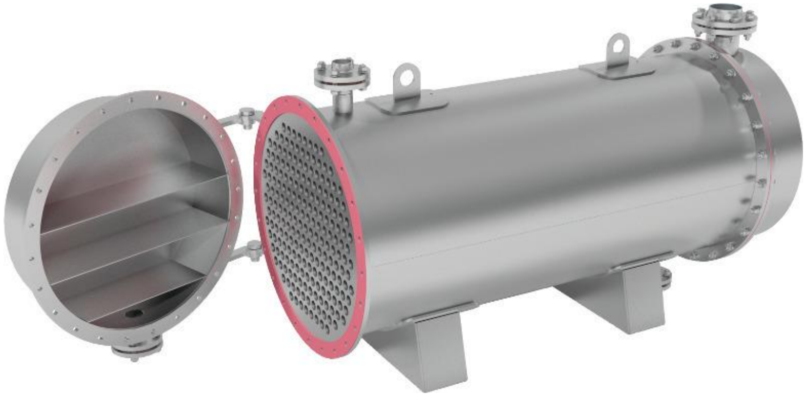
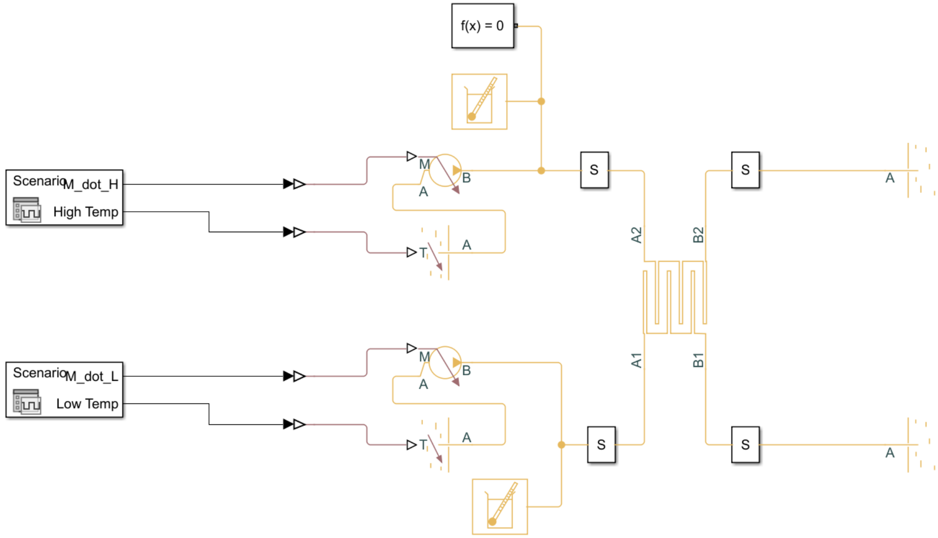
Predictive Maintenance of a Heat Exchanger





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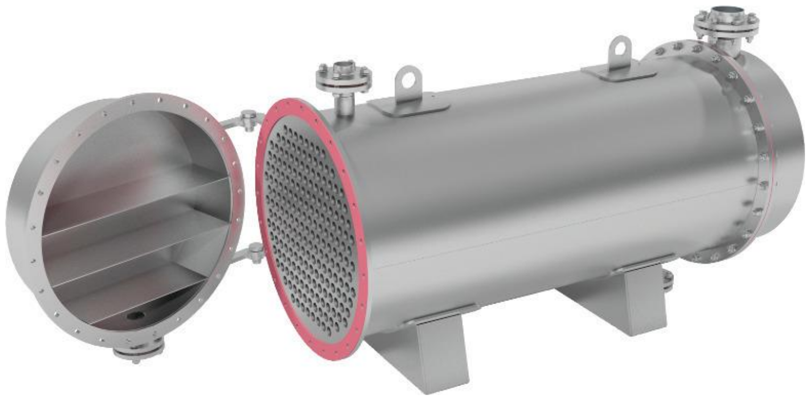
Motivation

- TEMA heat exchangers
  - Over 30 heat exchangers in refinery
  - 200 to 350 heat exchangers in petrochemical plants
- Shell and tube type heat exchangers
- Focus on heat exchanger fouling
- Degrade overall efficiency, increase downtimes
- Implicit equations based on field data



Heat Exchanger Model with E-NTU Method

$$Q_1 = -Q_2 = \epsilon Q_{Max},\ 0 < \epsilon < 1$$

$$Q_{Max} = C_{Min}(T_{1,in} - T_{2,in})$$

$$C_{Min} = min(\dot{m}_1 c_{p,1}, \dot{m}_2 c_{p,2})$$

$$\epsilon = \frac{2}{1 + C_{rel} + \sqrt{1 + C_{rel}^2}\,\frac{1+\exp\left(-NTU\sqrt{1+C_{rel}^2}\right)}{1-\exp\left(-NTU\sqrt{1+C_{rel}^2}\right)}}$$ [1]

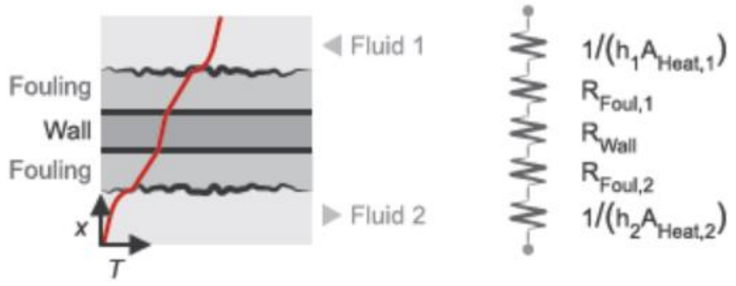
$$C_{rel} = \frac{C_{Min}}{C_{Max}}$$

$$NTU = \frac{1}{C_{Min} R_{Overall}}$$

$$R_{Overall} = \frac{1}{U_{overall} A_{Heat}} = \frac{1}{h_1 A_{Heat,1}} + R_{Foul,1} + R_{Wall} + R_{Foul,2} + \frac{1}{h_2 A_{Heat,2}}$$

- Variables depending on operating conditions and cases – short time process
- Variables depending on deposition of fouling layers – long time process

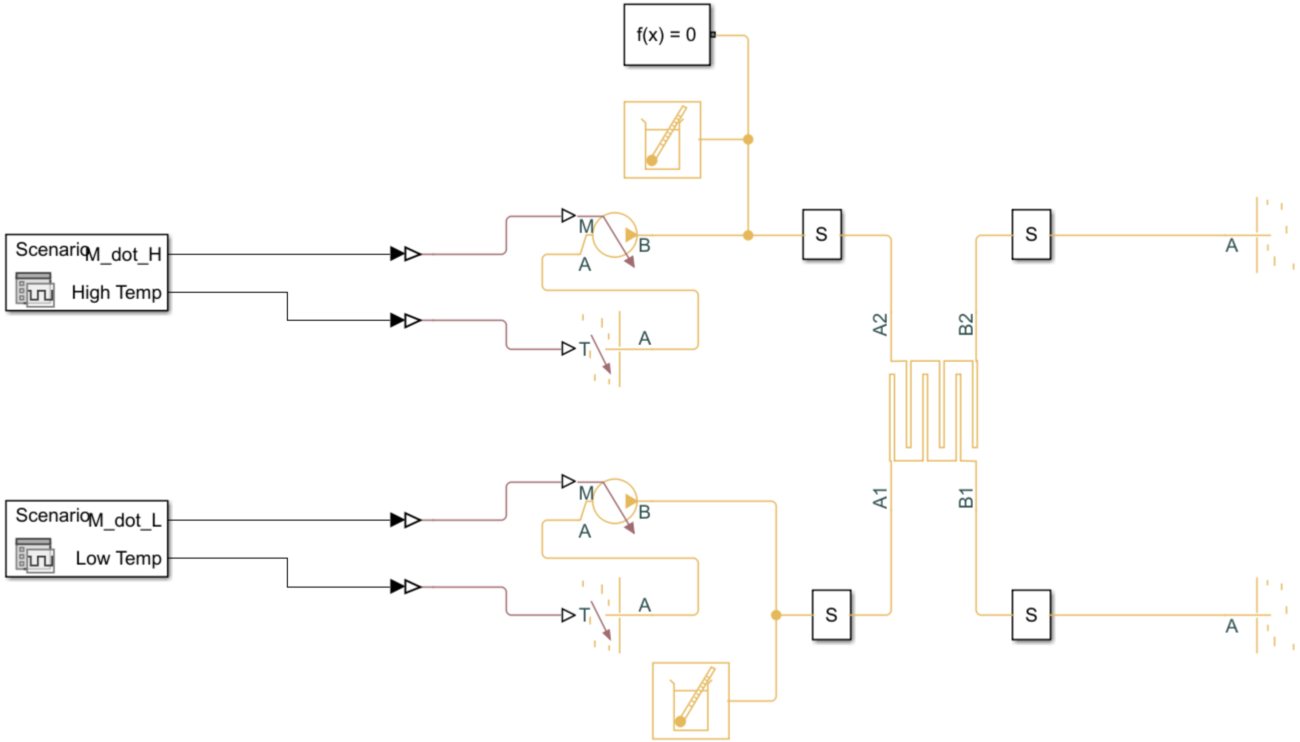
Heat Transfer From Fluid 1 to Fluid 2

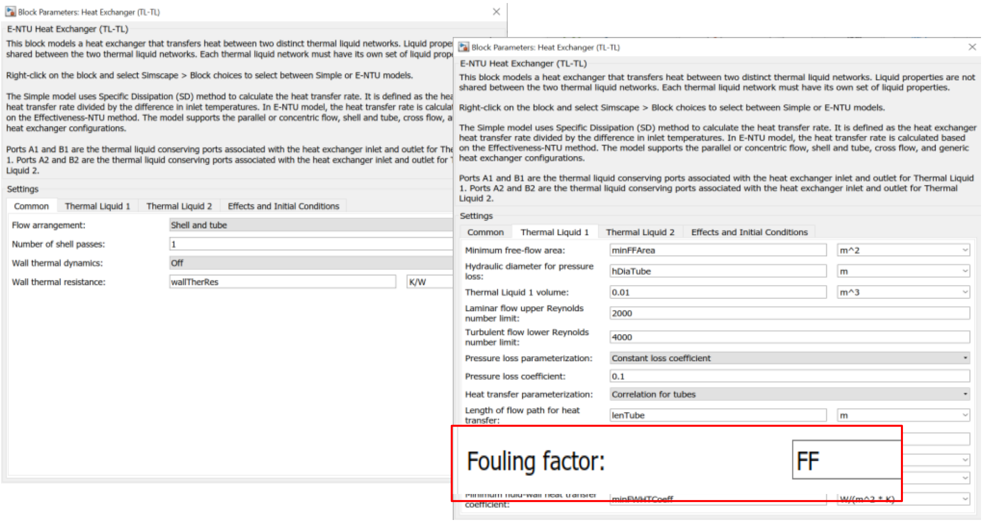


[1] Holman, J. P. *Heat Transfer*. 9th ed. New York, NY: McGraw Hill, 2002.

Simscape Model

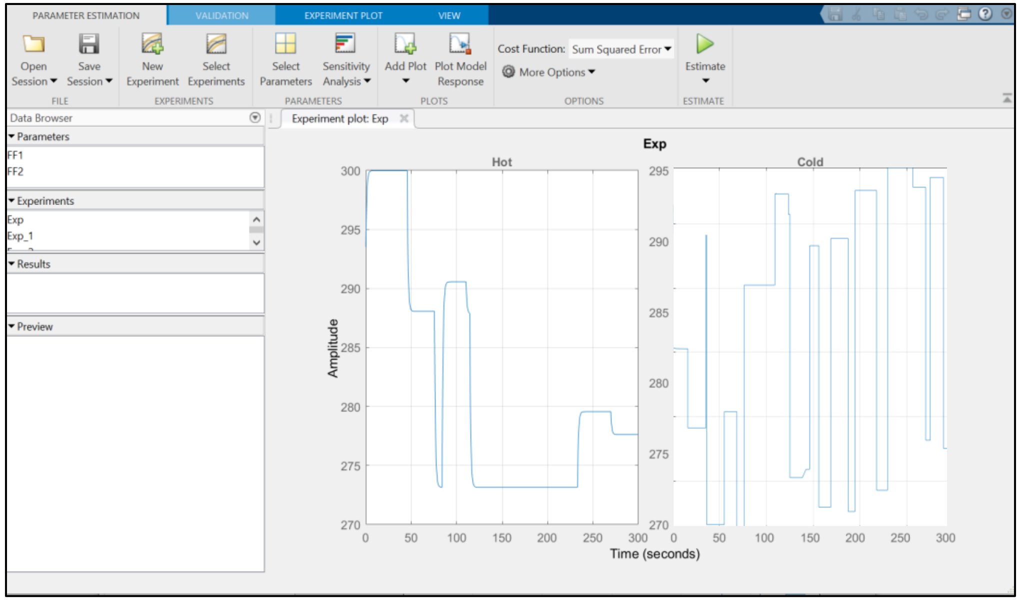
- Thermal liquid network model
- E-NTU heat exchanger block
- Short time process variables
  - Signal Editor with field data
- Long time process variables
  - Unknown, to be estimated





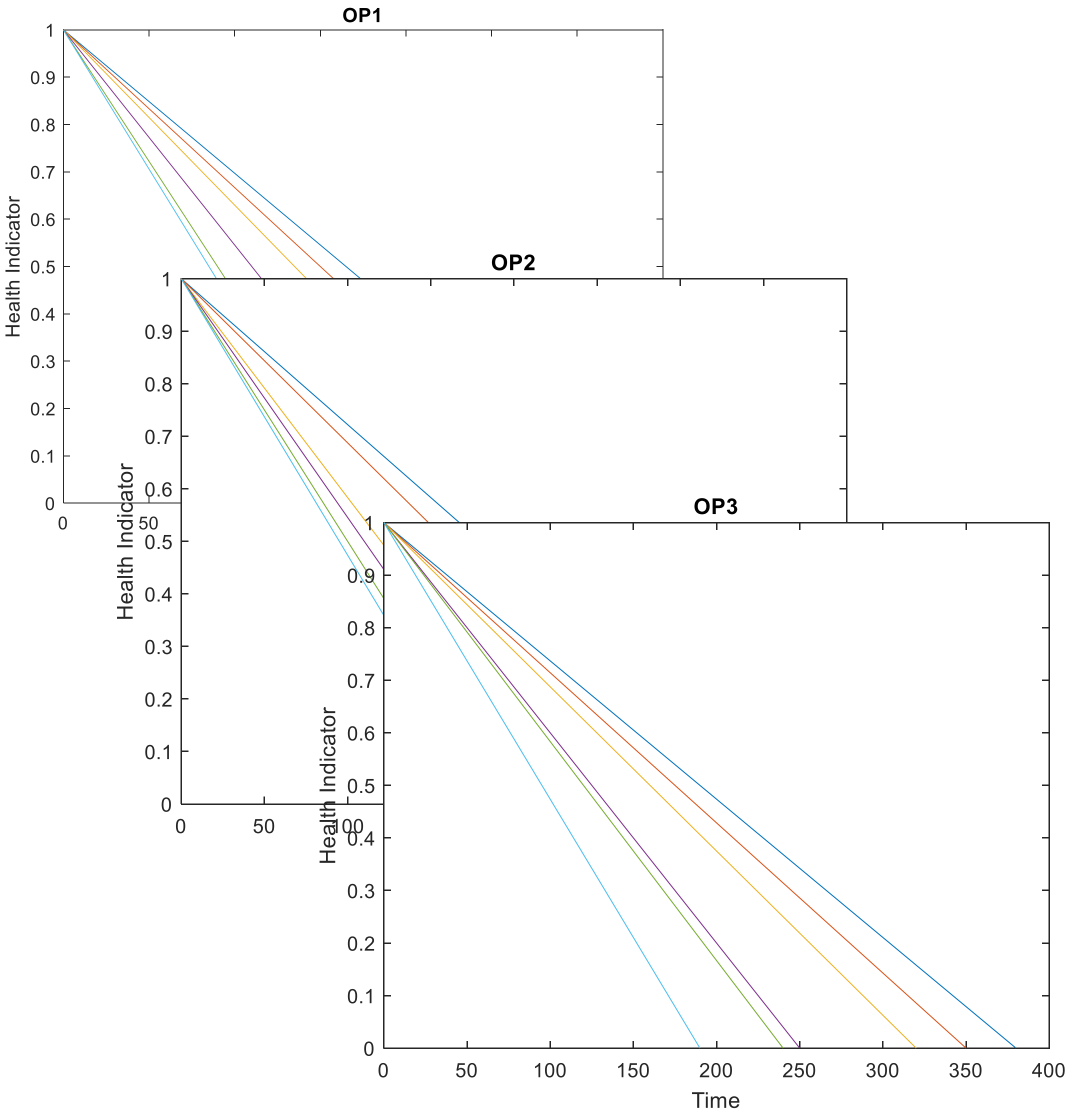
Estimating Fouling Factor With Simulink Design Optimization

- Parameterizing fouling factors
- Separate field data for controlled operating conditions – temperature and mass flow rate
- Iterate fouling factor estimation over time to correlate with efficiency of heat transfer
- Multiple scenarios of operating conditions for fouling factor correction



Fluid (Water)	Fouling Resistances(m^2K/KW)	
Demineralized or distilled	0.009	
Hard	0.043	
Soft	0.017	
Treated cooling tower water	0.034	
Coastal sea water	0.043	
Ocean sea water	0.026	
River water	0.043	
Engine jacket	0.052	
Lubricating oil	0.017	- 0.043
Vegetable oil	0.017	- 0.052
Organic solvents	0.009	- 0.026
Steam	0.009	
General process fluids	0.009	- 0.052

Heat Transfer Degradation Simulations and RUL Estimation



- Similarity-based RUL model
- Generation of degradation map
  - Simulating model with degradation time
  - Simulating model with operating conditions
- Parameter estimation of fouling factors
  - Inlet temperature, mass flow rate couples
  - Measurements of heat exchanger outlet temperature
  - Mapping back to degradation map to determine current degradation status

Summary

- Heat exchanger efficiency degradation with fouling
- Identified variables of interests with heat transfer equations
- Modeled heat exchanger with thermal liquid network using Simscape
- Searched ranges of fouling factor related to degradation and operating conditions
- Generated degradation map using simulations under multiple scenarios
- Identified current degradation level by back-calculating fouling factors