Control Methodology and Test Modes during the Qualification Test of ITER Cold Circulator

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Paper ID: Thu-Af-O14-3

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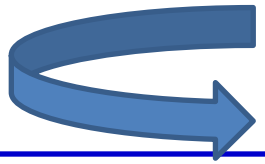
Introduction

- ITER cold circulators [1] are unique with unprecedented high supercritical mass flow rate and dynamic operating condition for superconducting magnets and cryopumps.
- Two 1:1 scale 'pre-series' cold circulators are in the design stage by IHI Corporation, Japan and Barber Nichols Inc., USA
- Both cold circulators will be integrated into the Test Auxiliary Cold Box (TACB).
- The qualification test [2] will be performed by integrating the TACB with cryogenic test facility at Japan Atomic Energy Agency (JAEA) - Naka

Qualification Test objectives & Approach

- To operate the cold circulator at the design condition and to obtain the actual performance
- The verification of
  - mass flow variation and its rate of change,
  - pressure head variation
  - high inlet pressure
  - high inlet temperature conditions
- Operation and control methodology to achieve the objectives have been developed and implemented using process simulation [3, 4, 6].

One cold circulator with different rotational speeds could meet the process requirements of TF, CS, PF&CC and CP.



TF Cold Circulator

ITER Cold Circulator

Operating Condition	Parameter	CS-cold circulator	TF-cold circulator	ST-cold circulator	PF&CC-cold circulator	CP-cold circulator
Common inlet conditions in nominal, maximum flow and maximum head operations	P_{in} (MPa)	0.51	0.46	0.56	0.51	0.34
	T_{in} (K)	4.3	4.3	4.3	4.3	4.3
Nominal operation	Mass flow (kg/s)	2.07	2.21	2.62	1.93	1.36
	ΔP (MPa)	0.1	0.15	0.05	0.1	0.07
Maximum flow rate operation	ΔP (MPa)	0.1	0.15	0.05	0.1	0.07
Maximum pressure head operation	Mass flow (kg/s)	2.07	2.21	2.62	1.93	1.36

Isentropic Efficiency at least 70 % or more [1]

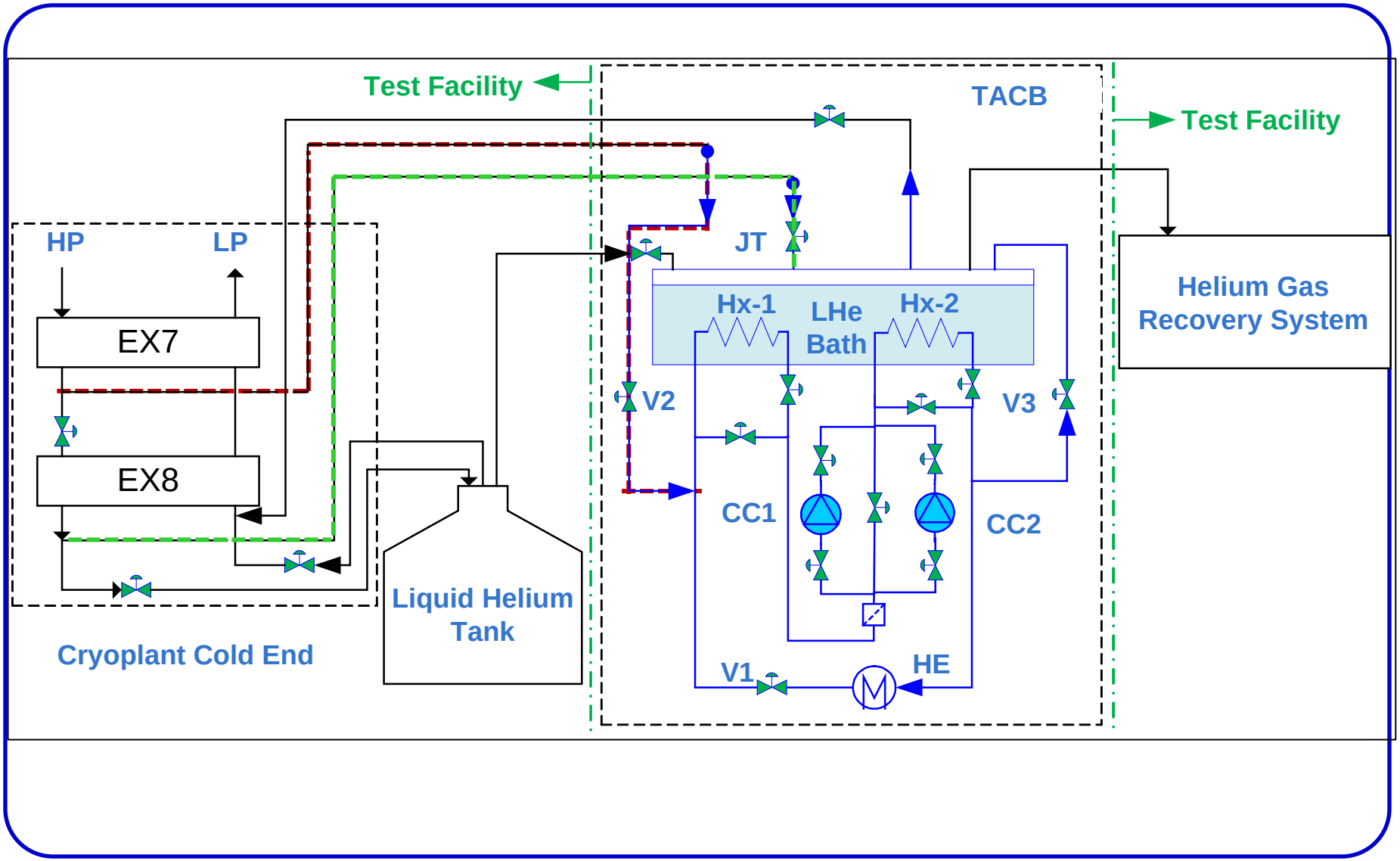
Test Auxiliary Cold Box

- TACB has been designed with process functionalities similar to the ITER Auxiliary Cold Box (ACB)

- Qualification Test Modes

  - Simultaneous cool down/warm-up of TACB along with the cryoplant;
  - Nominal operation of cold circulator at 100 % rotational speed;
  - Ramp-up/ramp down of cold circulator;
  - Maximum mass flow rate operation of cold circulator at 110 % speed;
  - Maximum pressure head operation of cold circulator at 110 % speed;
  - 1.0 MPa inlet pressure operation of cold circulator;
  - 6 K inlet temperature of cold circulator

Process Scheme

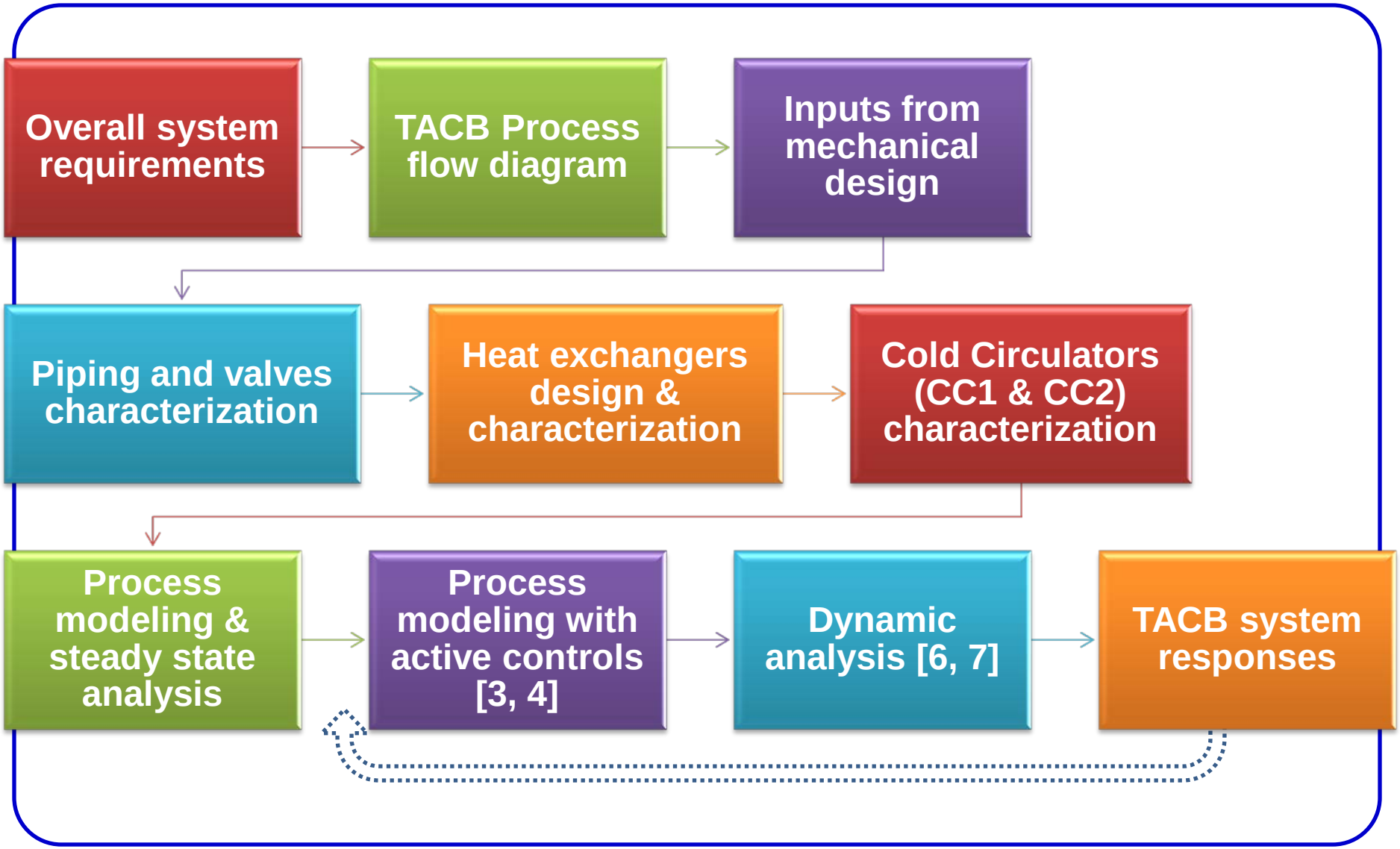


Cryogenic Test Facility at JAEA

- Cryogenic Test Facility [5]
  - Cryoplant Capacity ~ 5 kW@4.5 or 800 l/h
  - Warm helium compressor ~ Two stage with mass flow 0.75 kg/s at pressure ratio 18
  - Liquid Helium Tank of 20 m^3
  - Helium Gas Recovery System
  - Control System

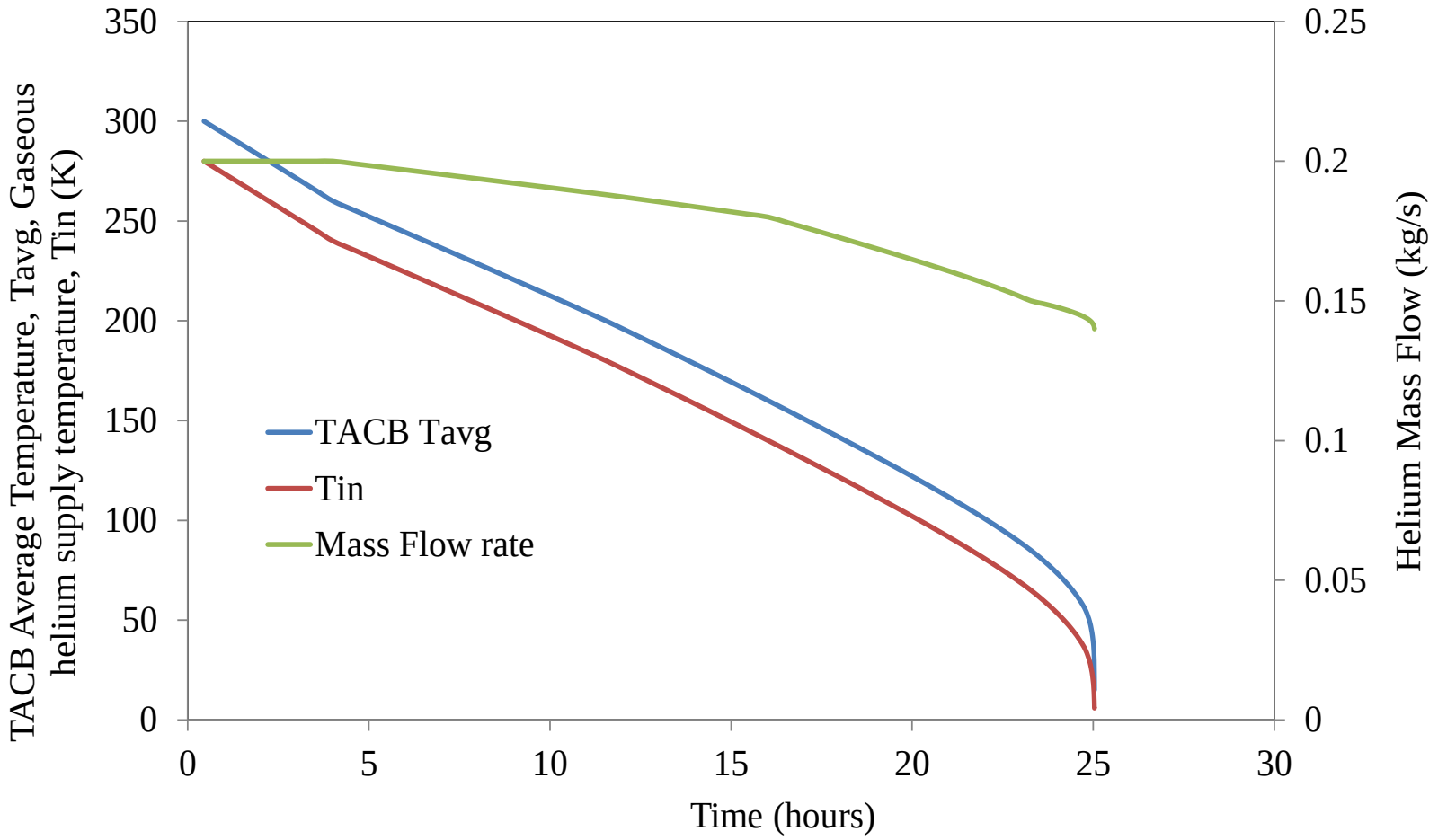
- Interfaces with TACB
  - High pressure cold helium supply
  - Medium pressure cold helium supply
  - Cold helium return
  - Liquid helium
  - Recovery System
  - TACB Control system
  - Utilities

Process Simulation Approach

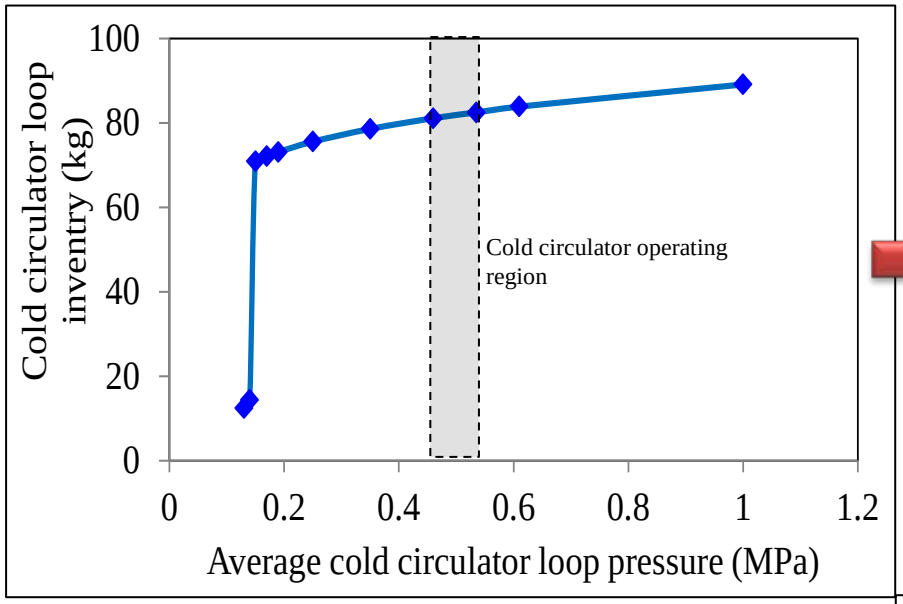


Results :: TACB Cool Down Analysis

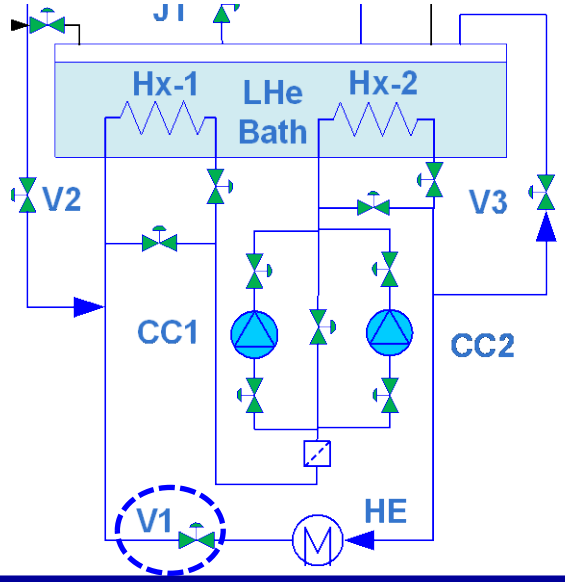
- **Cold mass ~ 2290 kg**
- **Maximum cool down mass flow ~ 0.2 kg/s**

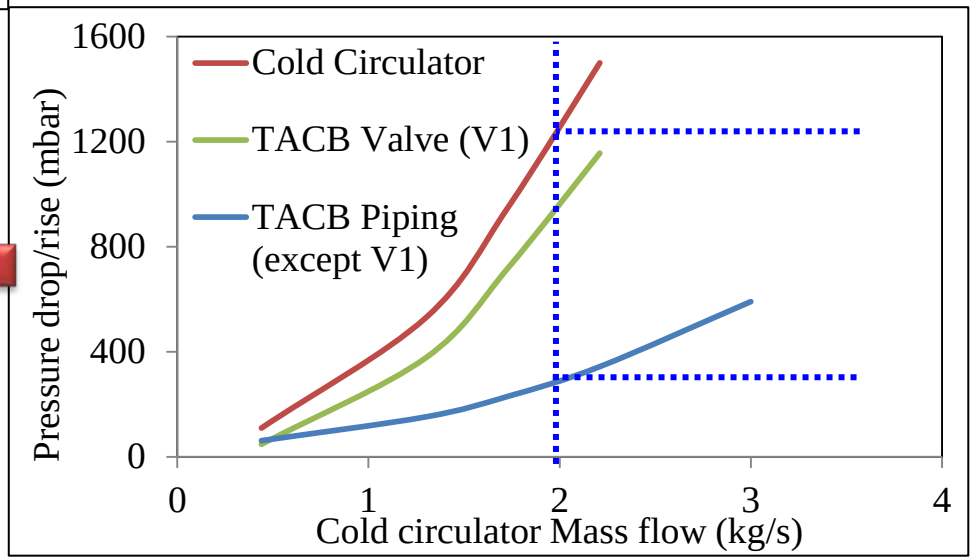


Cold Circulator Responses in Closed Loop



- Case-1: Average closed loop pressure of 0.13 MPa
- Case-2: Average closed loop pressure of 0.46 MPa
- **Case-3: Average closed loop pressure of 0.51 MPa**





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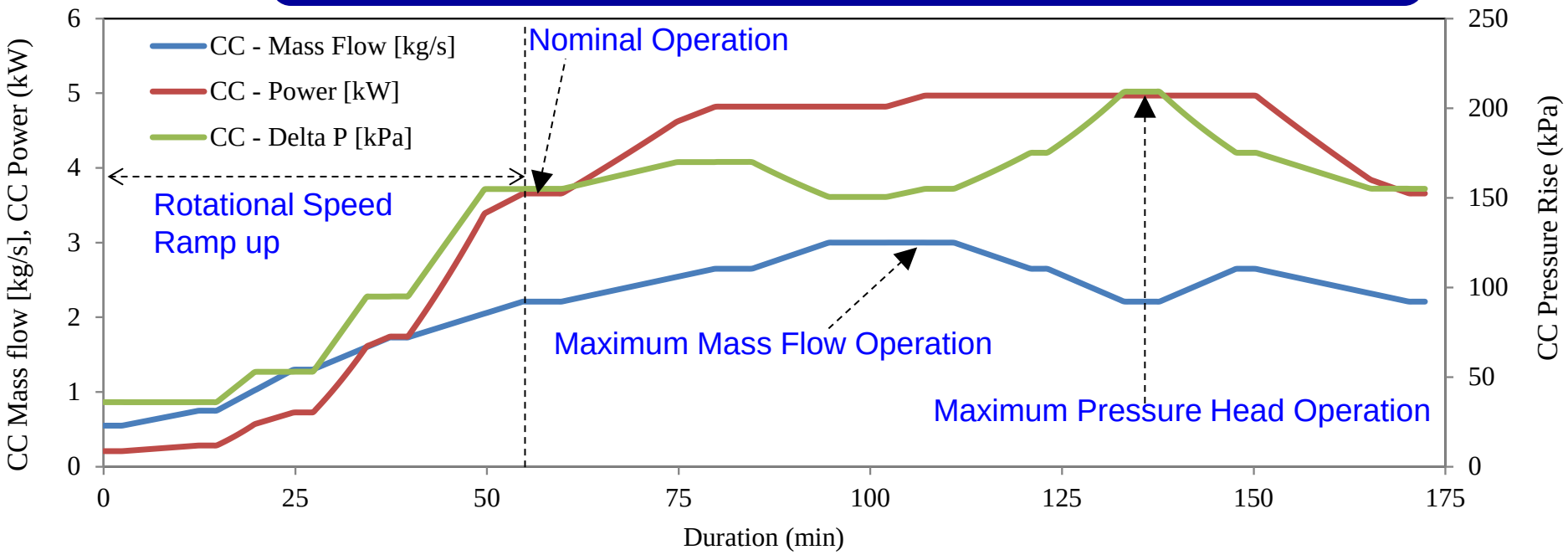
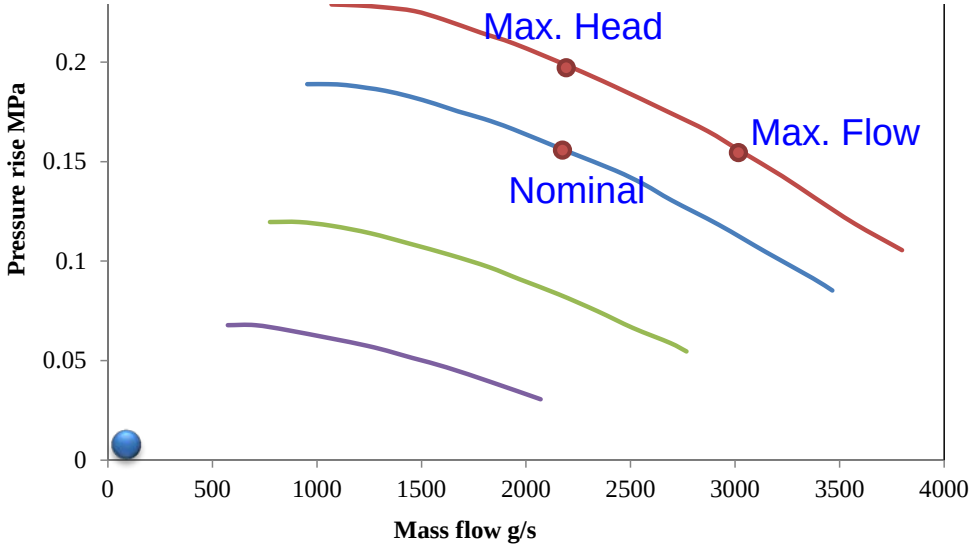
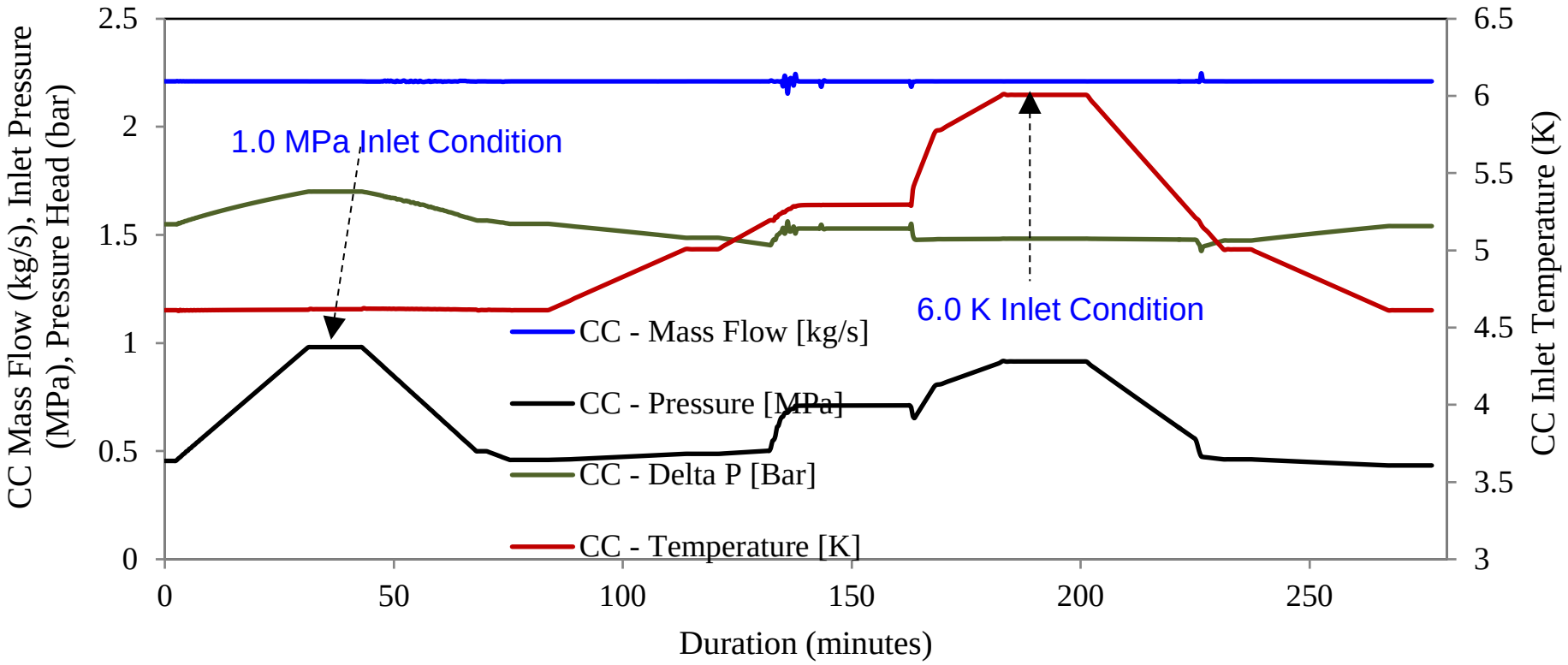


- Ramp-up: Variable speed, mass flow and pressure head
- Performance mainly, isentropic efficiency, mass flow and pressure head will be measured.



Cold Circulator Responses in Closed Loop



- Inlet pressure (1.0 Mpa): valve V2 has been regulated to pressurize the cold circulator
- Inlet Temperature (6.0 K): achieved in step by periodically by-passing the heat exchangers Hx-1 and Hx-2

Conclusion

- Process design and simulation of qualification test modes along with of the test facility interface condition have been performed.
- Simulation with controls in terms of mass flow and pressure head regulations along with control valves regulations have been implemented to obtain the stable operation during the dynamic operating condition in each mode.
- Efficiency of the cold circulator will be measured in each of the modes during the qualification test.
- The work successfully demonstrates the stable operation of cold circulator along with the TACB by analysis during the simulated test modes.

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