NBSR Thermodynamic Performance Analysis

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Background

- B.S. in Mechanical Engineering at Texas A&M University-Kingsville
- Graduated in May 2018

- Masters student in Engineering Technology (Mechanical Systems) at the University of North Texas starting Fall 2018

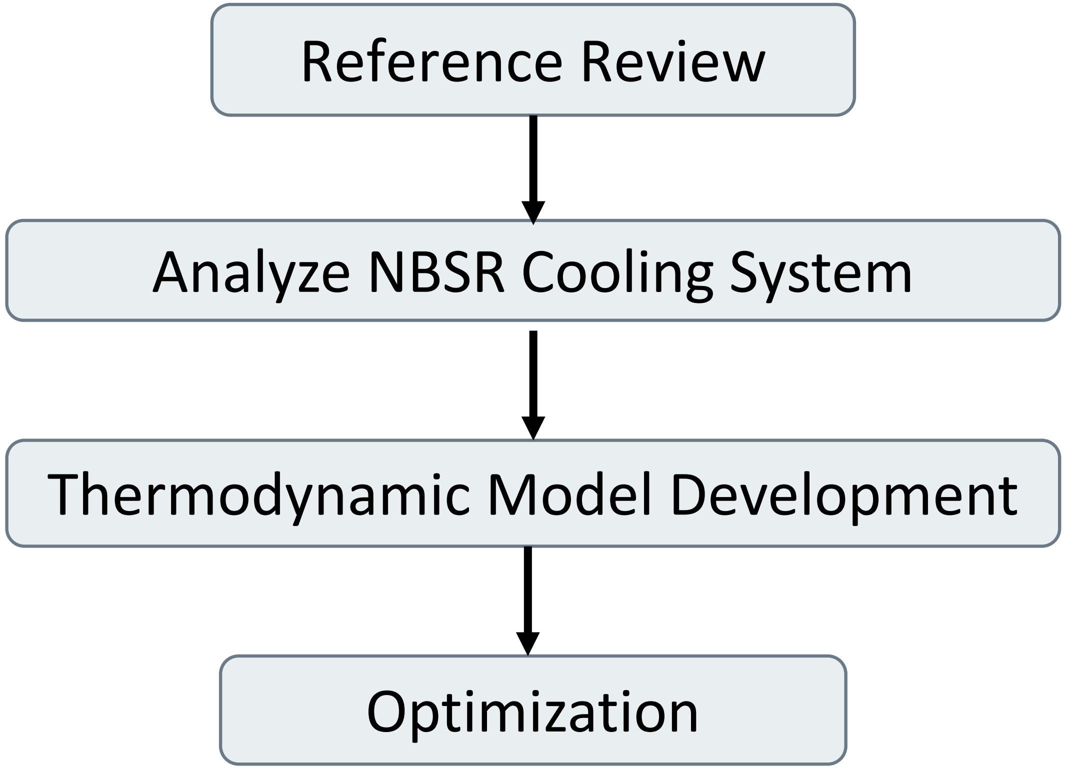
Motivation

- Optimized thermodynamic parameters increase the operational range of the NBSR secondary cooling system.

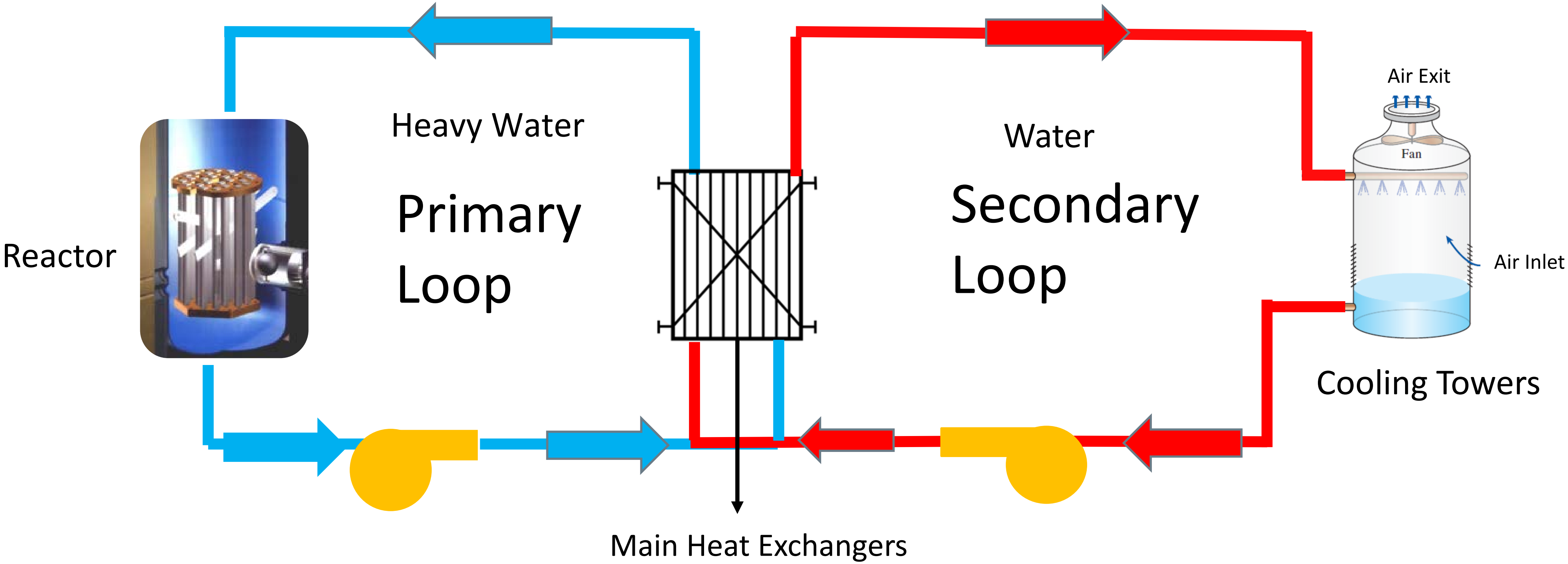
- Impact of environmental conditions.

- Monthly energy savings.

Project Overview



NBSR System Overview

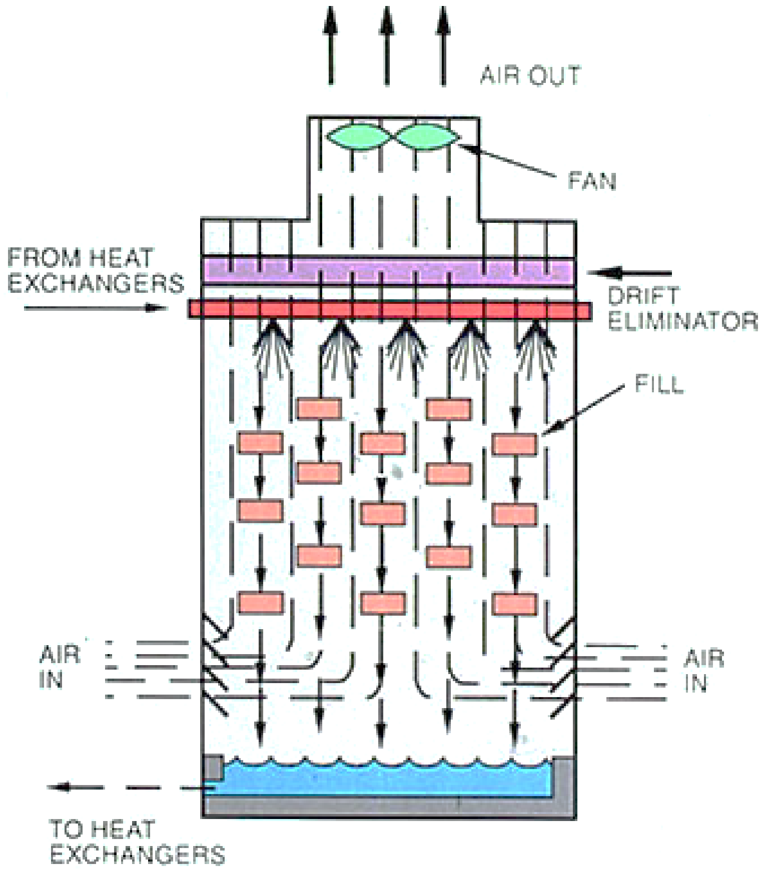


Thermodynamics of Cooling Towers

- Evaporative Cooling

- Dry & Wet-bulb Temperature

$$\boldsymbol{n} = \frac{(t_i - t_o)}{(t_i - t_{wb})} \; \boldsymbol{x\ 100}$$



https://www.suezwatertechnologies.com/handbook/cooling_water_systems/fig31-3.jsp

Hensley J., "*Cooling Tower Fundamentals.*", SPX Cooling Technologies, (2009).

United States Department of Energy, " *Cooling Towers: Understanding Key Components of Cooling Towers and How to Improve Water Efficiency*." (2011).

Assumptions and Limitations

Limitations:

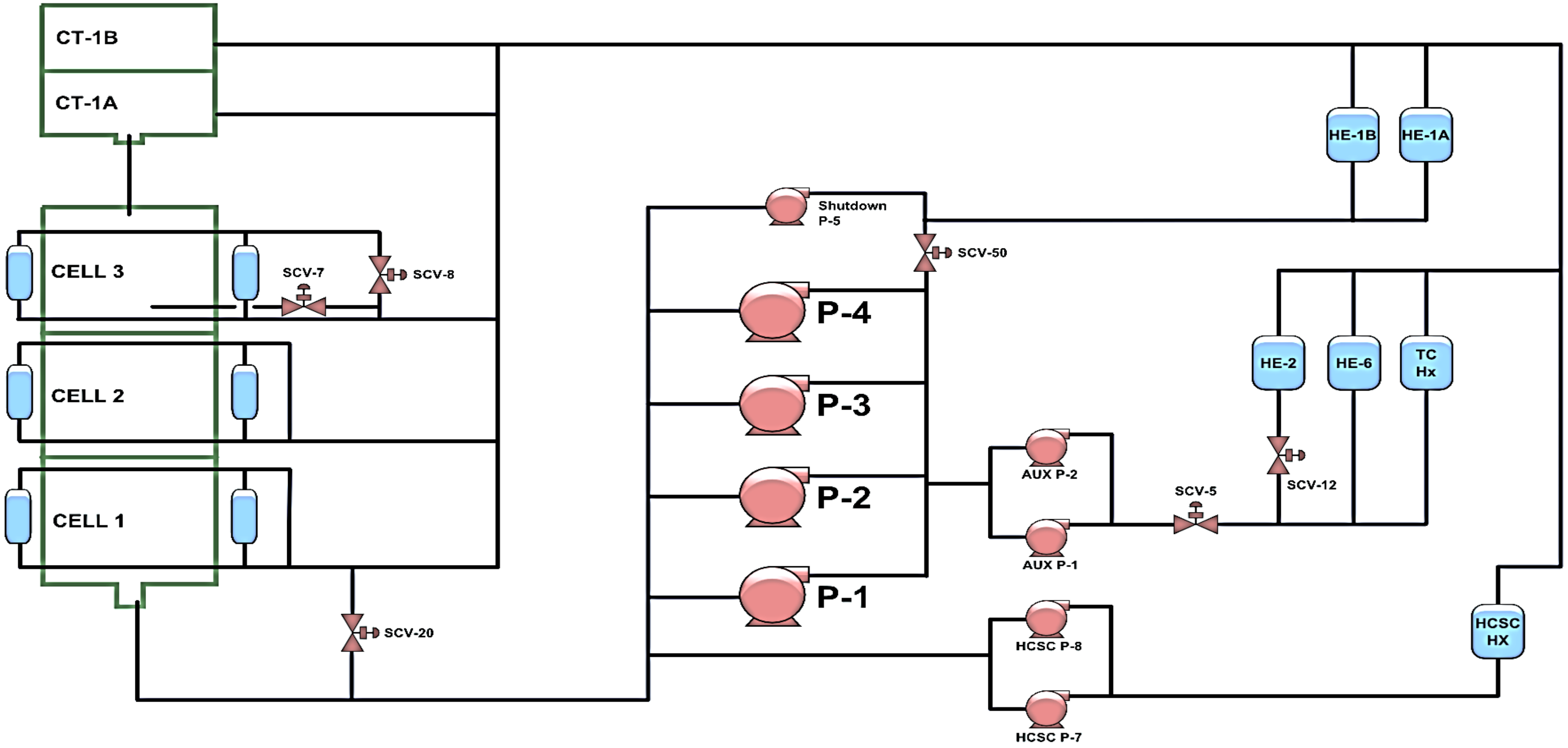
- The reactor outlet temperature must be below 130 °F.
- The reactor inlet temperature is less than 110 °F.
- The secondary cooling flow rate can not be less than 6,000 GPM.

Assumptions:

- Cooling tower cells are combined.
- Heat transfer through the pipes and friction is neglected.
- Secondary and primary pumps are modeled as 1 pump each.

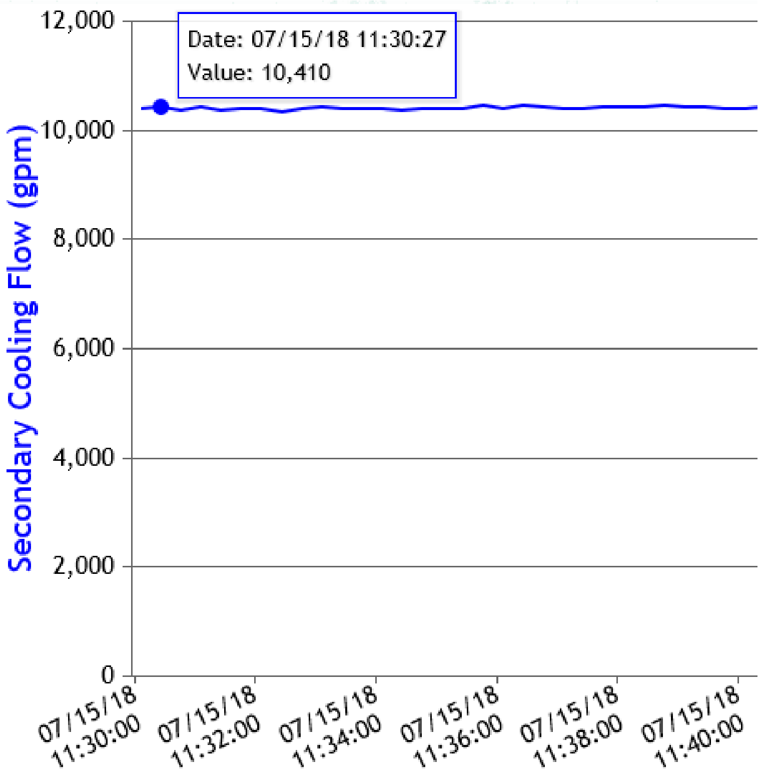
NIST, “*Safety Analysis Report for the National Institute of Standards and Technology Reactor – NBSR.*” National Institute of Standards and Technology

Secondary Loop Diagram



Input Process Parameters

- Reactor Power 20 MW
- Primary Flow 8,760 GPM
- Secondary Flow= 10,400 GPM
- Secondary Aux Flow= 711.4 GPM
- SCV-20 Position = 0%



Heat Exchanger Data

Table 1. Heat Exchanger Parameters

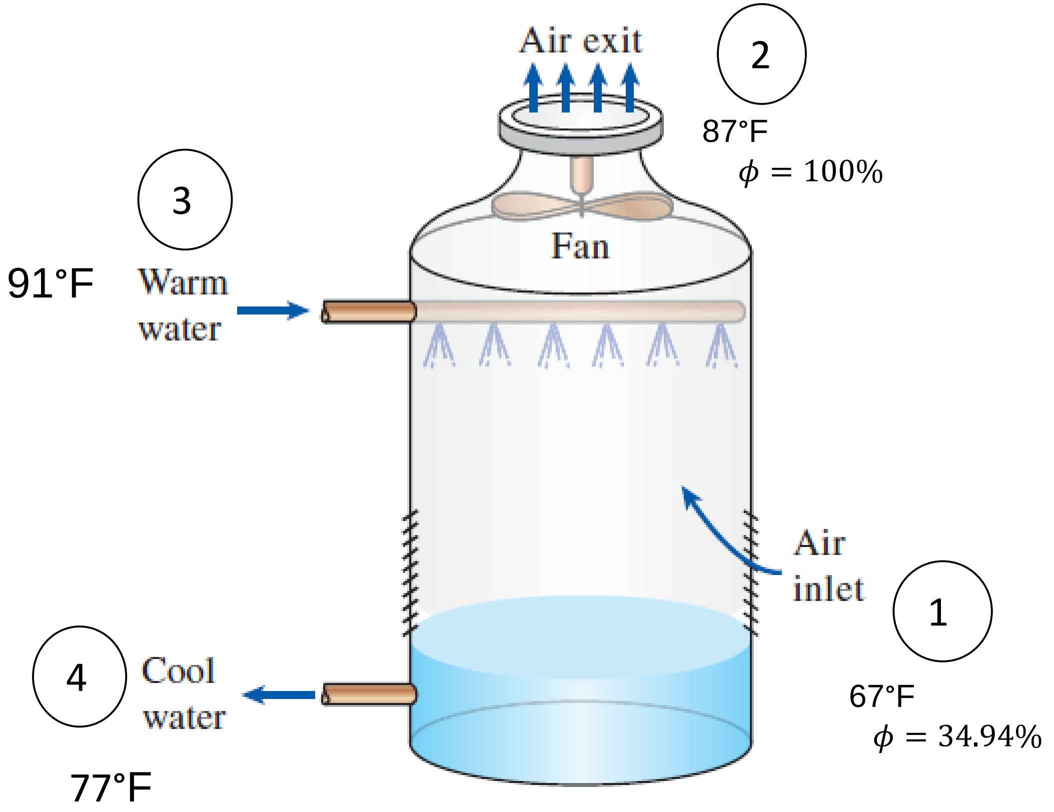
Hot Side				Cold Side			
	Inlet Temp (°F)	Outlet Temp (°F)	Flow (GPM)	Inlet Temp (°F)	Outlet Temp (°F)	Flow (GPM)	Heat Duty (kW)
HE-1A	113.6	100.4	4250	77	90	4500	8,555.92
HE-1B	113.6	102.4	4250	77	92	4800	10,529.39
HE-2	103.16	80.52	170	77	83.44	102	89.45
HE-6	101.96	95.15	222.8	77	91.5	567.5	829.52
HE-9	108.43	102	7.96	77	82	41.9	30.67
HE-10	95	90	490	77	80	388.6	170.89

Cooling Tower Parameters

$\sum_{in} \dot{m}$h=$\sum_{out} \dot{m}$h=$\dot{m}_{a_1}$+$\dot{m}_3 h_3 = \dot{m}_{a_2} h_2 + \dot{m}_4 h_4$

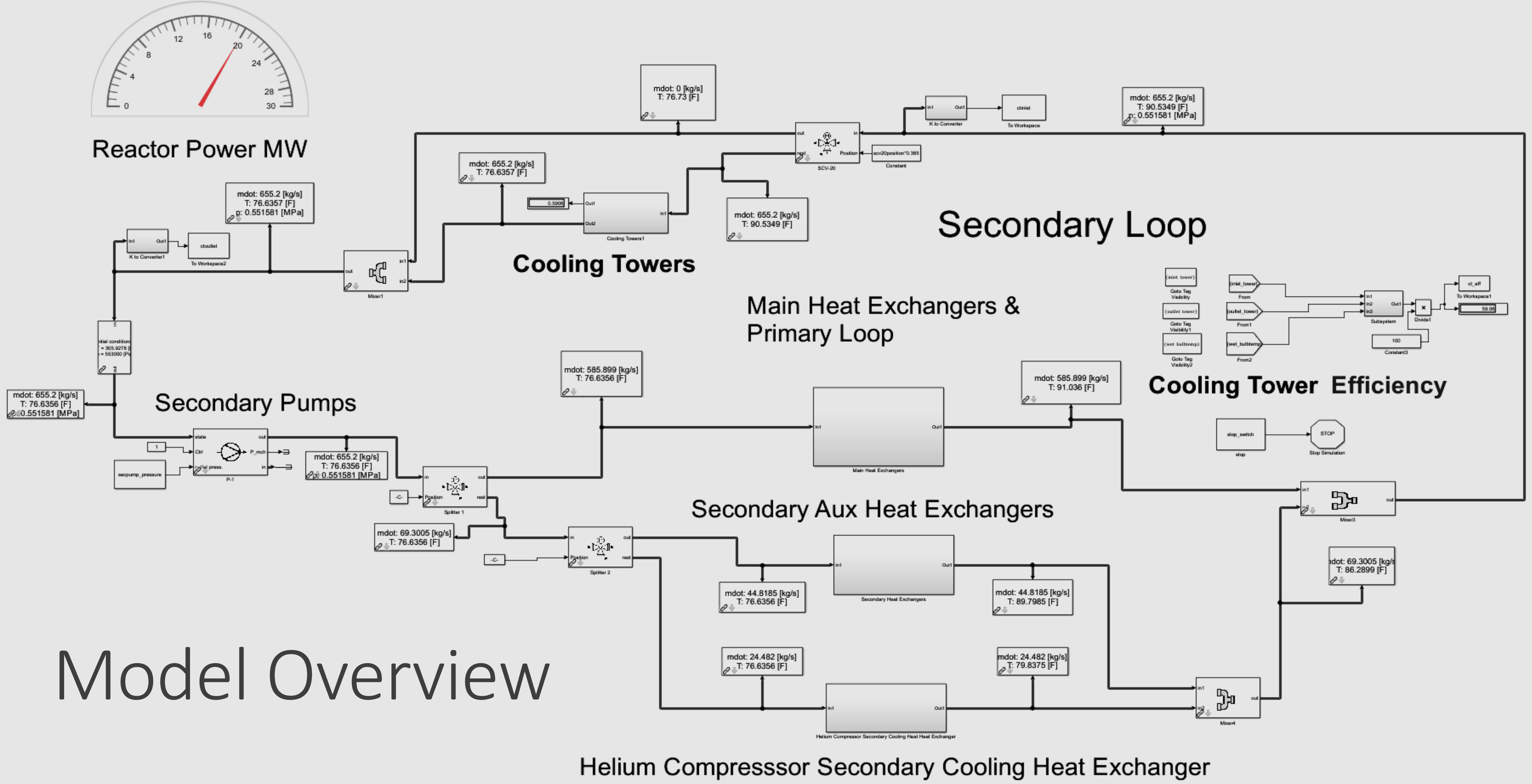
$$\dot{m}_a = \frac{\dot{m}_3(h_3 - h_4)}{(h_2 - h_1) - (\omega_2 - \omega_1)h_4}$$

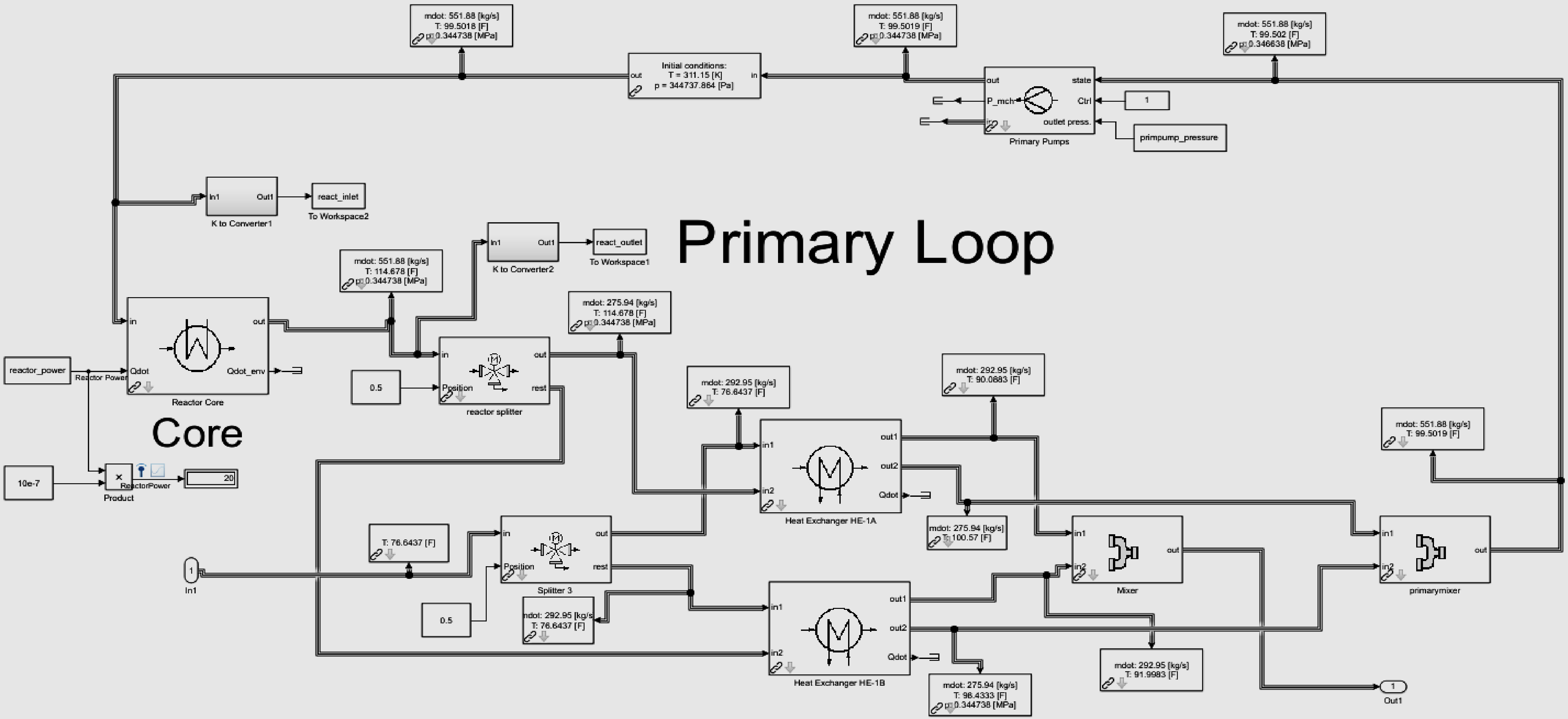
- Wet-bulb Temp = 67 °F
- Dry Bulb Temp= 87 °F
- Relative Humidity of Ambient Air = 34.94 %
- Cooling Tower Airflow= 405.99 $\frac{m^3}{s}$



Çengel Y. A. Boles, M. A. "*Thermodynamics: An engineering approach*." Boston: McGraw-Hill (2015).

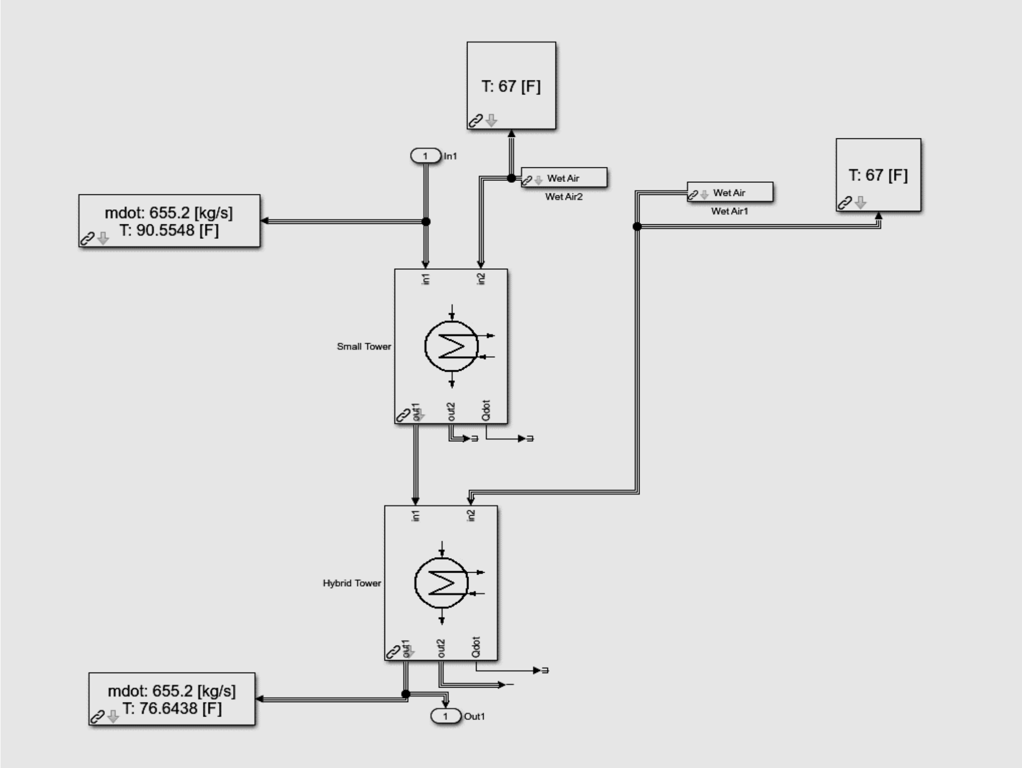
Model Overview





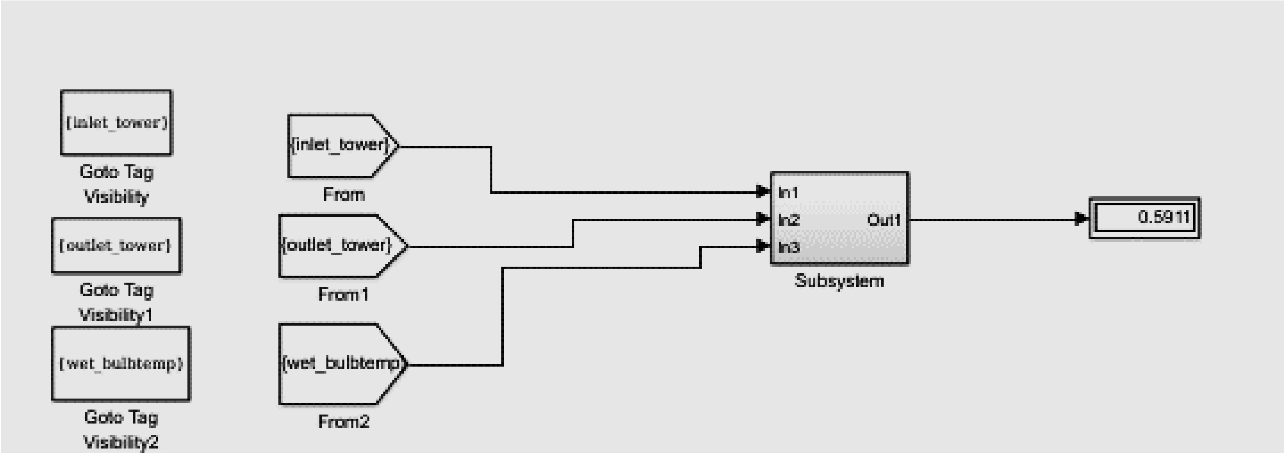
Main Heat Exchangers

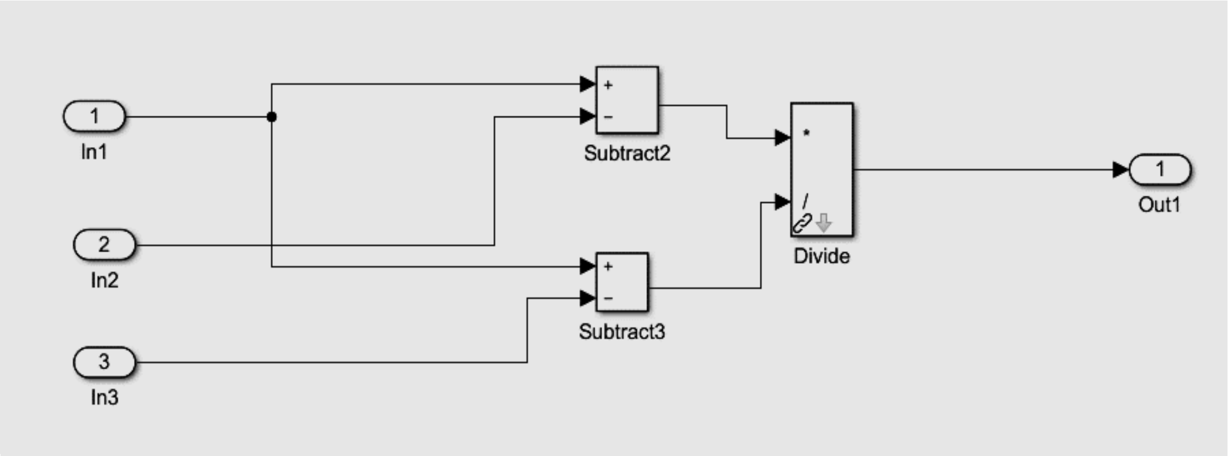
Cooling Towers



Cooling Tower Efficiency Calculator

$$\boldsymbol{n} = \frac{(t_i - t_o)}{(t_i - t_{wb})} \; \boldsymbol{x\ 100}$$





Model Verification

Table 2. Case 1 at 7/15/18 11:30 a.m.

	Historical Data Temperature (°F)	Simulink Model Temperature (°F)	Relative Error (%)
Reactor Inlet	100.4	99.5	0.90
Reactor Outlet	114.5	114.7	0.17
Cooling Tower (Outlet)	75	76.6	2.13

Table 3. Case 2 at 7/15/18 5:30 p.m.

	Historical Data Temperature (°F)	Simulink Model Temperature (°F)	Relative Error (%)
Reactor Inlet	104	101.3	2.60
Reactor Outlet	118.2	116.4	1.52
Cooling Tower (Outlet)	78	78.6	0.77

Table 4. Case 3 at 7/15/18 7:30 p.m.

	Historical Data Temperature (°F)	Simulink Model Temperature (°F)	Relative Error (%)
Reactor Inlet	104.5	102.4	2.01
Reactor Outlet	118.5	117.1	1.18
Cooling Tower (Outlet)	80	79.5	0.63

Analysis and Results

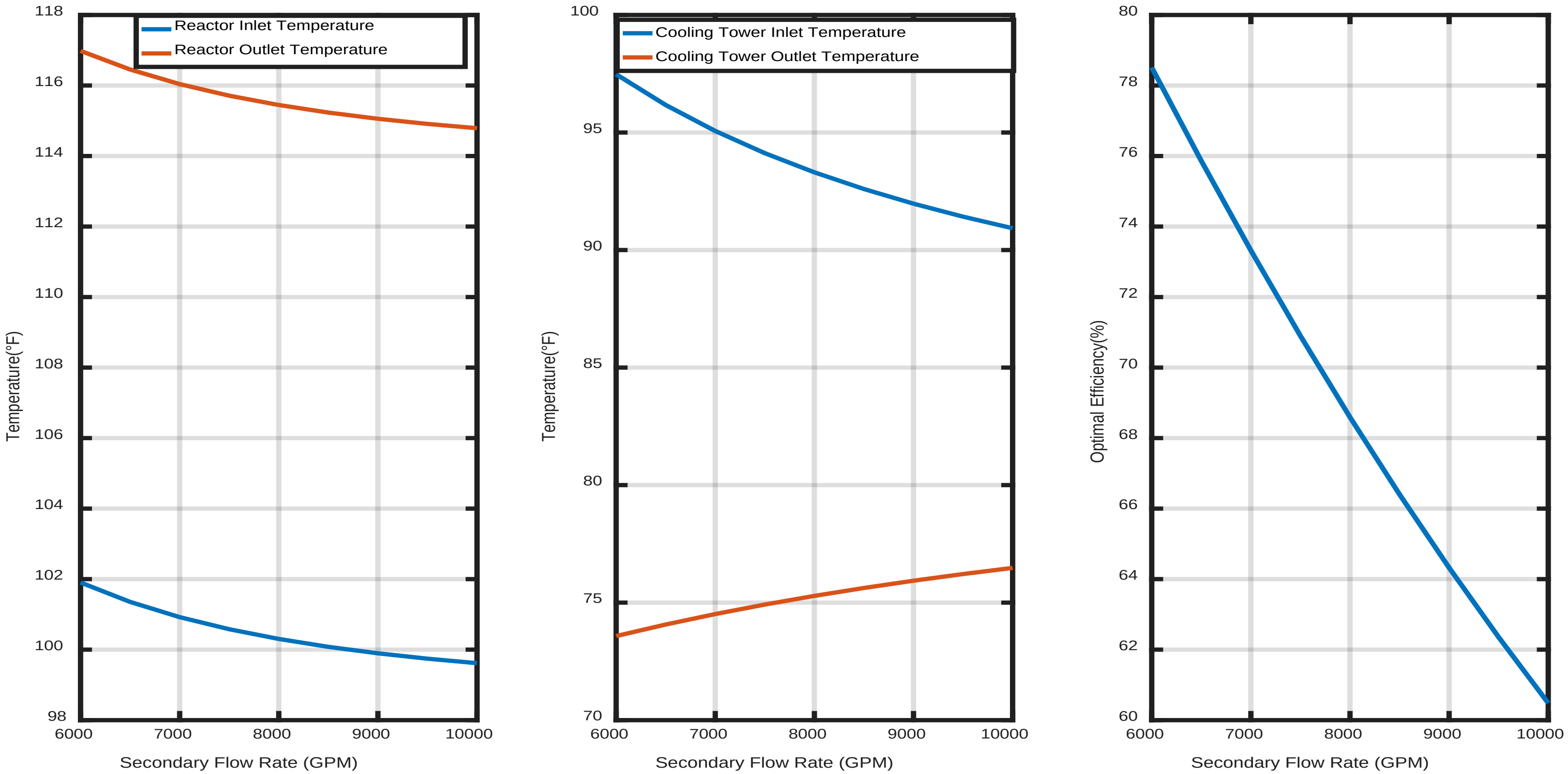
- Conducted by varying environmental wet-bulb temperatures, secondary flow rates, and SCV-position.

- MATLAB script was written to perform simulations.

- Model converged at 0.00001 deviation.

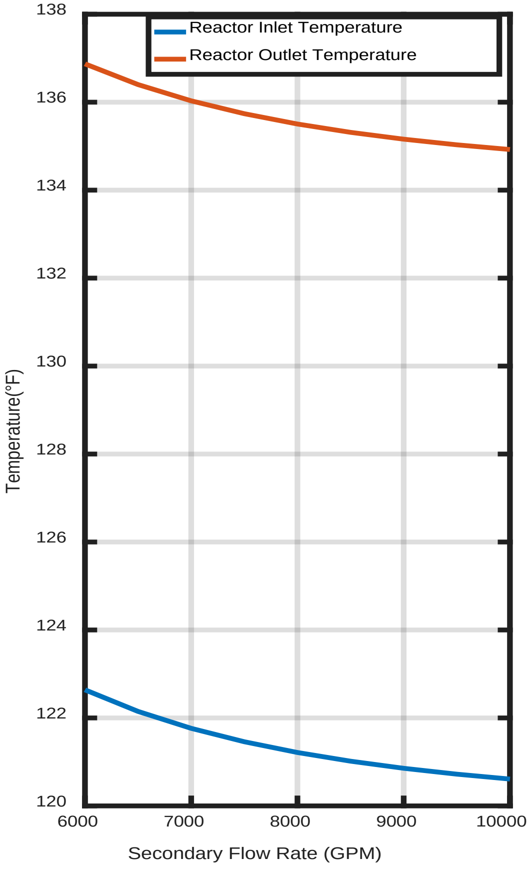
Effect of Secondary Flow Rate at Benchmark

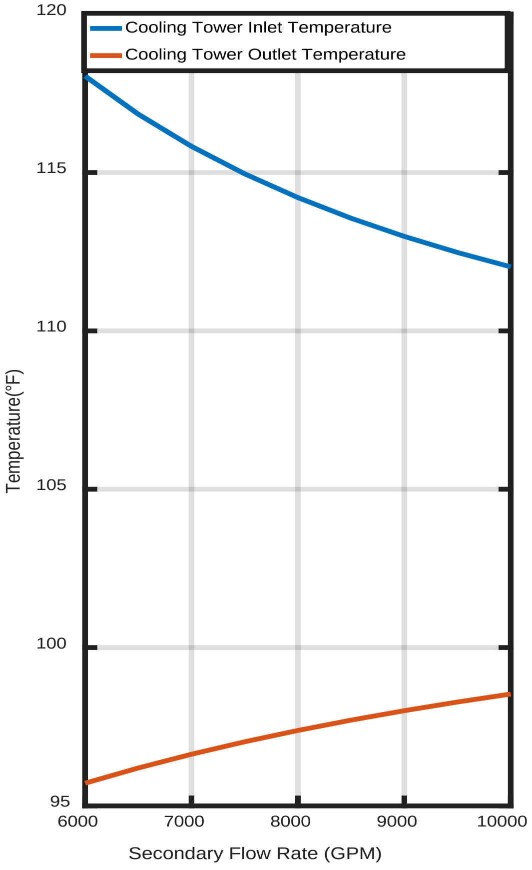
- 67°F Wet-bulb, 34.94% Relative Humidity

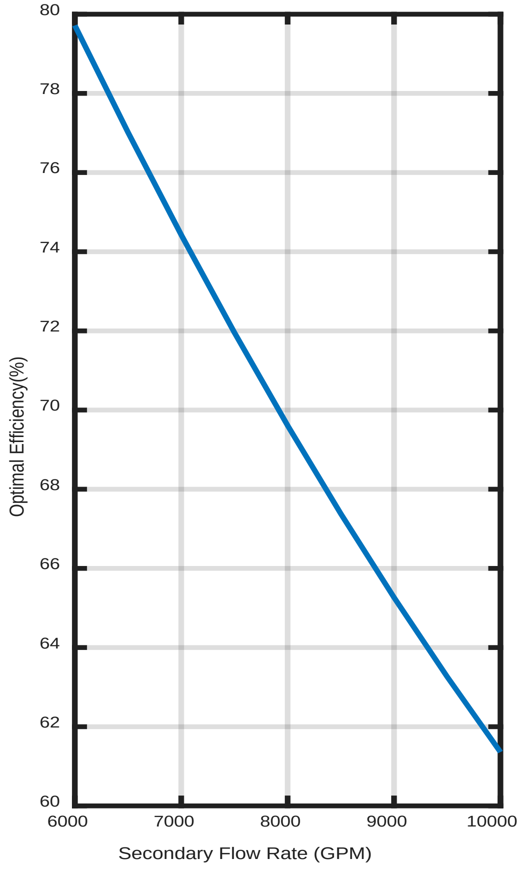


Effect of Secondary Flow Rate during Summer

- 90°F Wet-bulb, 60 % Relative Humidity

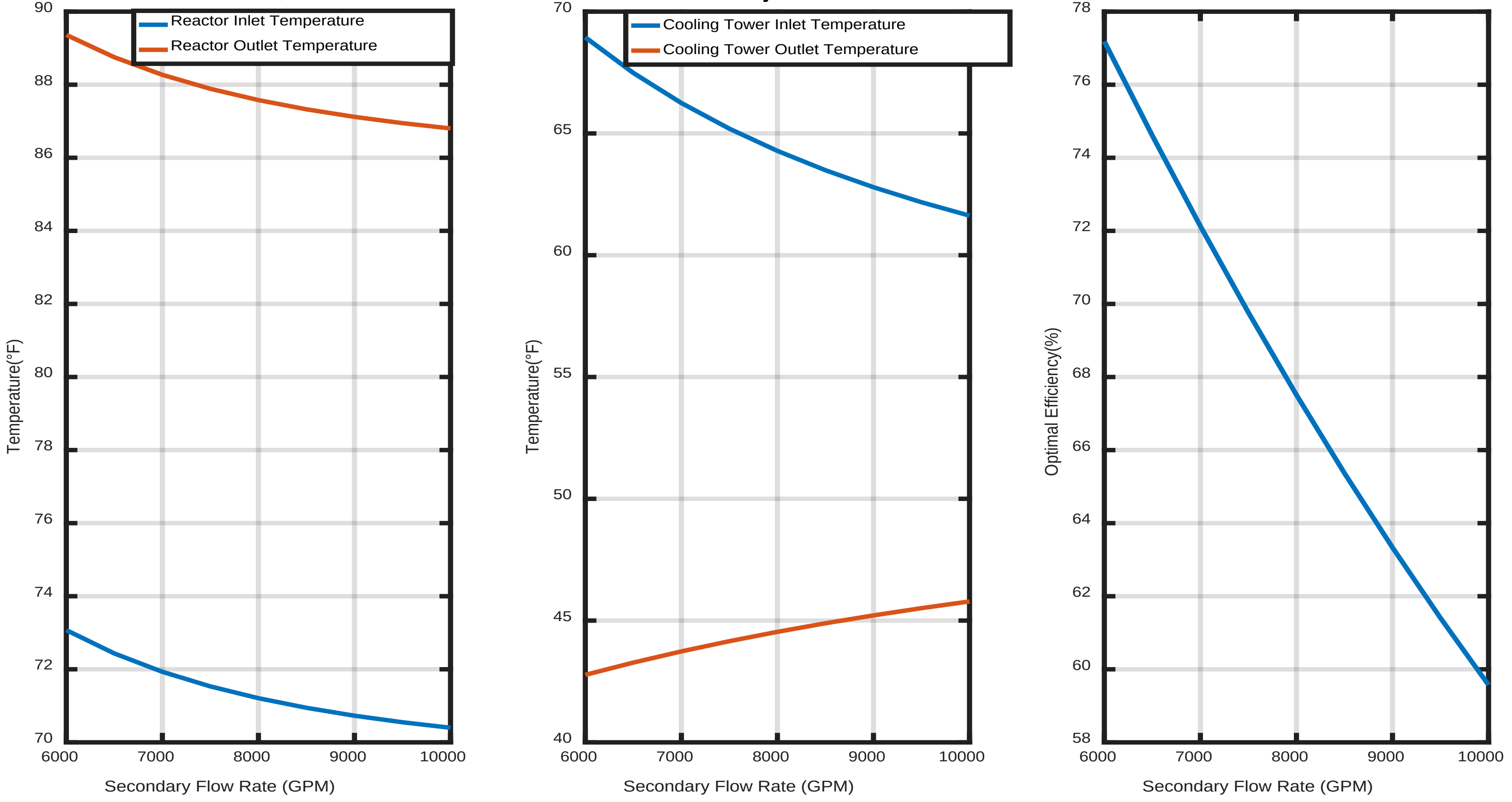






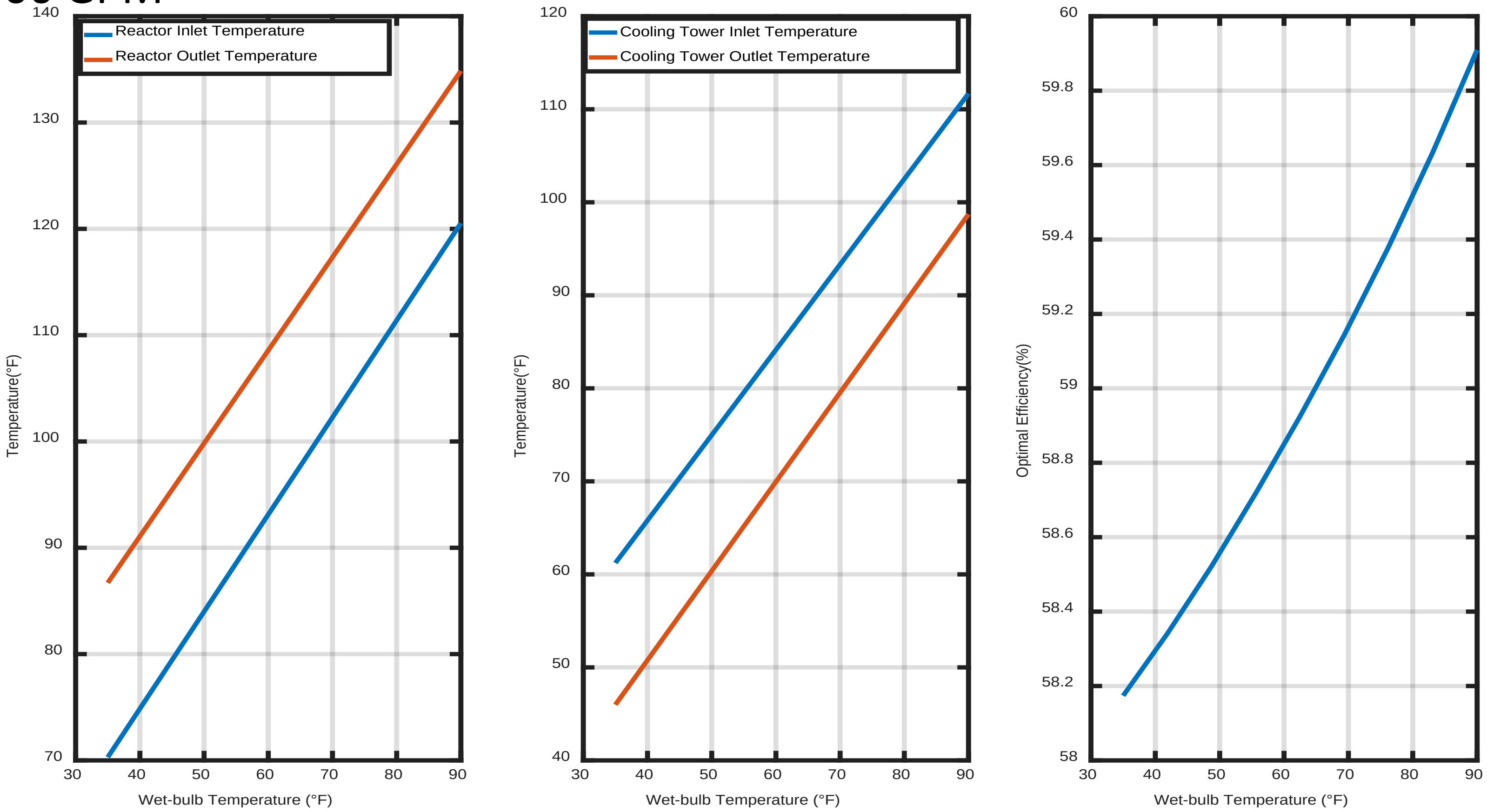
Effect of Secondary Flow Rate during Winter

- 35°F Wet-bulb, 60 % Relative Humidity

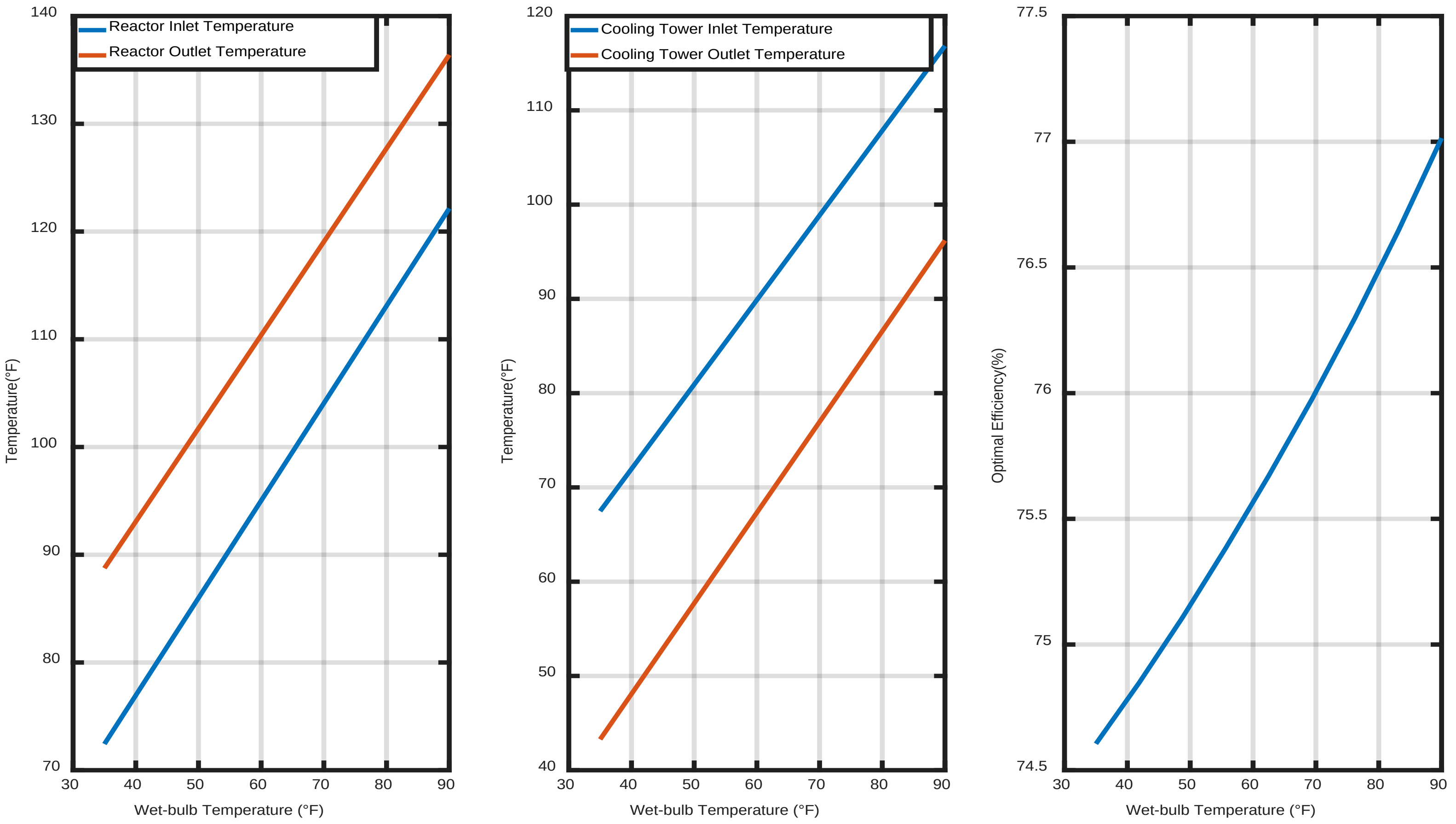


Effect of Wet-bulb Temperature at Benchmark

- 10,400 GPM

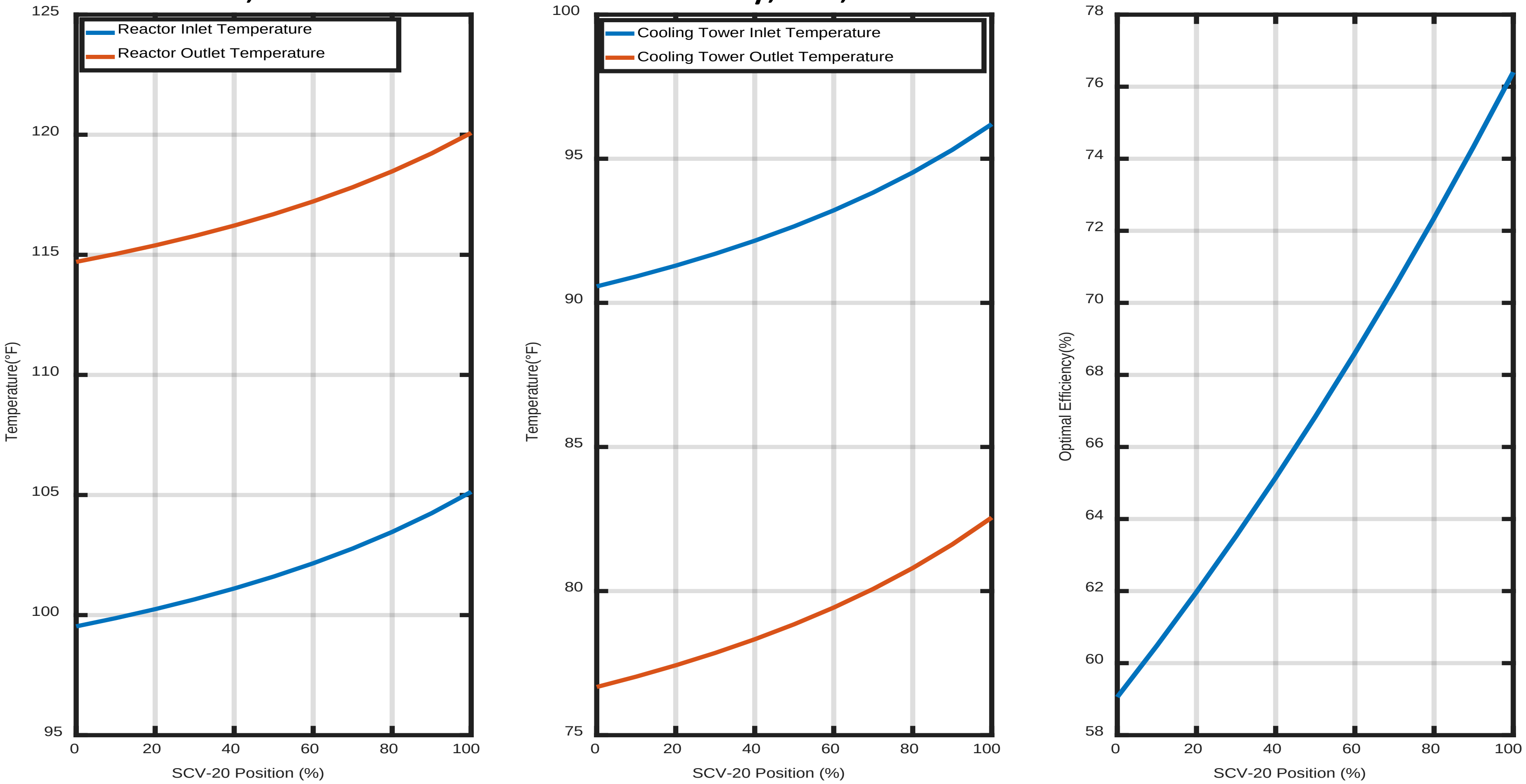


Effect of Wet-bulb Temperature at 6,500 GPM



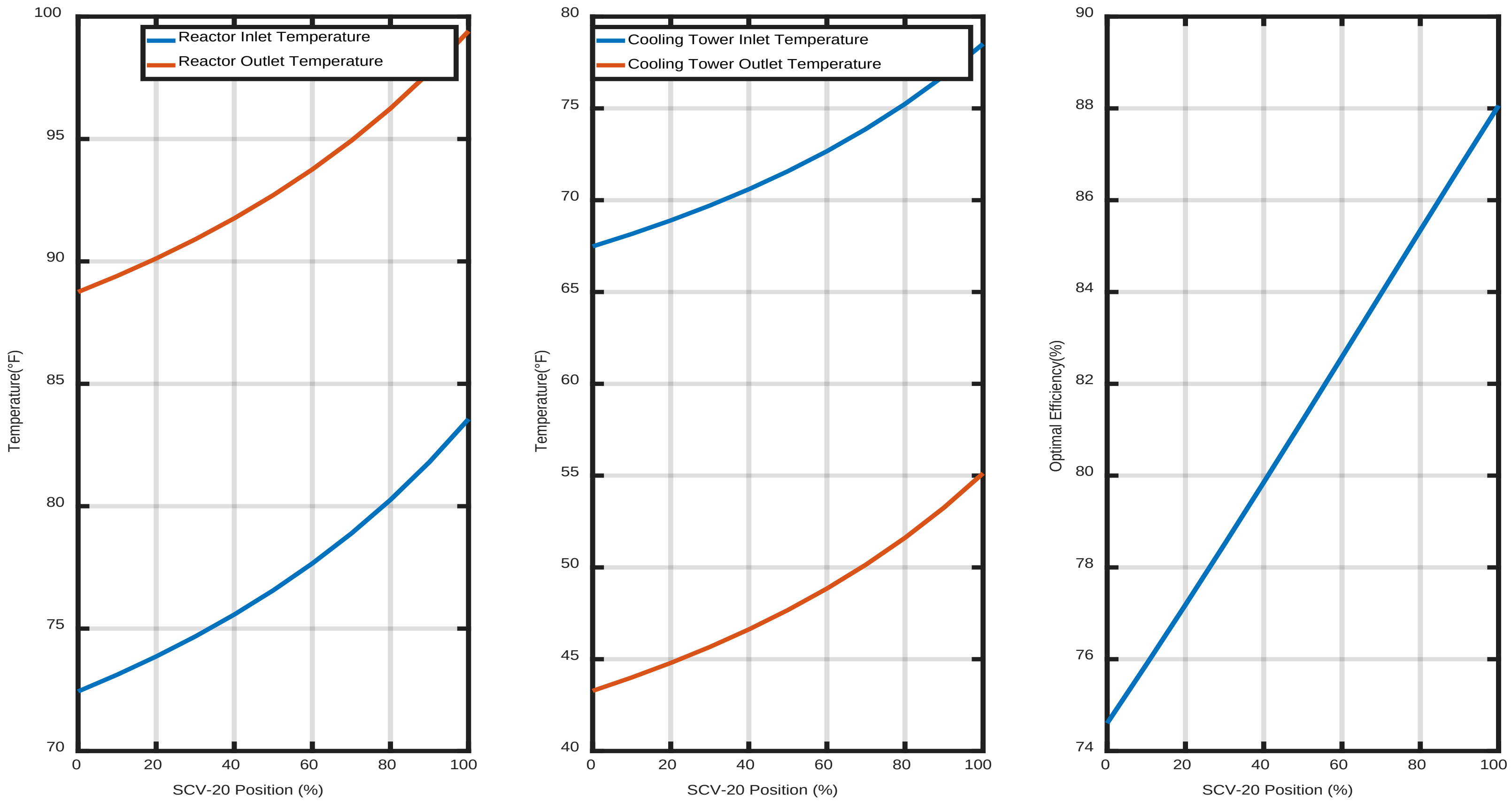
Performance of SCV-20 at Benchmark

- 67°F Wet-bulb, 34.94% Relative Humidity, 10,400 GPM



Performance of SCV-20 during Winter

- 35℉ Wet-bulb, 60 % Relative Humidity, 6,500 GPM



Key Findings

1. Secondary flowrate

- For every decrease of 500 GPM cooling tower efficiency increased by ~ 3.4% and increased reactor inlet temperature by ~ 0.5%.

2. Wet-bulb temperatures

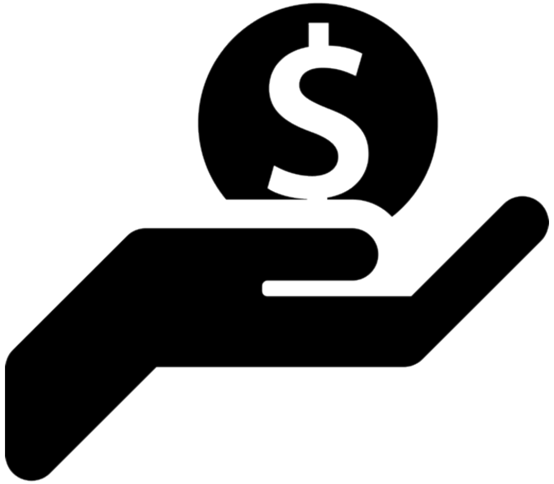
- For every 6.875 °F increase in wet-bulb temperature, reactor inlet temperatures increase by ~7%.

3. SCV-20 position

- For every 10% SCV-20 position change, cooling tower efficiency will increase by ~2.5% and reactor inlet temperature will increase by ~0.6%.

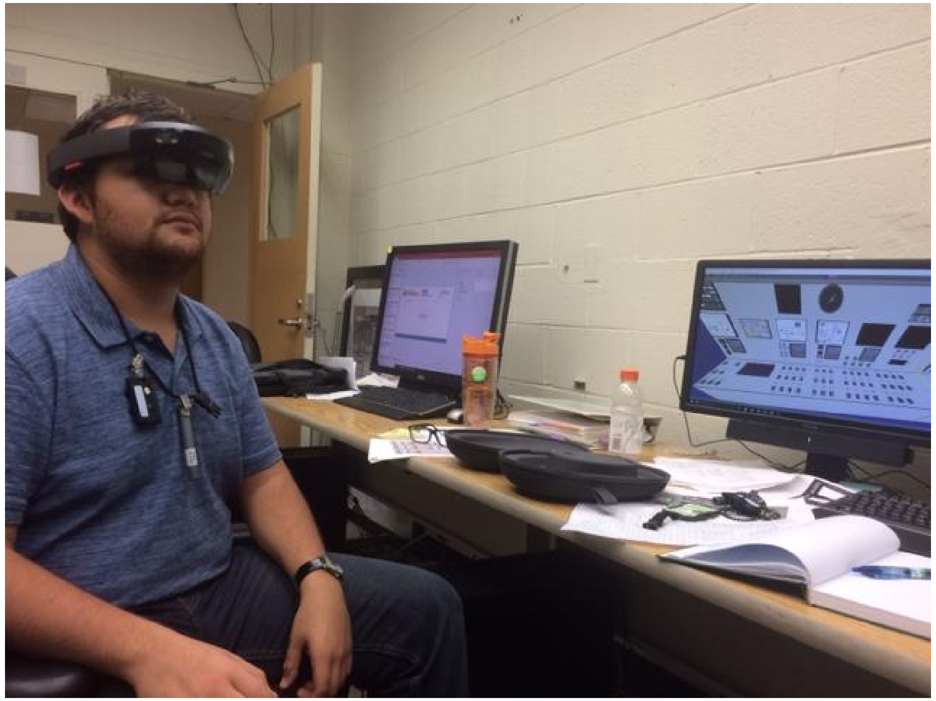
Energy Savings

- If 6,500 GPM secondary flow rate was implemented during summer months cooling tower efficiency would increase by about 27 % and save approximately $5,800 per month.



Future Work

- Thermodynamic engine for NBSR Augmented Reality Simulator.
- Model will be available when further analysis is needed.
- Engineering changes affecting the reactor thermodynamics can be analyzed using the model.



Conclusion

- Thermodynamic model was created.

- Decreasing secondary flow rate improves cooling tower efficiency.

- Energy savings will be present.

Acknowledgements

- Dr. Dağistan Şahin
- Dr. Xue Yang
- Daniel Mattes
- Joseph Dura
- Julie Borchers
- Reactor Operations and Engineering
- Special thanks to Samuel MacDavid, Scott Arneson, Paul Liposky, Marcus Schwaderer, Dan Khan, Randolph Strader and NCNR reactor operators

Disclaimer

Certain commercial equipment, instruments, or materials are identified in this study in order to specify the experimental procedure adequately. Such identification is not intended to imply recommendation or endorsement by the National Institute of Standards and Technology, nor is it intended to imply that the materials or equipment identified are necessarily the best available for the purpose.

Thank You