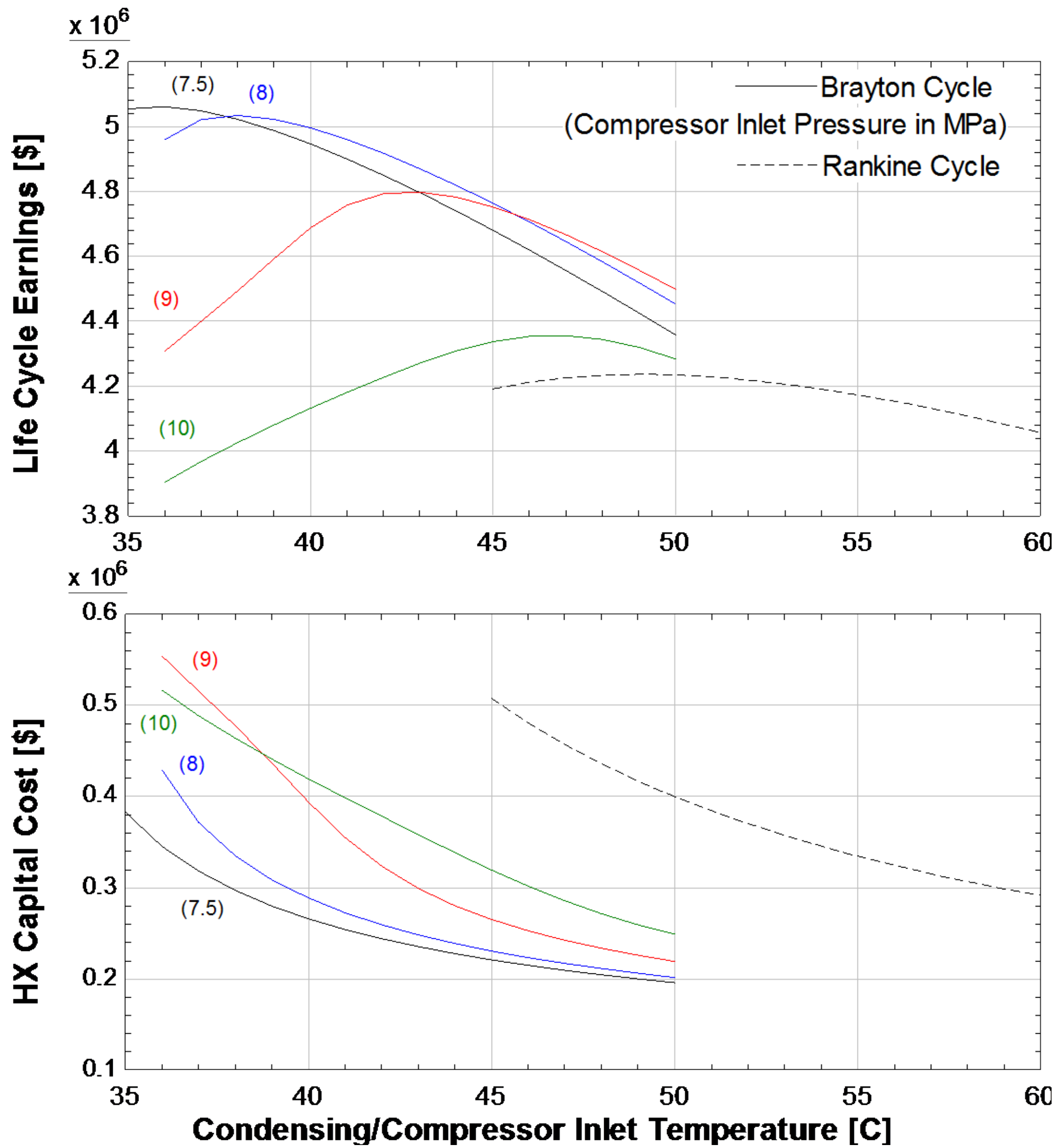


	Brayton Cycle	Rankine Cycle
Working Fluid	Supercritical Carbon Dioxide	Steam
Compact Heat Exchanger	Finned circular tubes, surface CF-7.34	
Cycle Inputs		
Total Net Power	10 MW	
Hot Temperature	700° C	
High Side Pressure	25 MPa	22 MPa
Cold Temperature	Variable	
Low Side Pressure	8 MPa	Saturation
Turbine Efficiency	85%	
Compressor/Pump Efficiency	85%	60%
Recuperator Conductance	1500 kW/K	-
Extraction Pressure	-	1.9 MPa
Cooler Pressure Drop	2%	
Air Side Inputs		
Ambient Temperature	30° C	
Ambient Pressure	1 atm	
Fan Power	Optimized (LCE)	
Fan Efficiency	50%	
Pressure Drop	200 Pa	
Economic Parameters		
Number of Years for Analysis	5	
Fuel Inflation Rate	2%	
Market Discount Rate	3.25%	
Cost of Electricity	0.05 $/kW-hr	
Cost of Thermal Energy	0.465 $/therm	

Life Cycle Earnings Optimization
Fan Power



Life Cycle Earnings Optimization Results



Summary and Conclusions

- Cycle models for S-CO_2 Brayton cycle and steam Rankine cycle
- Dry air-cooling crossflow heat exchanger models for S-CO_2 precooler and steam condenser
- Economic comparison and life cycle earnings analysis
- S-CO_2 Brayton cycle is superior to the steam Rankine cycle for use with dry air-cooling in terms of both cycle efficiency and the physical size of the cooling heat exchanger

Thanks!

QUESTIONS?

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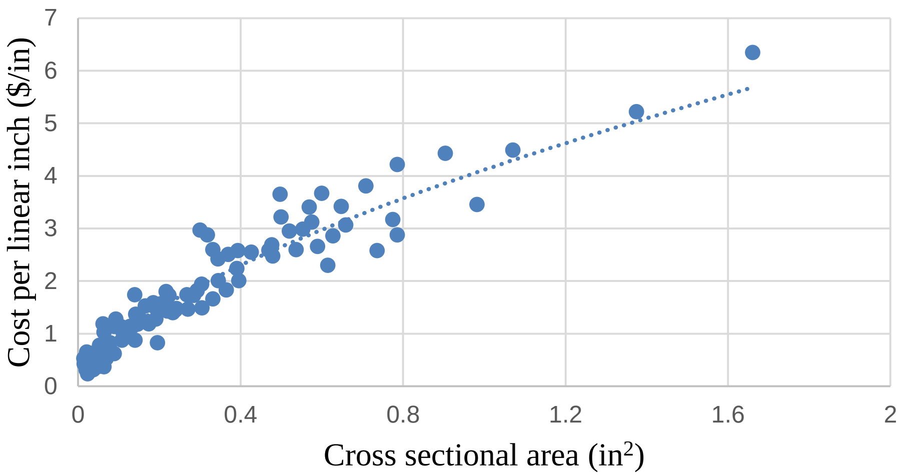
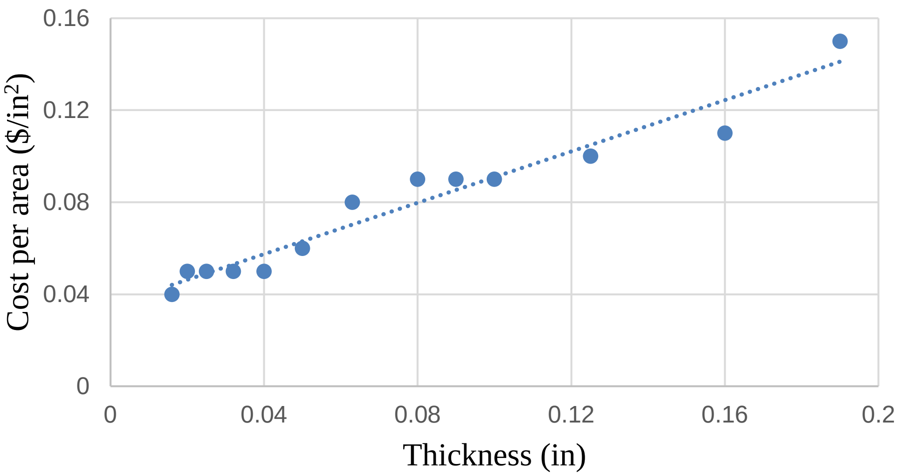
Heat Exchanger Cost Model

Stainless Steel Tubing



$$C_{tubing} = 4.1163\left(A_{tubing}\right)^{0.6349}$$

Aluminum Fins



$$C_{fins} = 0.5576\, th_{fin} + 0.0352$$

Heat Exchanger Cost

$$C_{HX} = 2.887\left(C_{HX,p}\right)^{0.8297}$$

*Material costing from OnlineMetals (2015)