Working Fluid Trade Study for a Two-Phase Mechanically Pumped Loop Thermal Control System

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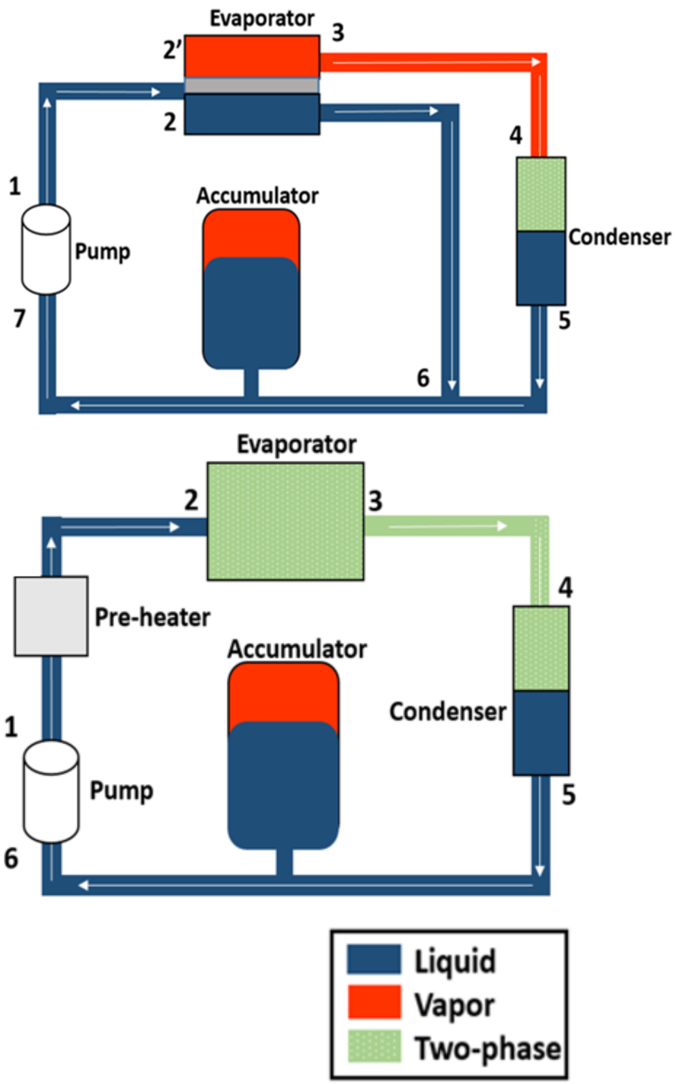
Overview

- Requirements for an advanced thermal control system
- The separated flow architecture
- Model description
- Working fluid trade study results
- Conclusion

TCS Requirements and loop architecture

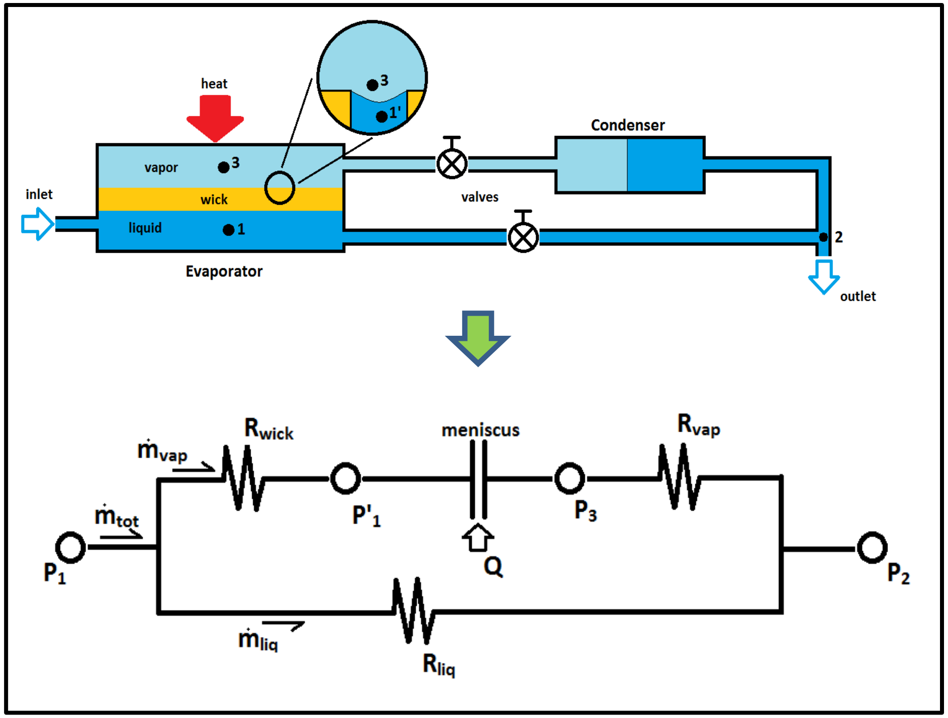


Thermal system requirements:

1. Develop a ~0.5 m^2 planar heat acquisition zone (evaporator) that can:
    a. Accommodate up to 1000 W
    b. Accommodate heat fluxes up to 5 W/cm^2
    c. Accommodate distributed, discrete heat loads
    d. Stay Isothermal (3°C across entire evaporator)
    e. Have temporal stability < 0.05 °C /min
2. Use less than 5 W of control power
3. Accommodate multiple evaporators and condensers
4. Provide at least a 15 year lifetime

Solution: develop a novel mechanically pumped two-phase fluid loop.

Basic Analysis I



Governing equations

(unknowns in red)

$$(1)\quad Q = \dot{m}_{vap}\lambda$$

$$(2)\quad \dot{m}_{tot} = \dot{m}_{vap} + \dot{m}_{liq}$$

$$(3)\quad P_1 - P_2 = \dot{m}_{liq} R_{liq}$$

$$(4)\quad P_3 - P_2 = \dot{m}_{vap} R_{vap}$$

$$(5)\quad P_1 - P_1' = \dot{m}_{vap} R_{wick}$$

- $P_{()}$ - pressure
- $\dot{m}_{()}$ - mass flow rate
- Q - heat load on evap
- $R_{()}$ - flow resistance
- λ - latent heat of vap.

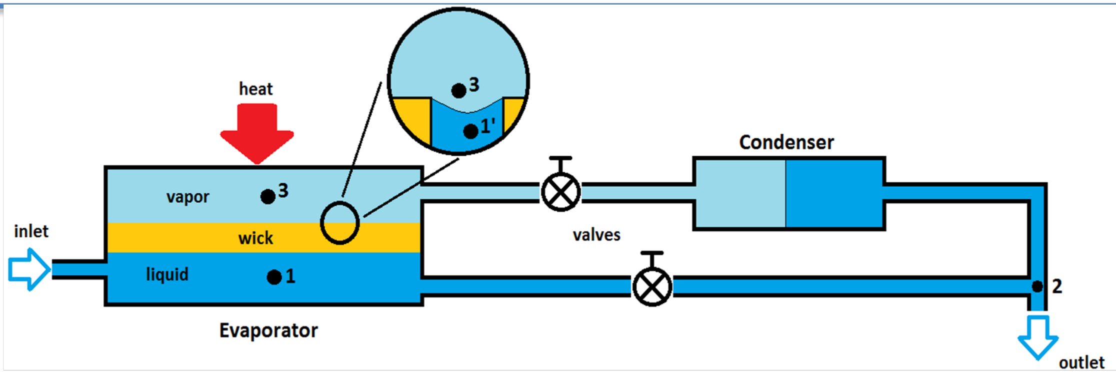
- Unknowns: $\dot{m}_{vap}, \dot{m}_{liq}, P_2, P_3, P_1'$
- System is fully constrained (5 eqns., 5 unknowns)

Constraints:

$$(P_3 - P_1) < \frac{2\sigma}{r}$$ (ΔP across wick must be less than available capillary pressure of wick)

$$(P_3 - P_1') > 0$$ (ΔP across wick must be greater than zero in order to prevent liquid leakage)

Basic Analysis II



Use constraints and equations to constrain range of allowable heat loads:

$$0 < (P_3 - P_1') < \frac{2\sigma}{r}$$

Constraints:

$(P_3 - P_1) < \frac{2\sigma}{r}$ (ΔP across wick must be less than available capillary pressure of wick)

$(P_3 - P_1') > 0$ (ΔP across wick must be greater than zero in order to prevent liquid leakage

$$\frac{\lambda(\dot{m}_{tot} R_{liq})}{(R_{vap} + R_{liq} + R_{wick})} < Q < \frac{\lambda\left(2\sigma/r + \dot{m}_{tot} R_{liq}\right)}{(R_{vap} + R_{liq} + R_{wick})}$$

Minimum allowable heat load

Maximum allowable heat load

The Fluid Model

Inputs

- Qmax-Qmin
- Pump mass flow rate
- Saturation temperature
- NPSHR
- System lines length
- Lines diameter range
- Wick pores diameter

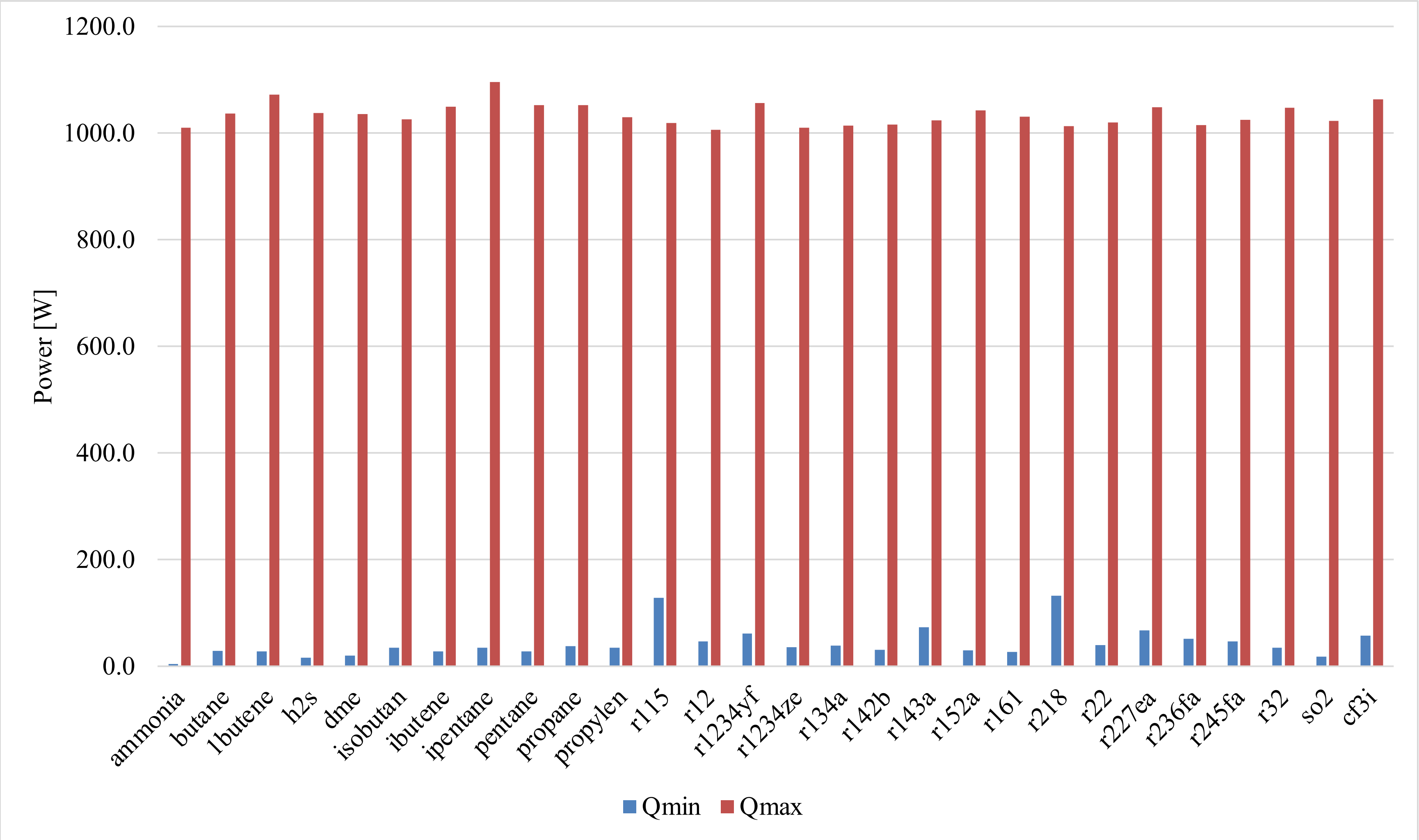
Process

- NPSH requirement
- Vapor line diameter to satisfy Qmax
- Liquid line diameter to satisfy Qmin
- Calculating tube, accumulator, evaporator, radiator mass
- Calculating fluid mass

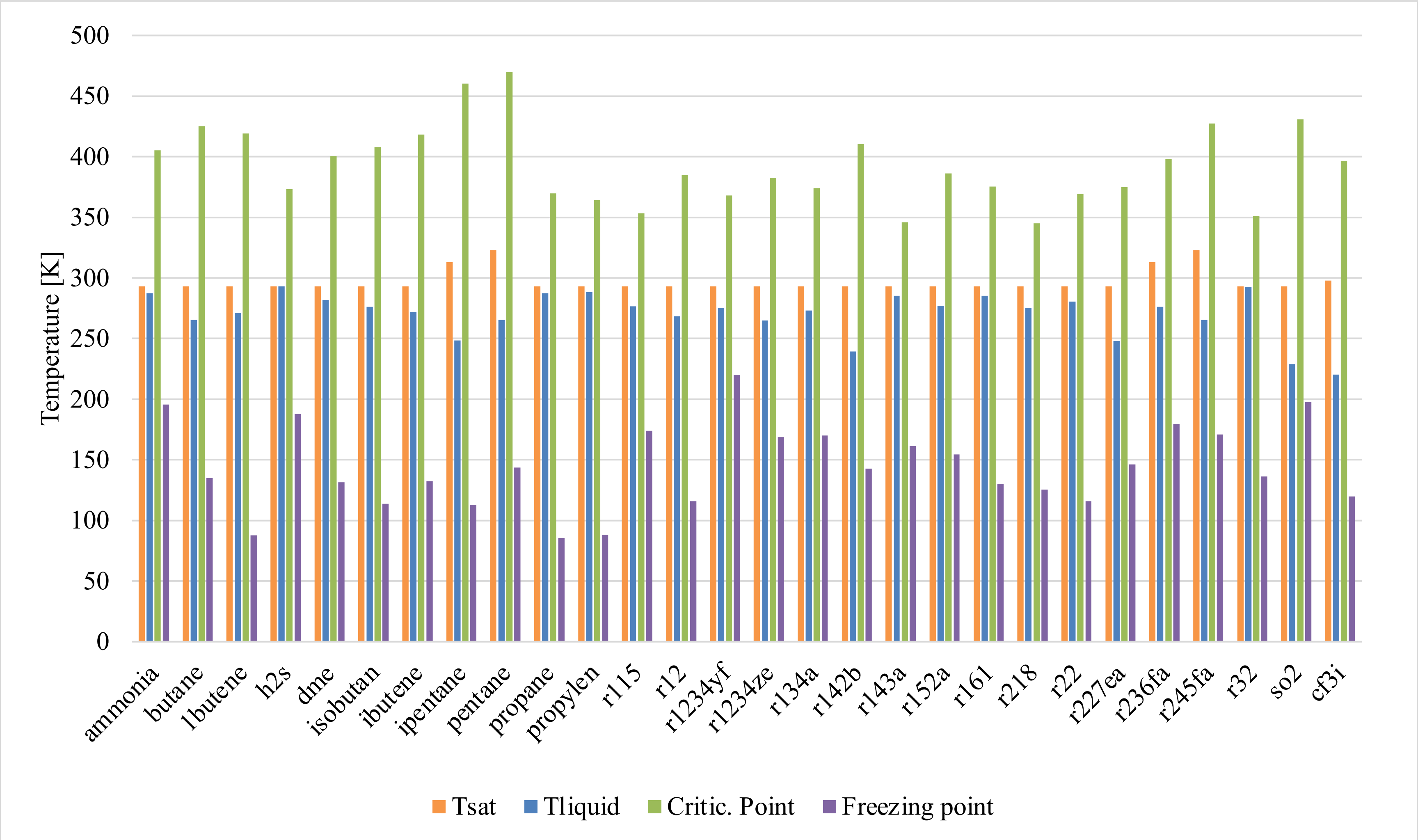
Outputs

- Qmax-Qmin Values
- System mass breakdown
- Mass flow rate
- System pressure
- Characteristic temperatures

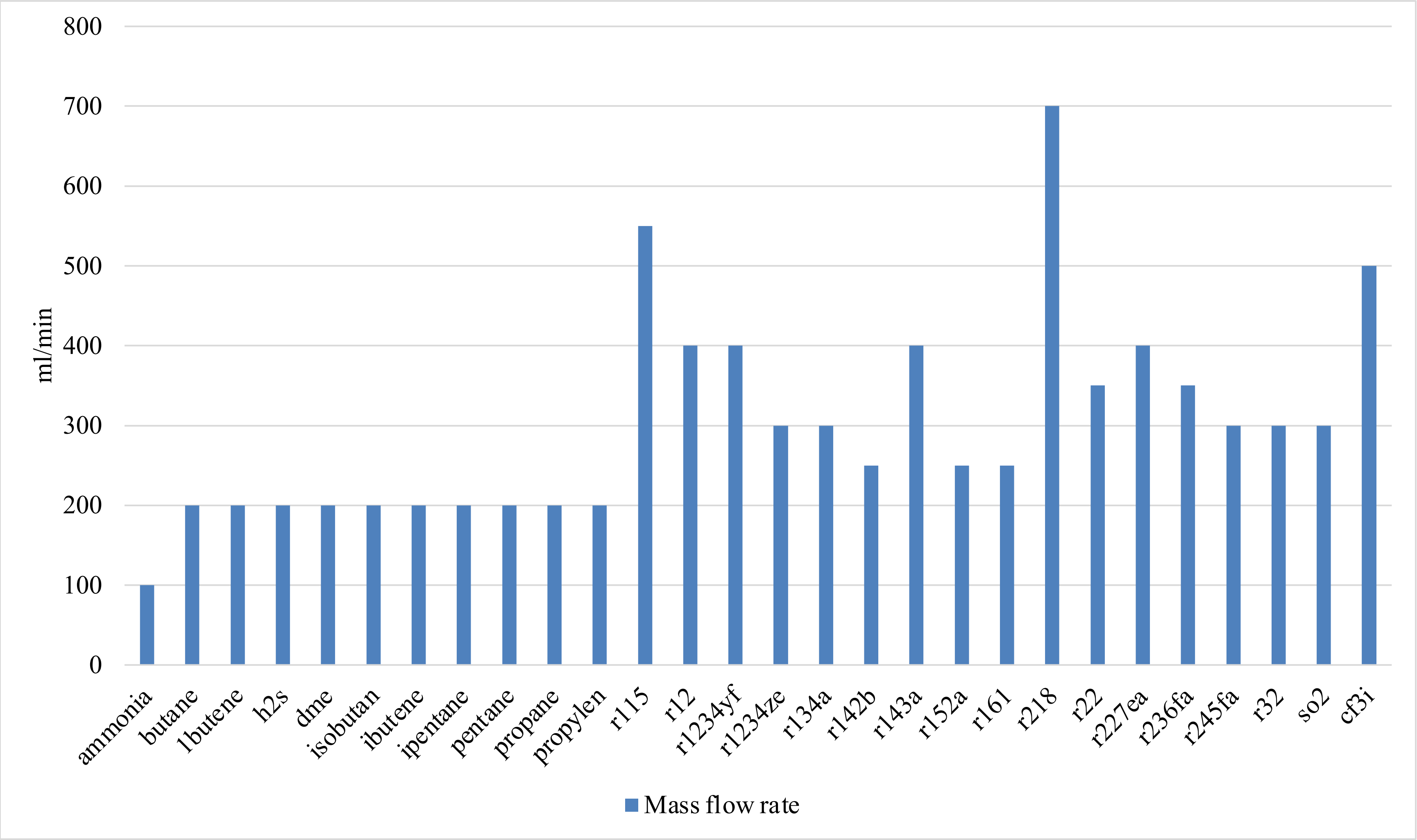
Qmax and Qmin model results



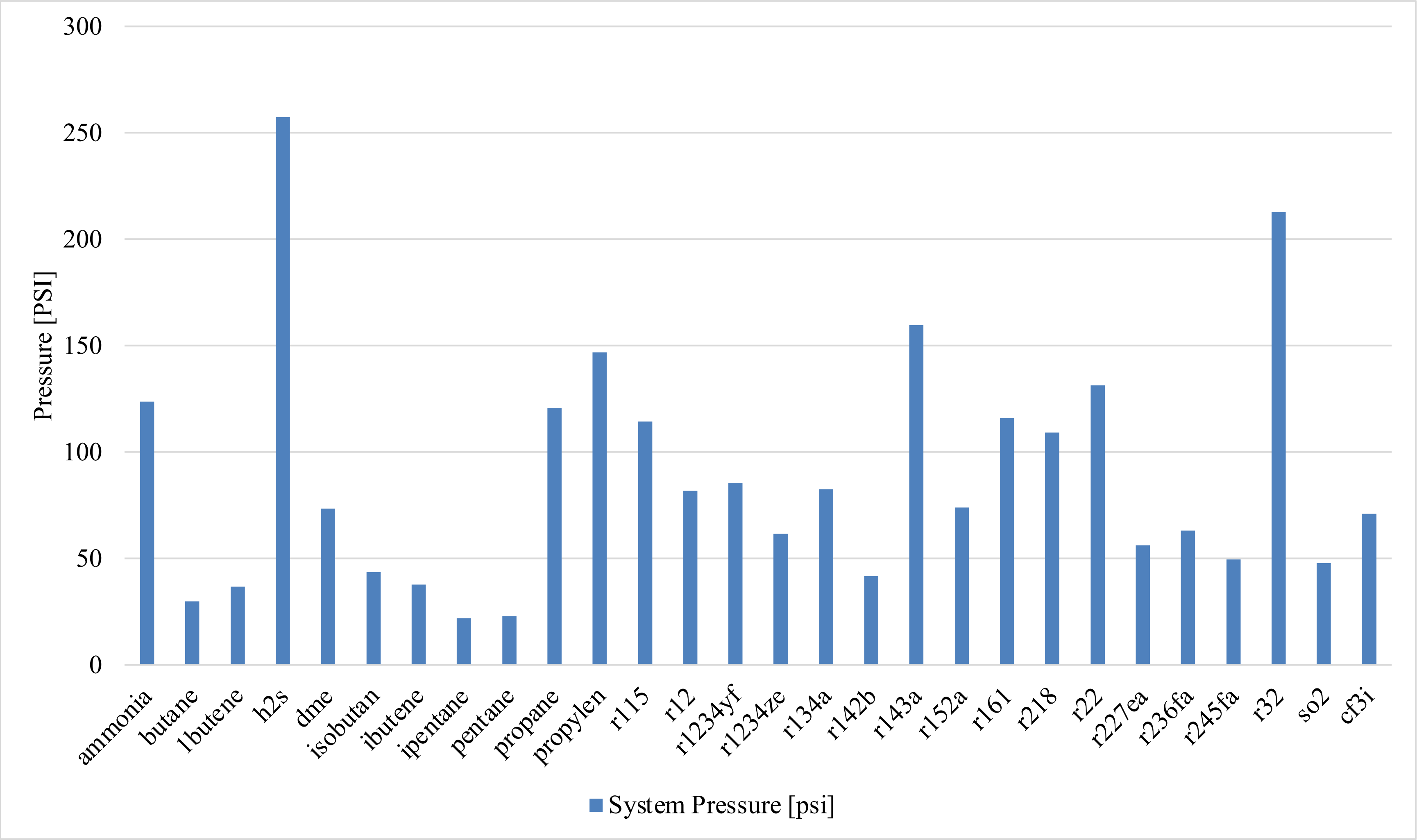
Characteristic temperatures comparison



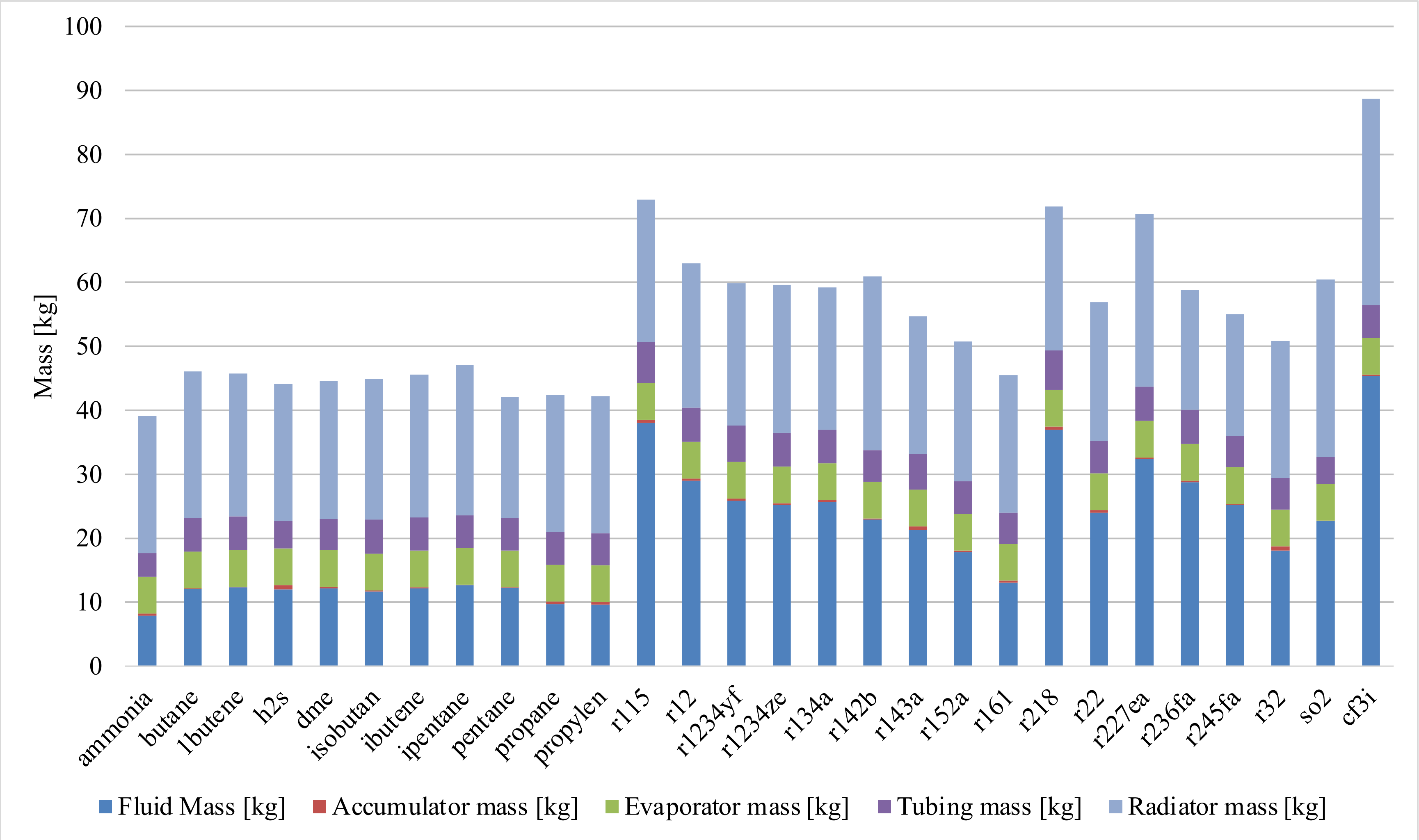
Mass flow rate



System pressure



System mass breakdown

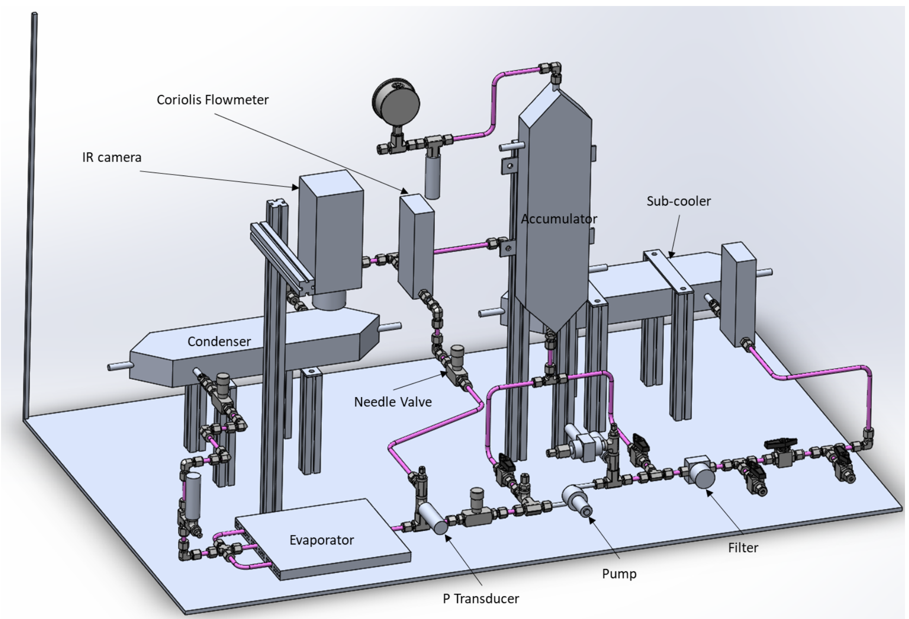


Hazards – Material compatibility – Heritage

Fluid	Health	Flammability	Reactivity	Aluminum compatability	Titanium compatability	316 SS compatability	Applications
ammonia	3	1	0	EXCELLENT	GOOD	EXCELLENT	Heat pipes
butane	1	4	0	EXCELLENT	EXCELLENT	EXCELLENT	Heat pipes
1-butene	1	4	0	EXCELLENT	?	EXCELLENT	?
Hydrogen Sulfide	4	4	0	POOR	GOOD	POOR	?
Dimethyl ether	1	4	1	POOR	?	POOR	?
Isobutane	1	4	0	EXCELLENT	?	EXCELLENT	?
Isobutene	1	4	0	EXCELLENT	?	EXCELLENT	?
Isopentane	1	4	0	EXCELLENT	?	EXCELLENT	Heat pumps
pentane	1	4	0	EXCELLENT	?	GOOD	Heat pipes
propane	2	4	0	EXCELLENT	EXCELLENT	EXCELLENT	Heat pipes
propylene	1	4	1	EXCELLENT	?	EXCELLENT	Heat pipes
r152	2	4	0	POOR	?	?	?
r161	2	4	0	?	?	?	?
r32	1	4	1	POOR	?	EXCELLENT	?

Conclusion

- The final choice for the MPFL working fluid is ammonia.
- An ammonia testbed is ready to start testing at JPL.
- One of the objectives of the testing will be to observe operation windows and stability at constant pump speed



Acknowledgements

Acknowledgments

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BACK UP

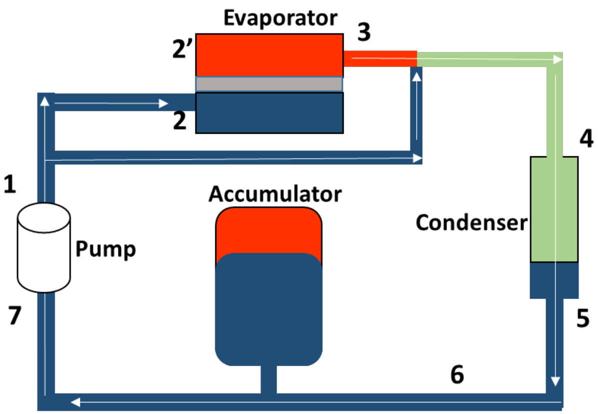
Are we better than a loop heat pipe?

Advantages compared to loop heat pipes:

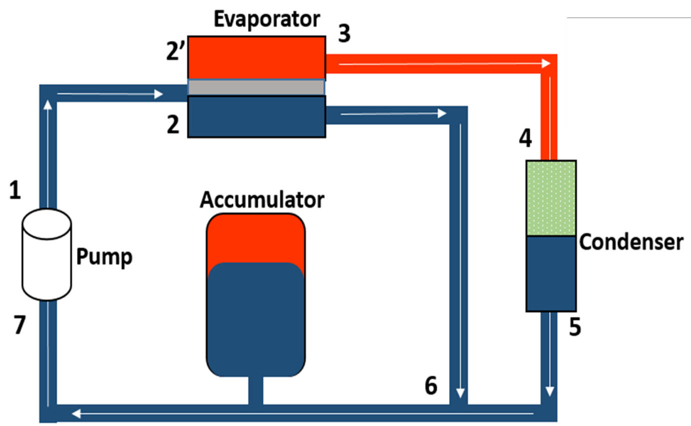
- Integration and test, fittings, geometry flexibility
- Wick only has to pump the liquid for a small portion of the loop. We do not rely solely on the wick to pump the fluid.
- Changing the pump speed allows to change the Qmax-Qmin window and to accommodate higher heat loads
- Flat geometry with wide plate

System Architectures

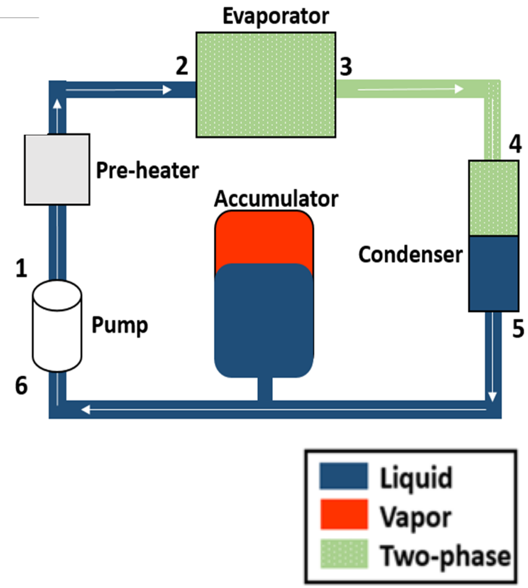
Separated Flow 1



Separated Flow 2



Mixed Flow



Separated Flow 1

- Longer radiator distance, pump takes care of pressure drops
- Big Delta Q self regulation window
- Potentially does not need pump speed control

- Higher pressure drops
- Radiator has to run at a lower average temperature and get rid of more sensible heat. Less efficient

Separated Flow 2

- Radiator running at higher T (more efficient)
- Less pressure drops, smaller pump
- Fall back mode in case of pump failure

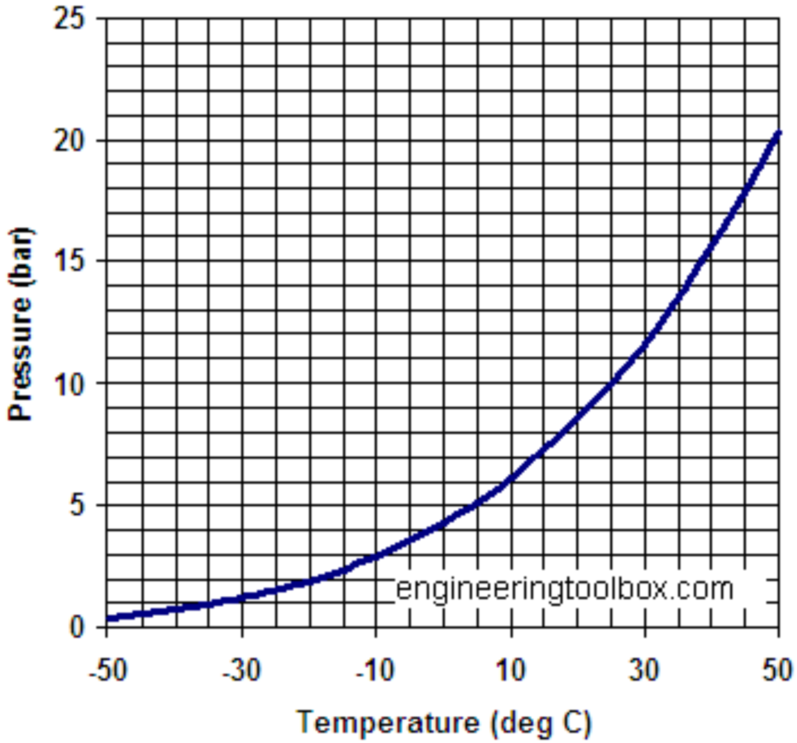
- Smaller Delta Q self regulation window
- Limited radiator distance, relies on pumping action of the wick

Mixed Flow

- No need for wick structure to manage phases

- Higher pressure drops, more pump power
- Need of preheater or recuperator to be able to achieve isothermality in evaporator

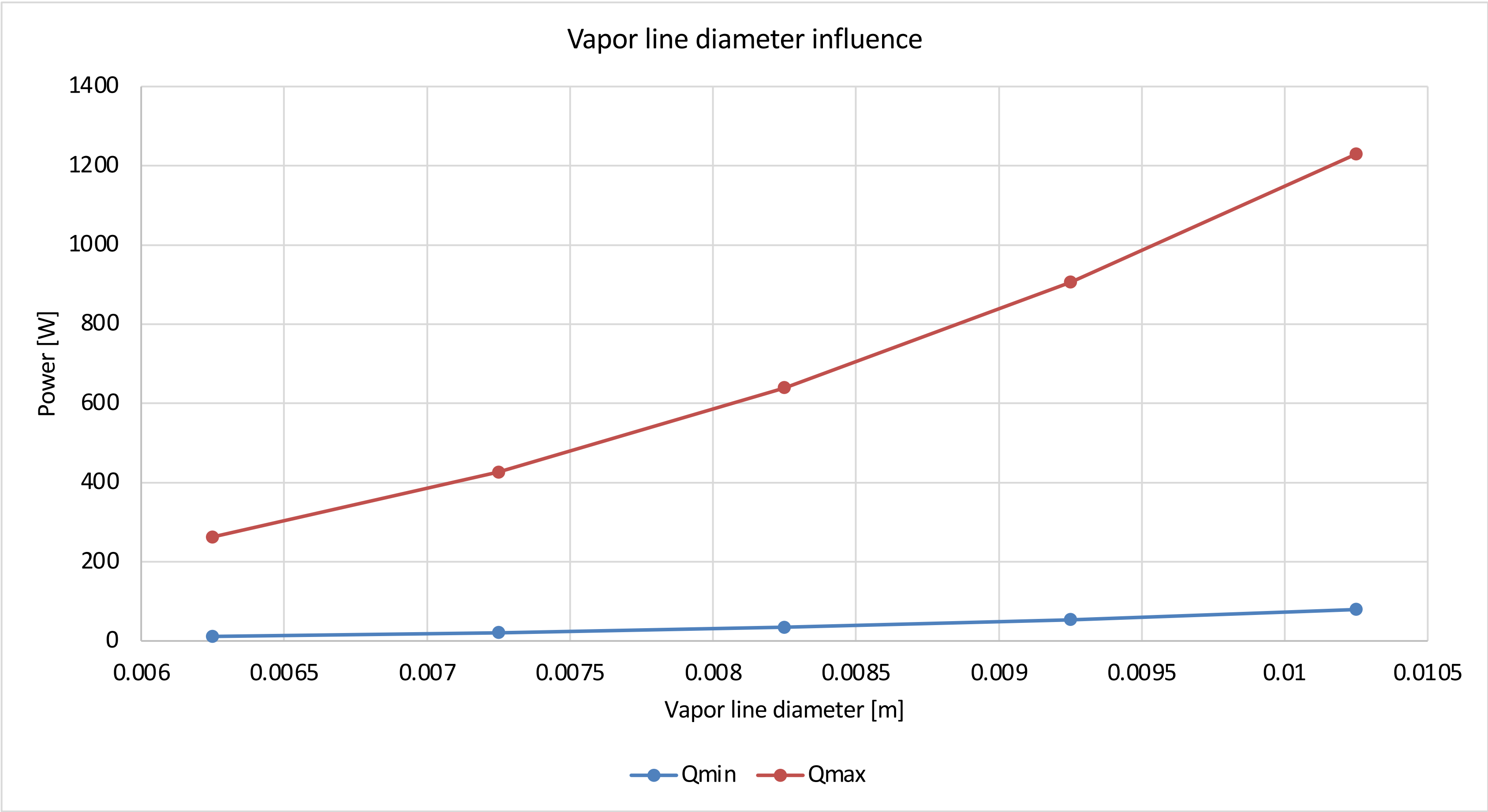
Saturation T on the steeper part of the curve



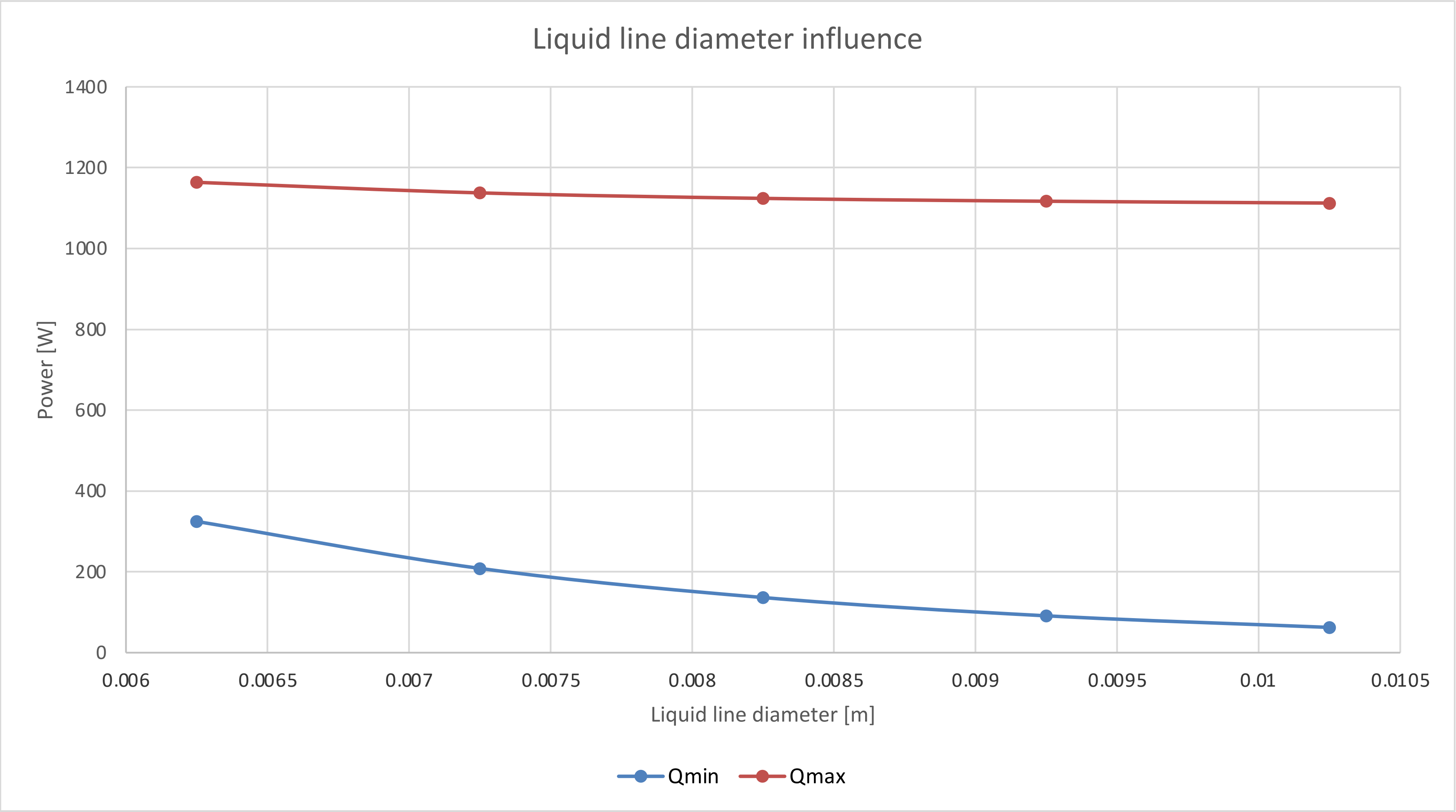
Subcooling effect:
Example 1:
Tsat: 40C, 10C subcooling → 4 bar

Example 2:
Tsat: 10C, 10C subcooling→ 2 bar

Inputs Influence



Inputs Influence



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