HElium Component Testing Out-of-pile Research (HECTOR) Facility

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Objective

- Design a helium component testing loop that will be able to test various components such as heat exchangers, valves, circulators, etc. at operating conditions up to 8MPa and 800°C.
- These conditions will help component testing supporting microreactor development and demonstration.

US Reactor Design Concepts

Developer	Name	Power Output (MWe/MWth)	Fuel	Coolant	Moderator	Gas Pressure	Outlet Temperature
BWXT	BANR	17/50	TRISO	He	Graphite	–	–
HolosGen	HolosQuad	10-13/–	TRISO	He/CO_2	–	7 MPa	620°C
Nugen, LLC	NuGen Engine	2-4/–	TRISO	He	–	–	–
Radiant Nuclear	Kaleidos Battery	1.2/–	TRISO	He	Graphite	–	700°C
Ultra Safe Nuclear	Micro Modular Reactor	5/15	TRISO	He	Graphite	3 MPa	565°C
X-Energy	Xe-100	80/200	TRISO	He	Graphite	6 MPa	750°C
General Atomics	GA-EMS	50/112	UO2	He	–	7 MPa	800ºC

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Currently Built Loops

Loop	Location	Max. temp.	Max. pressure	Flow Rate	Material of construction for piping	Purpose
HTHL	Czech Republic	900 C	7 MPa	38 kg/hr	Titanium stabilized 18%Cr - 10%Ni	Structural materials testing and helium coolant chemistry investigation.
HELOKA	Germany	700C	10 MPa	0.083-5.5 kg/s		Component testing for nuclear fusion facilities.

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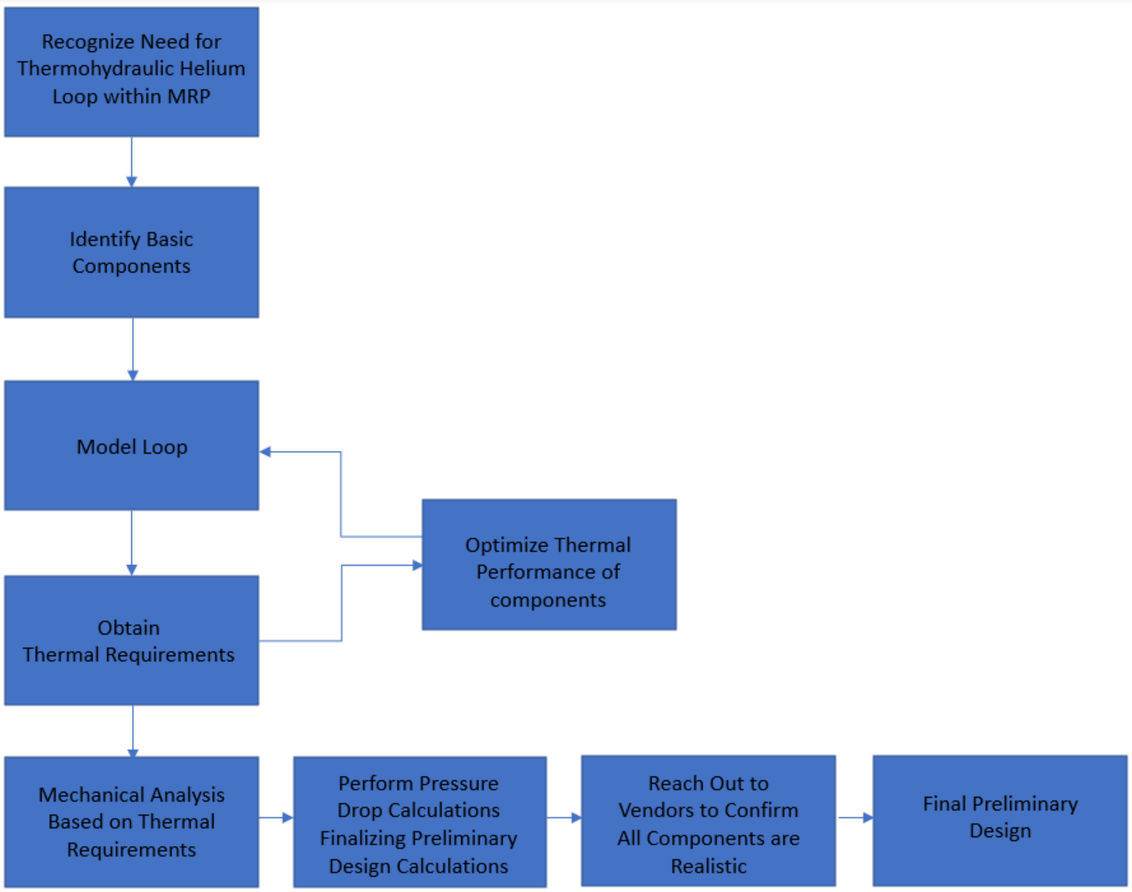
Design Process Overview



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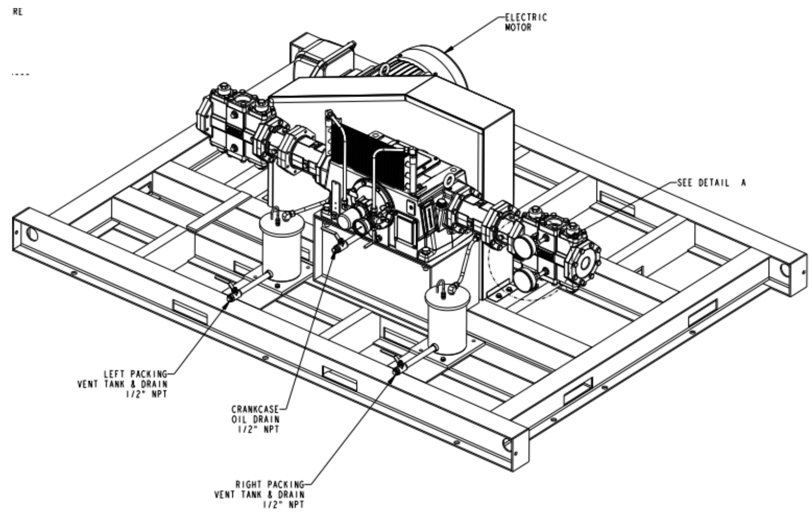
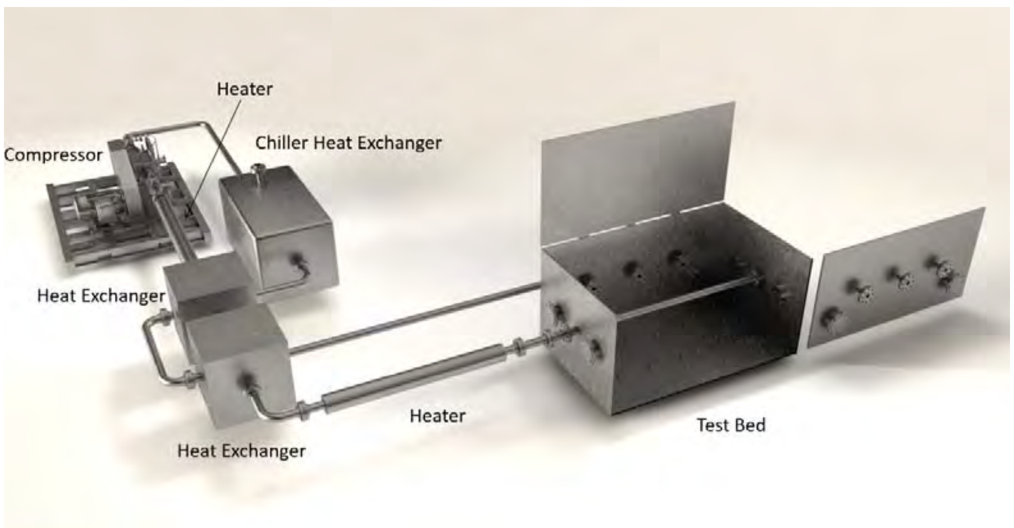
Proposed helium loop design

- 1 compressor (provided by University of Idaho)
- 2 heaters
- 1 cooler
- 2 recuperators
- 1 test section
- Footprint estimated to be $25m^2$ to 30 m^2





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Operating Conditions

Pressure	4 - 8MPa
Temperature	Up to 800°C
Mass Flow	0.01 – 0.15 kg/s
Reynold’s Number Range	12800 - 412560

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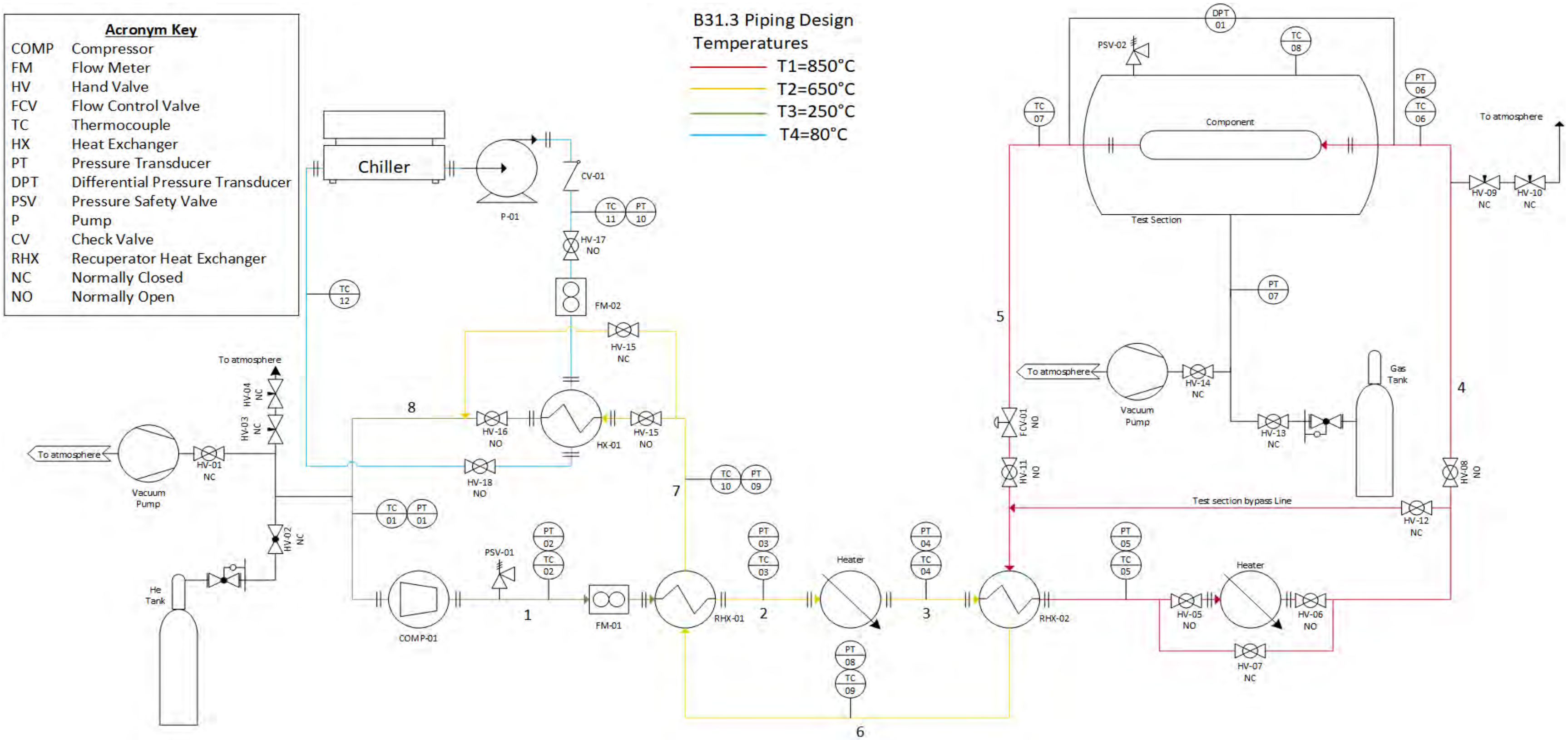
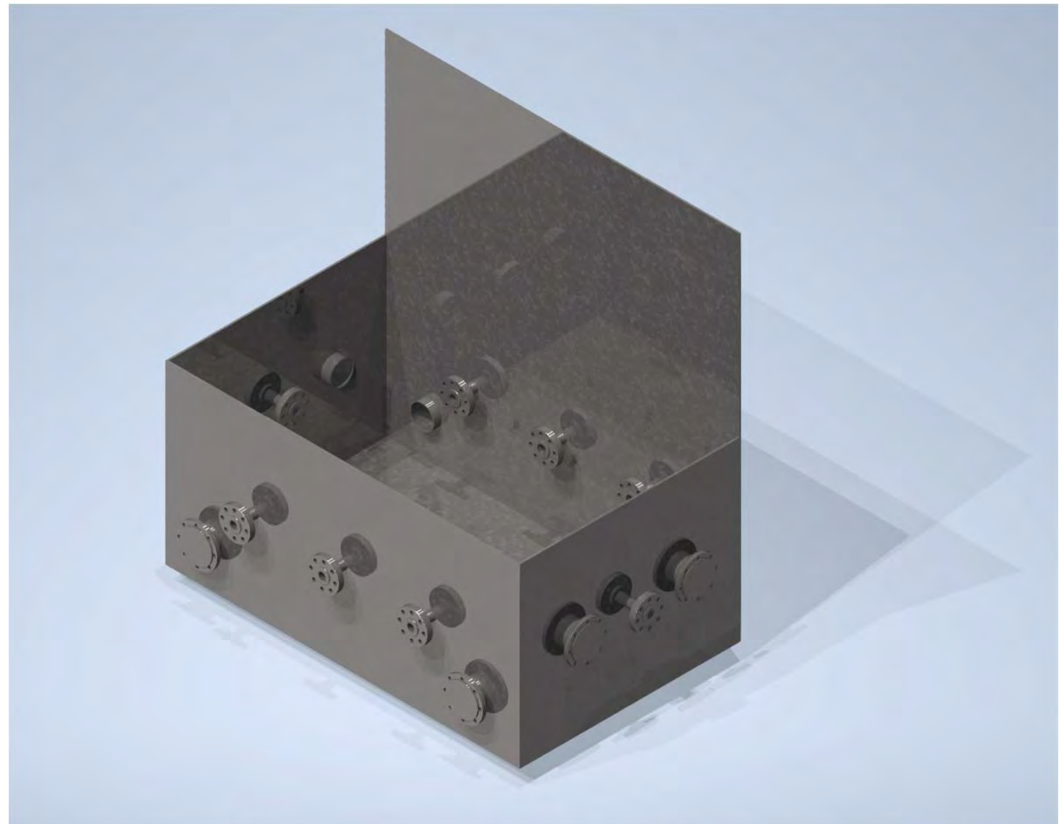
P&ID Overview



Test Section Design

- Vacuum box design to allow for inert gas to backfill into the chamber
- Two flanges on front and back faces of test bed to allow for helium gas line piping
- A total of 8, 6” flanges for instrumentation and power hookups as well as a vacuum pump line
- 6 pipe hook up for cross flow for testing heat exchangers
  - Additional infrastructure needed for heat exchanger testing based on vendor specifications
- Top opening to allow for easy access to change out test articles



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Pressure Drop Limitations

- Calculated allowable pressure drop through system
- Compressor pressure drop given by manufacture for various cases ran
- PCHE pressure drops were estimated using values from literature
  - Ultra high pressure sCO2 loops used to study pressure drops through various PCHE channel designs
- Heater pressure drops were assumed using pipe calculations with elbows
- Test section allowable pressure drop was designed utilizing a HYSYS model to perform a parametric study
- Available pipe length to stay below allowable pressure drop for the compressor 247m
  - Based on 1.5inch piping smooth wall piping

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Thermal Analysis

- Thermal Load Required
  - 45kW
    - This was found utilizing $Q = m_{dot} * C_p * (T_2 - T_1)$
- Required heated length of 8.1m
- Two heaters in the loop
  - First heater inline
  - Second heater radiative heater from Watlow
- Required outer pipe wall temperature 825°C
  - Found through thermal resistance calculation for a cylindrical tube with fluid flowing through the center

Heater 2 Option (Radiant heater)

- Vendor: Watlow
- Material: Ceramic Fiber
- Max. Temp.: 1204C (2200F)
- Watt densities: 0.8-4.6 W/cm2
- Uses “radiant” heat transfer exclusively

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Material Considerations

- List of high temperature alloys that were explored
  - Alloy 230
    - Not readily available for piping
  - Alloy 625
    - We have a quote for this piping
  - Alloy 617
  - Stainless steel 316/304
  - Alloy 800H
    - We have quote for this piping
- Alloy 617 and both alloys of stainless steel had allowable stresses below what the loop will be experiencing at 8MPa

Alloy	UNS Number	Product Form	Spec No.	Nominal Chemical Composition (wt%)
617	N06617	Seamless pipe & tube	SB-167	52Ni-22Cr-13Co-9Mo
		Plate, sheet, strip	SB-168	
230	N06230	Seamless pipe & tube	SB-622	57Ni-22Cr-14W-2Mo-La
HR-160	N12160	Seamless pipe & tube	SB-622	37Ni-30Co-28Cr-2.7Si
HX	N06002	Seamless pipe & tube	SB-622	47Ni-22Cr-9M0-18Fe
556	R30556	Seamless pipe & tube	SB-622	21Ni-30Fe-22Cr-18Co-3Mo-3W
800HT	N08811	Seamless pipe & tube	SB-407	33Ni-42Fe-21Cr
800H	N08810	Seamless pipe & tube	SB-407	33Ni-42Fe-21Cr
625	N06625	Seamless pipe & tube	SB-444	60Ni-22Cr-9Mo-3.5Cb

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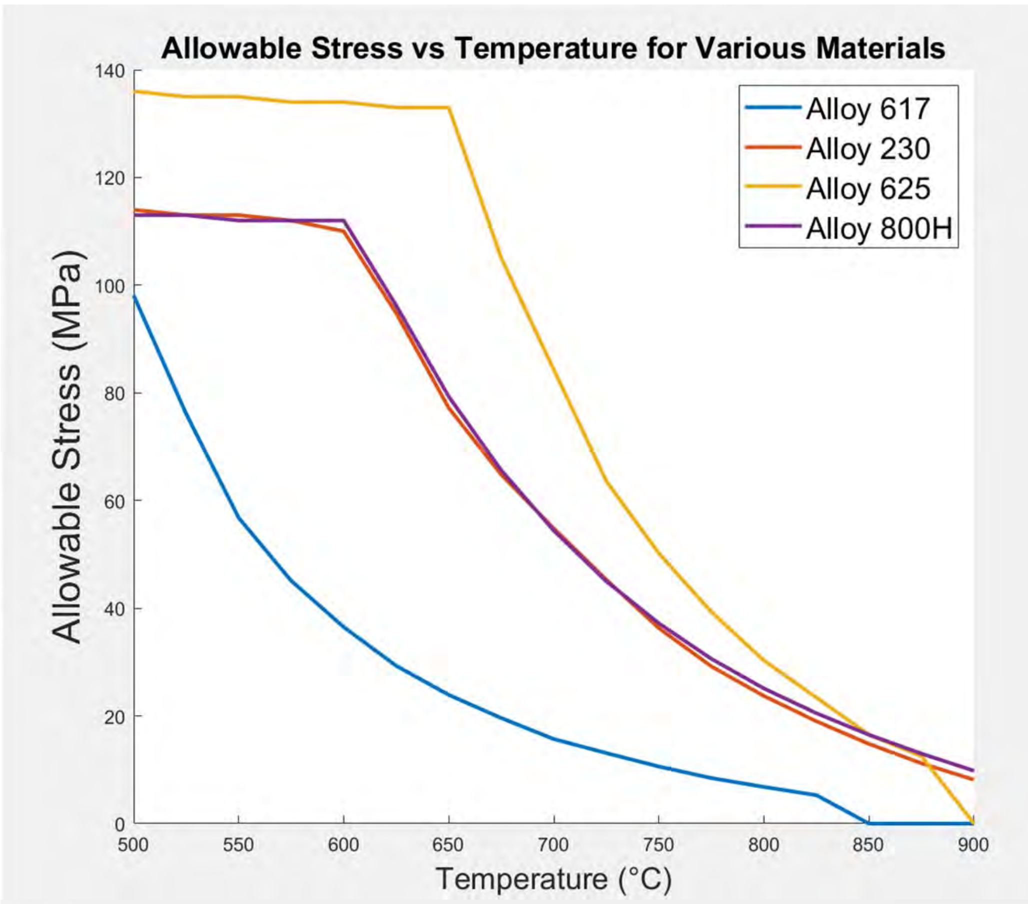
Temperature vs Allowable Stress



- All values obtained from ASME BPVC

Mechanical Analysis

- The limiting stress in the system is found at the second, radiative heater
- Calculate hoop stresses
- Compare stresses to materials found in ASME BPV code
- Calculation shows a required thickness of 0.281in
  - 1.5in schedule 160 piping meets this requirement
- Alloy 800H is primary candidate for the loop given the allowable stress as well as the cost
- Alloy 625 has higher allowable stress but 3x the cost
  - $322.57/ft vs $126.35/ft for alloy 800H

$$thick := .281in$$

$$P := 8MPa$$

$$nomD := 1.5in$$

$$Hoop := P \cdot \frac{nomD}{(2 \cdot thick)}$$

$$Hoop = 21.352 \cdot MPa$$

$$SF := \frac{21.42MPa}{Hoop}$$

$$SF = 1.003$$

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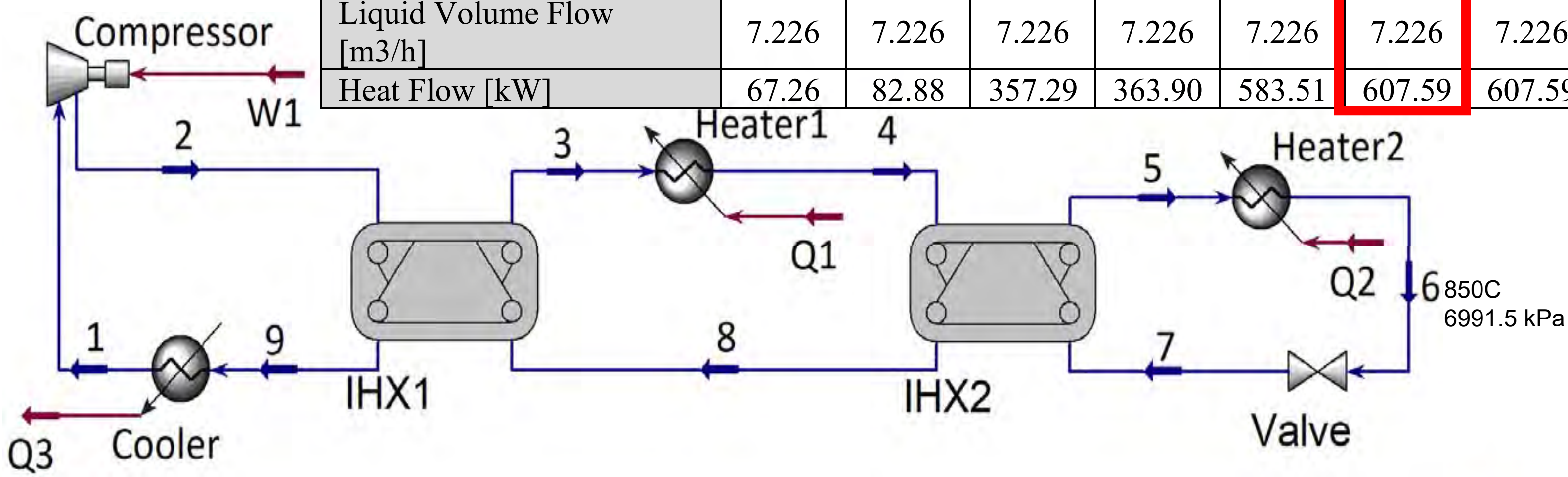
HYSYS Base model

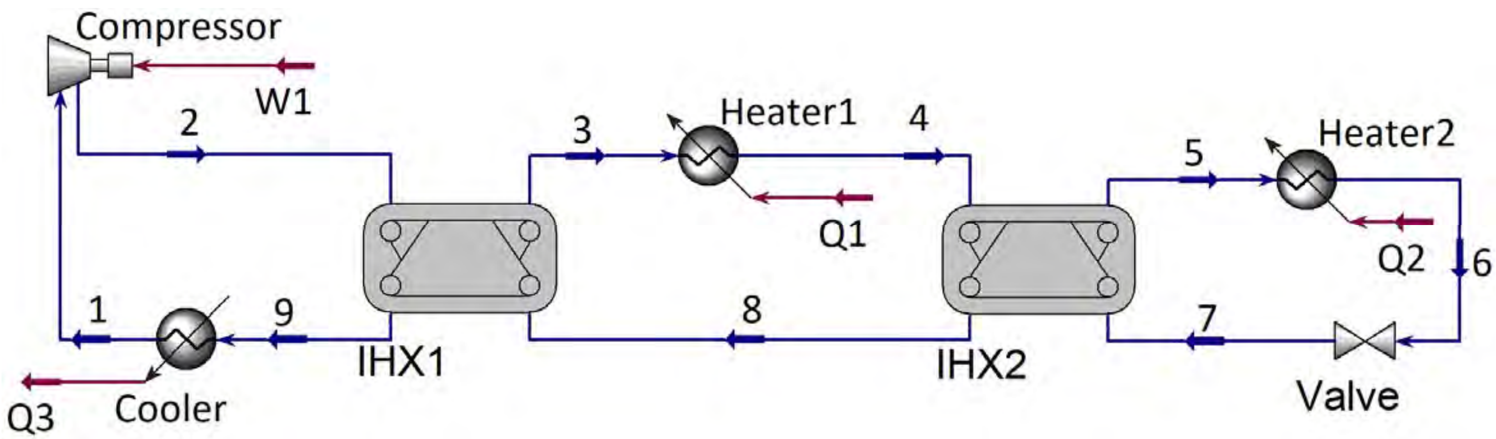
- HYSYS software used to perform parametric studies

Stream	1	2	3	4	5	6	7	8	9
Vapour Fraction	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Temperature [C]	107.2	126.7	478.6	487.2	769.0	800.0	800.1	518.3	166.5
Pressure [psia]	1103.3	1231.6	1219.2	1195.3	1183.5	1160.3	1148.7	1137.2	1125.8
Molar Flow [kgmole/h]	134.9	134.9	134.9	134.9	134.9	134.9	134.9	134.9	134.9
Mass Flow [kg/s]	0.150	0.150	0.150	0.150	0.150	0.150	0.150	0.150	0.150
Liquid Volume Flow [m3/h]	7.226	7.226	7.226	7.226	7.226	7.226	7.226	7.226	7.226
Heat Flow [kW]	67.26	82.88	357.29	363.90	583.51	607.59	607.59	387.98	113.57



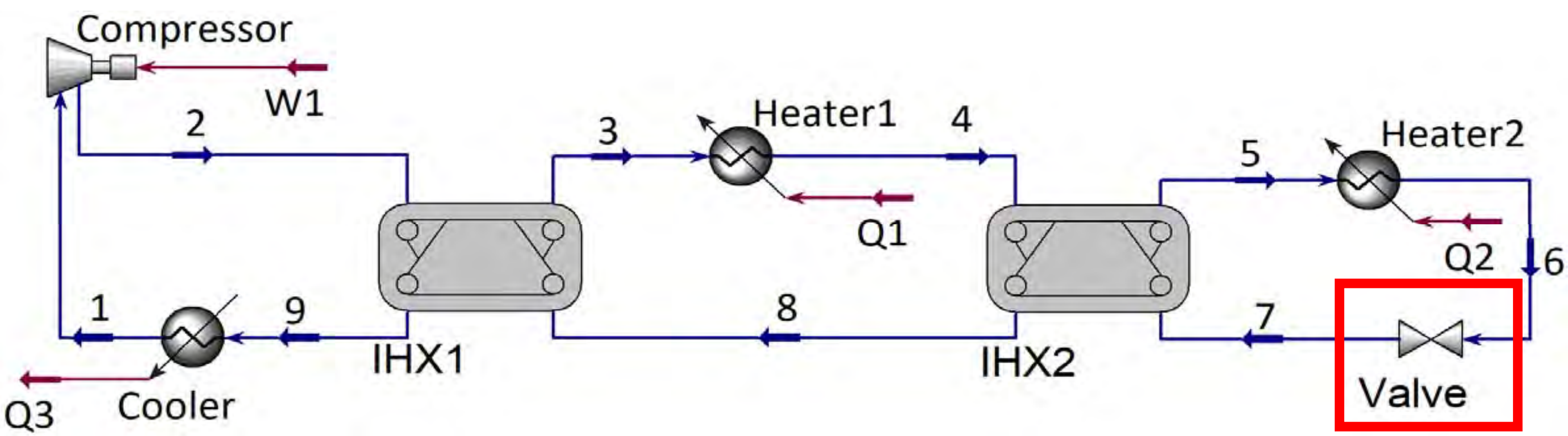
HYSYS Base model

Component	Duty
Compressor with 88% adiabatic efficiency	15.62 kW
Heater 1 with inlet/outlet diameter size of 1.338 in.	6.605 kW
Heater 2 with inlet/outlet diameter size of 1.338 in.	24.08 kW
Cooler with inlet/outlet diameter size of 1.338 in.	46.31 kW

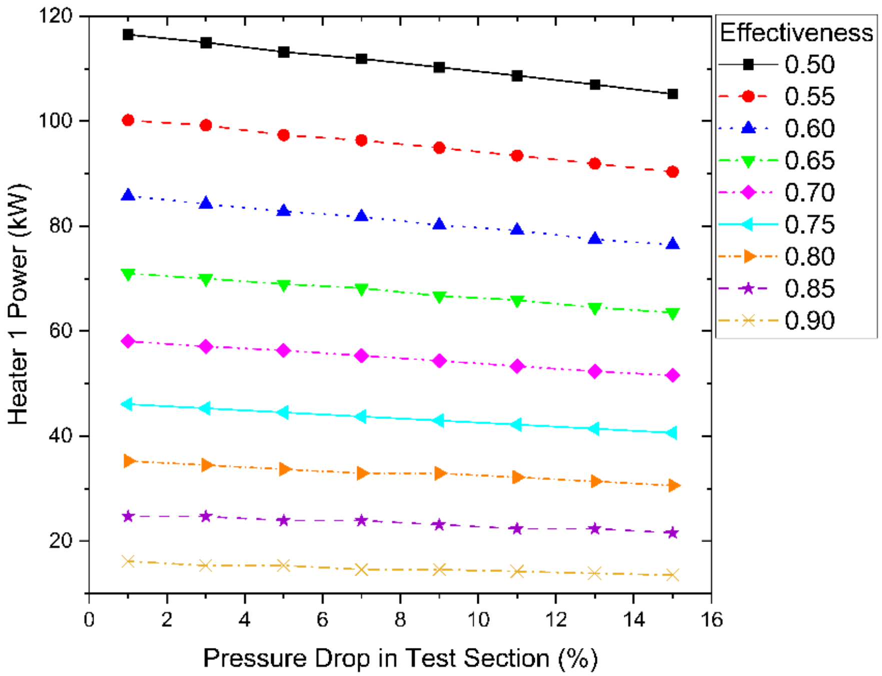


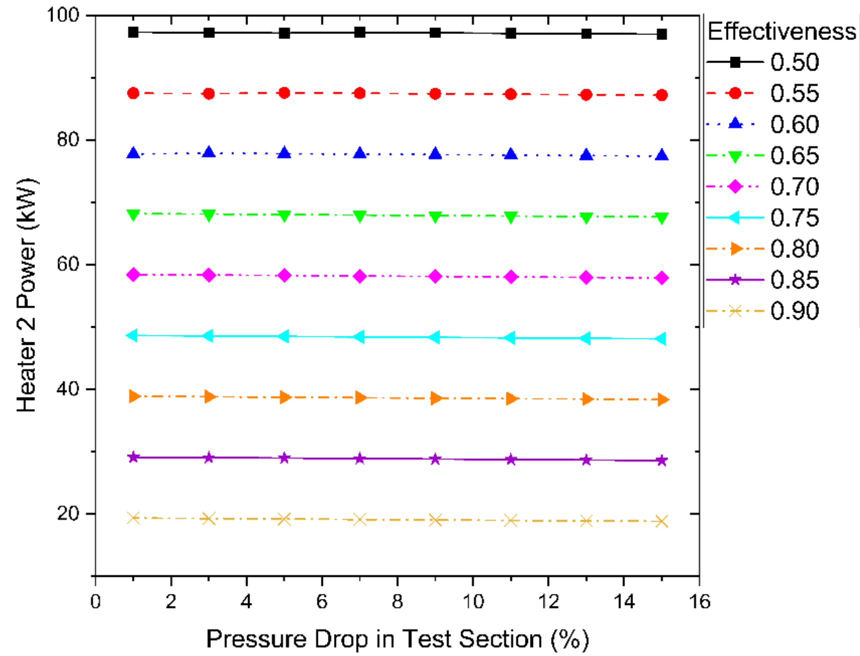
HYSYS parametric study

- Evaluate the system with varying pressure drops and effectiveness values
  - Pressure drop of the valve was varied from 1 to 15%
  - Effectiveness of IHXs was varied from 0.50 to 0.90



HYSYS parametric study: Pressure drop results





- Heater 1 power requirement decreases as pressure drop increases for all effectiveness cases
- Heater 2 power requirement remains relatively the same

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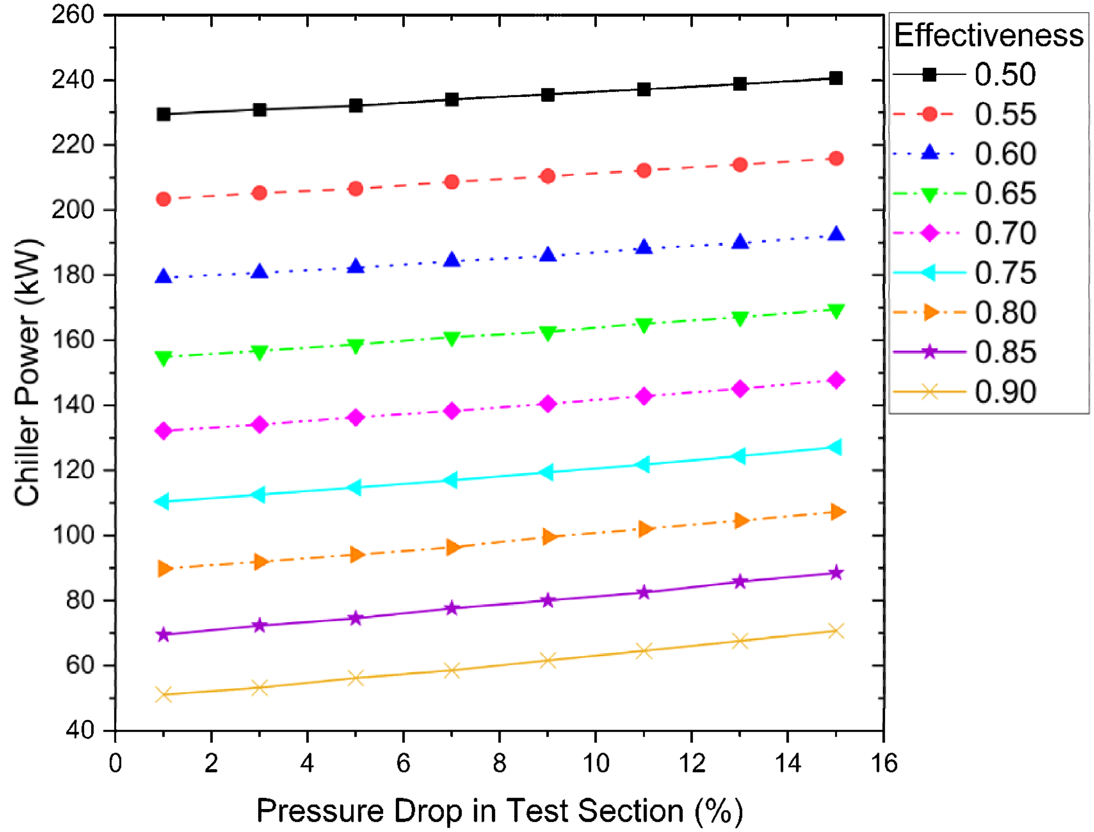
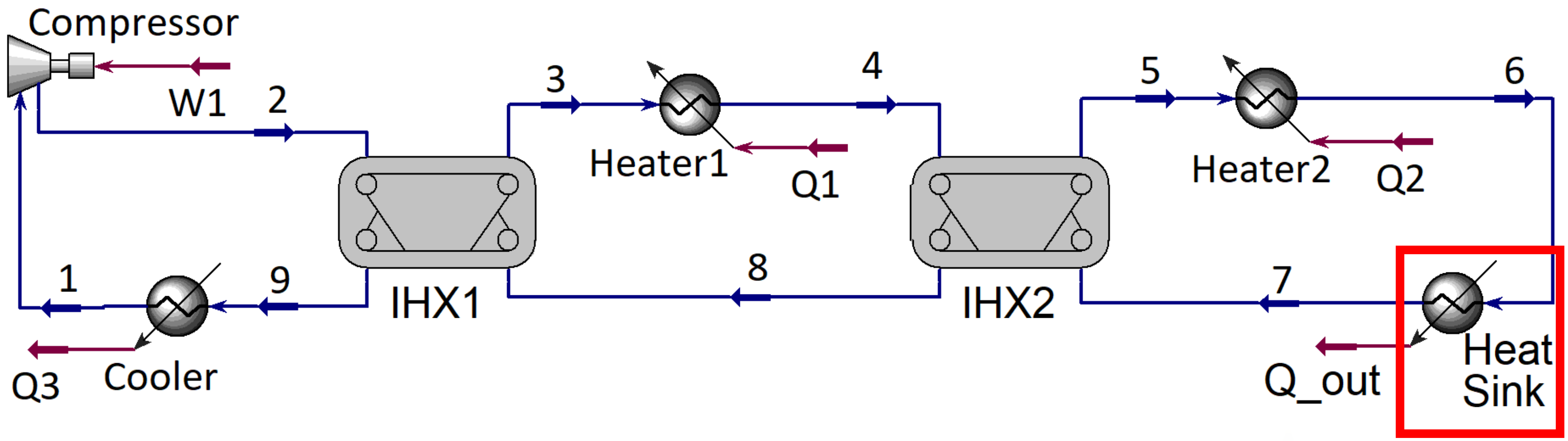
HYSYS parametric study: Pressure drop results

- Chiller power increases as pressure drop in the test section increases



HYSYS parametric study

- Valve was replaced with a heat sink to mimic a HX or chiller
  - 2.5 to 25kW of heat removed from test section
  - Pressure drop at test section kept constant



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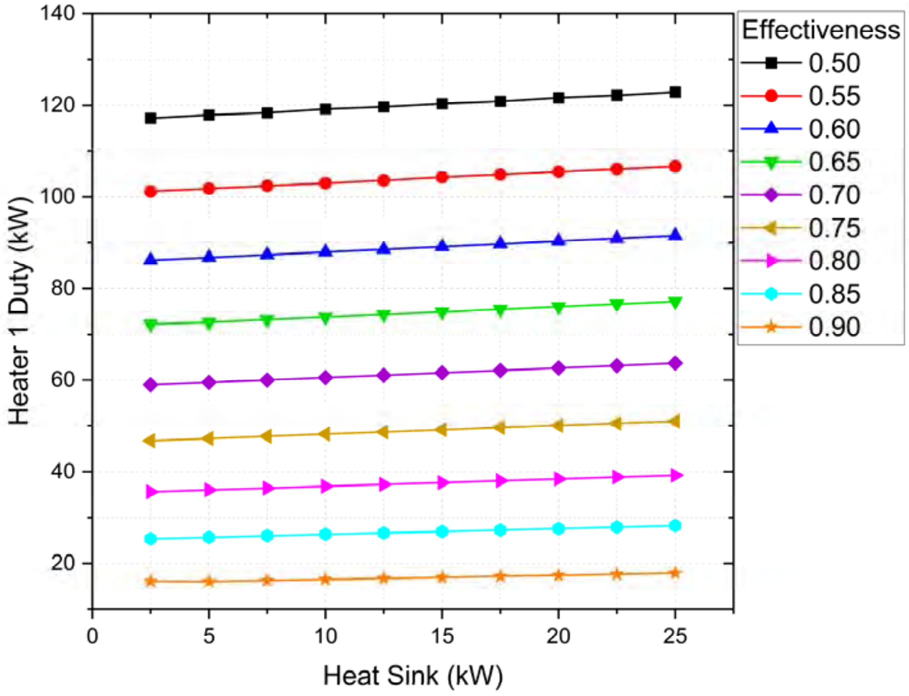
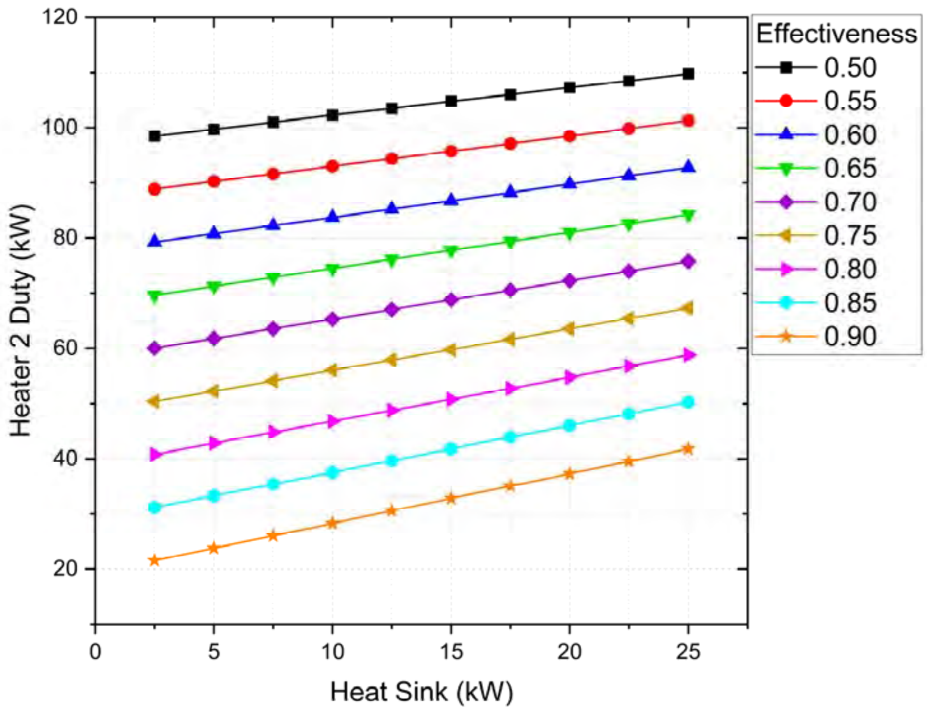
HYSYS parametric study: Heat removed

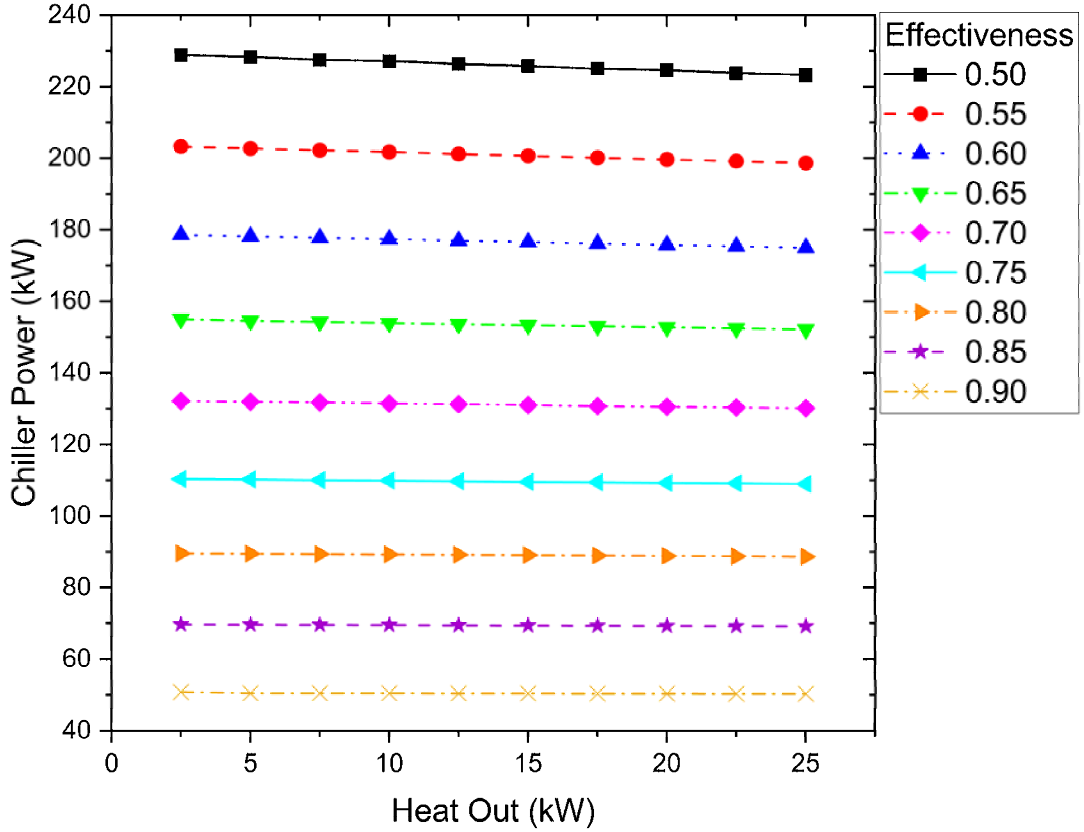
- Power requirement for both heaters increase as more heat is removed from the loop through the test section





HYSYS parametric study: Heat removed

- Power requirement for chiller decreases as more heat is removed from the test section
  - Minimal with higher IHX effectiveness



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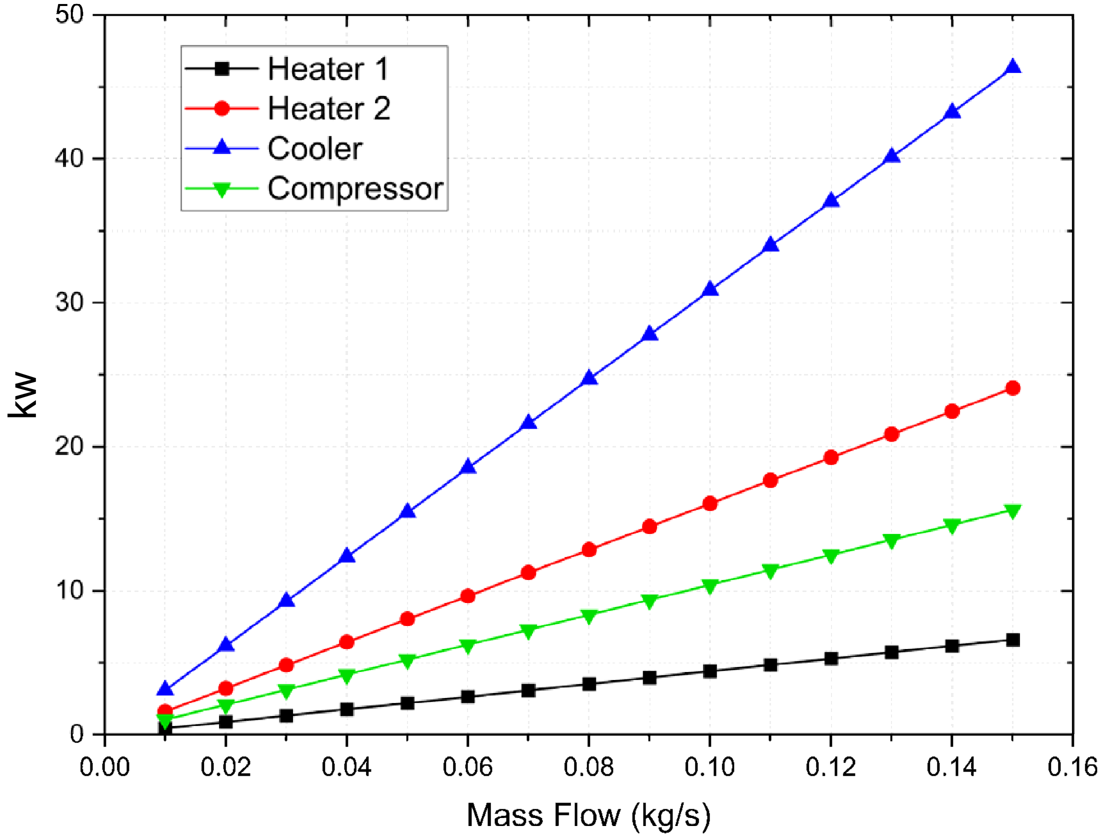
HYSYS parametric study: Mass flow rate

- Mass flow rate was also varied from 0.01 to 0.15 kg/s



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