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

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Presented By

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Overview

1. Requirements for an advanced thermal control system
2. The separated flow architecture
3. Model description
4. Working fluid trade study results
5. Conclusion

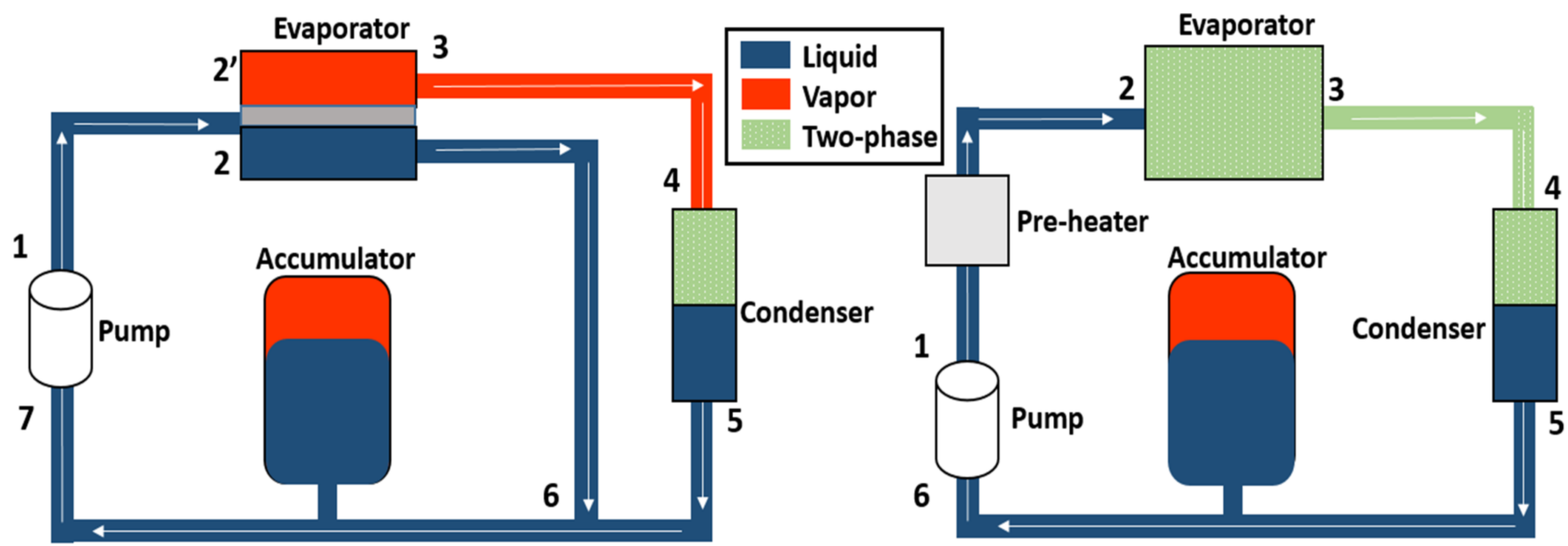
TCS Requirements

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. Maintain isothermality within a temperature band of 3° C across entire evaporator
   e. Provide temporal stability of less than 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.

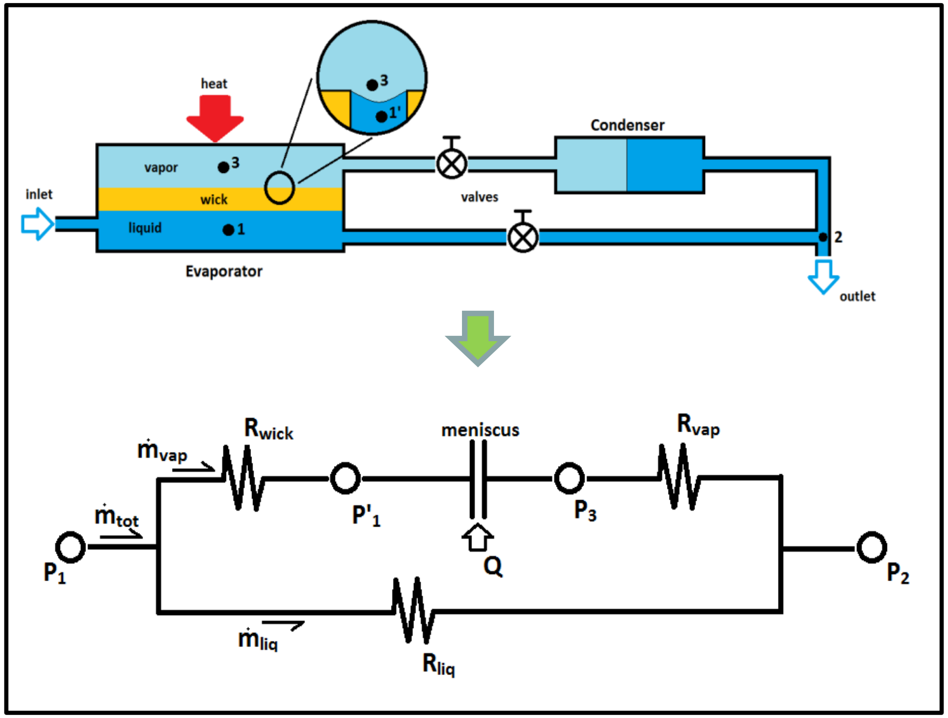
System Architecture



Advantages of separated flow:

- **Minimal 2-phase flow → more predictable behavior**
- **Lower pressure drop → less pumping power needed**
- **No pre-heater required → more power efficient**

Basic Analysis I



Governing equations

(unknowns in red)

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

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

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

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

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

$P_{()}$ - pressure

$\dot{m}_{()}$ - mass flow rate

Q - heat load on evap

$R_{()}$ - flow resistance

λ - latent heat of vap.

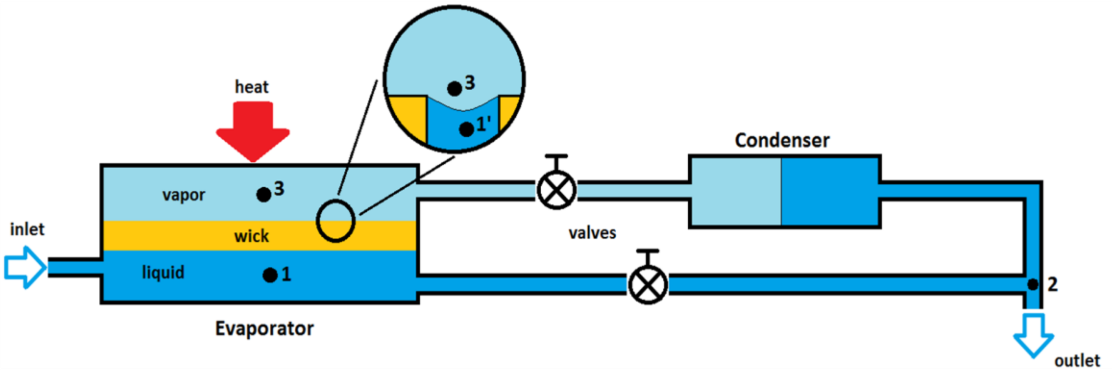
- Unknowns: $\dot{m}_{vap}, \dot{m}_{liq}, P_2, P_3, P_1'$
- System is fully constrained (5 eqns., 5 unknowns)

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

Model Description

User sets Saturation Temperature

Model calculates Psat and verifies 20 PSI NPSHR requirement is satisfied

Model verifies Tsubcooled liquid is greater than Tfreezing

Qmax set by the user at 1000 W

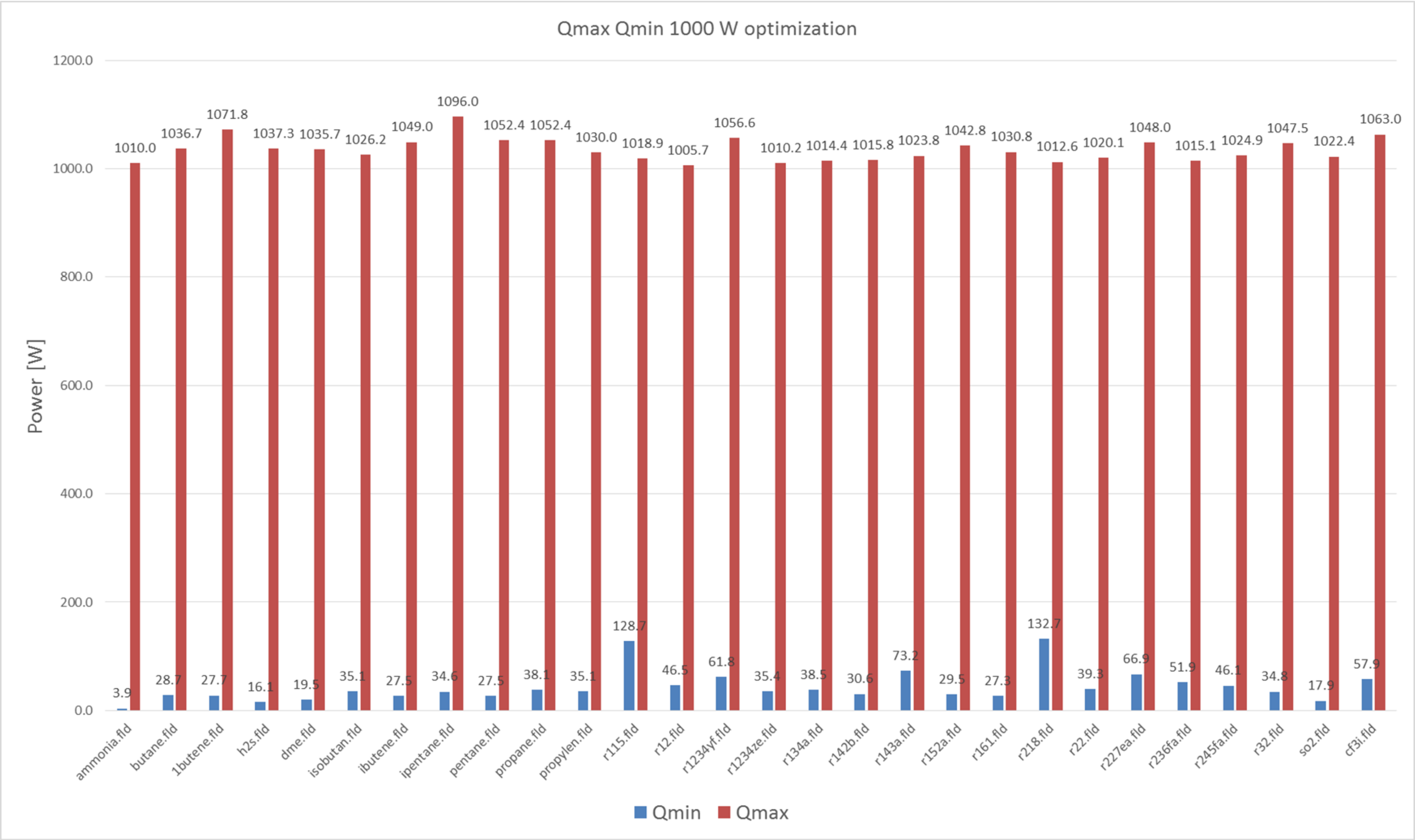
Model calculates minimum mass flow rate to lift Qmax
$Qmax < 0.9\dot{m}tot(Cp\Delta T + \lambda)$

Model verifies that
$Qmax < \frac{\lambda\left(\frac{2\sigma}{f}\dot{m}totRliq\right)}{(Rvap+Rliq+Rwick)}$ is satisfied by adjusting vapor line diameter

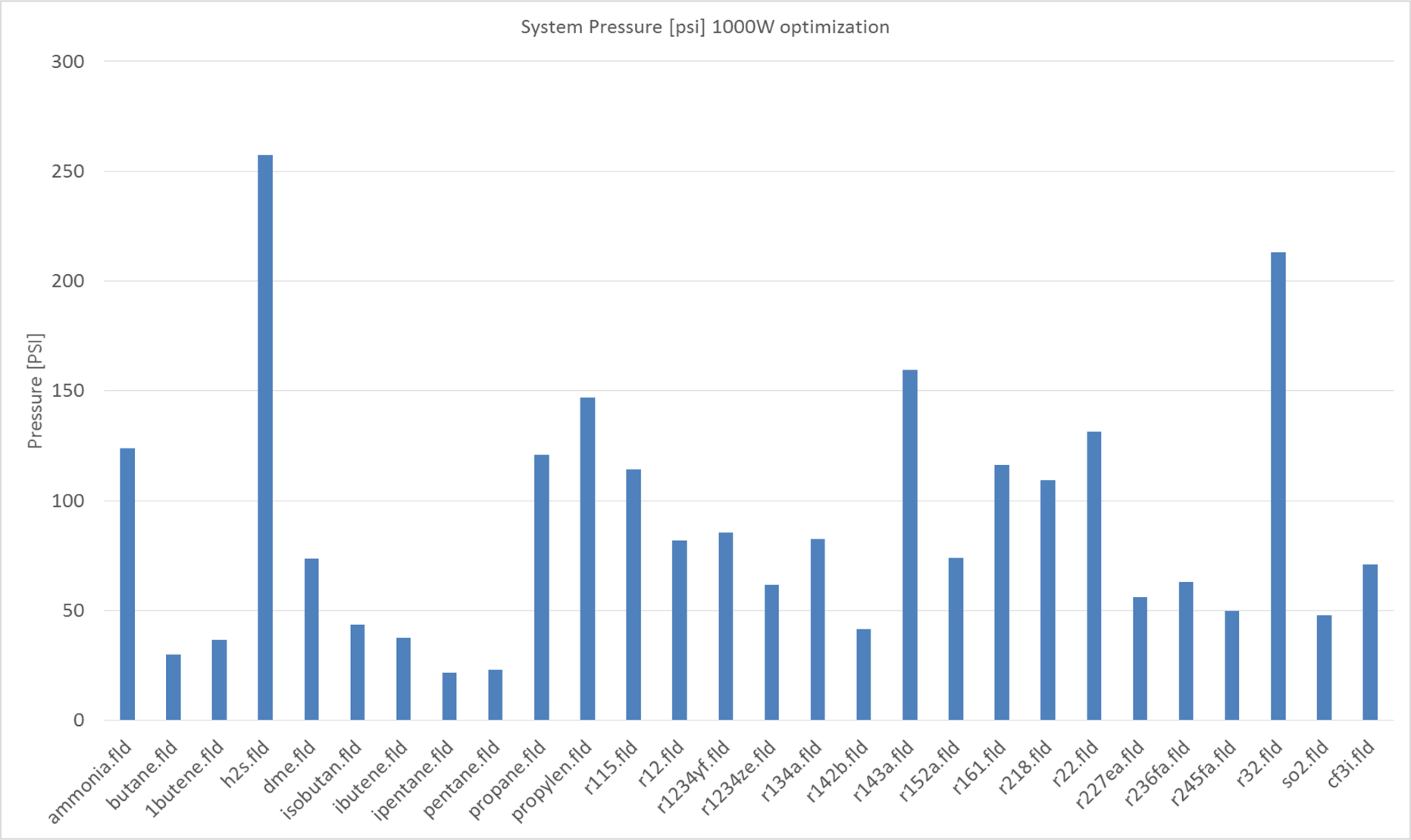
Model calculates Qmin trying to reduces it adjusting liquid line diameter

- Characteristic temperature comparison Tfreezing, Tcritic, Tsubcool, Tsat
- Mass flow rate comparison
- System Mass comparison
- System Pressure Comparison
- Toxicity, Flammability, material compatibility, wettability

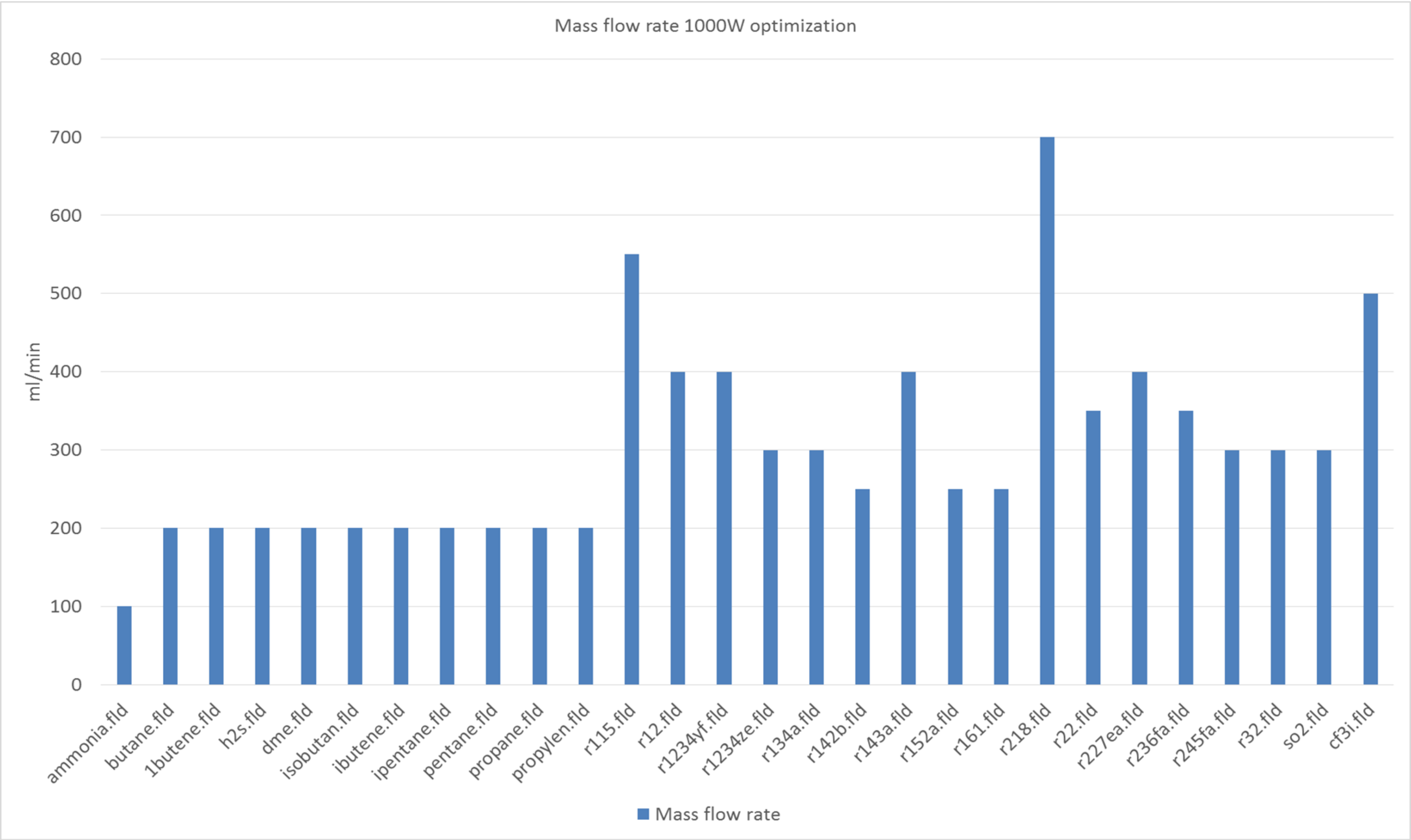
Working fluid study results



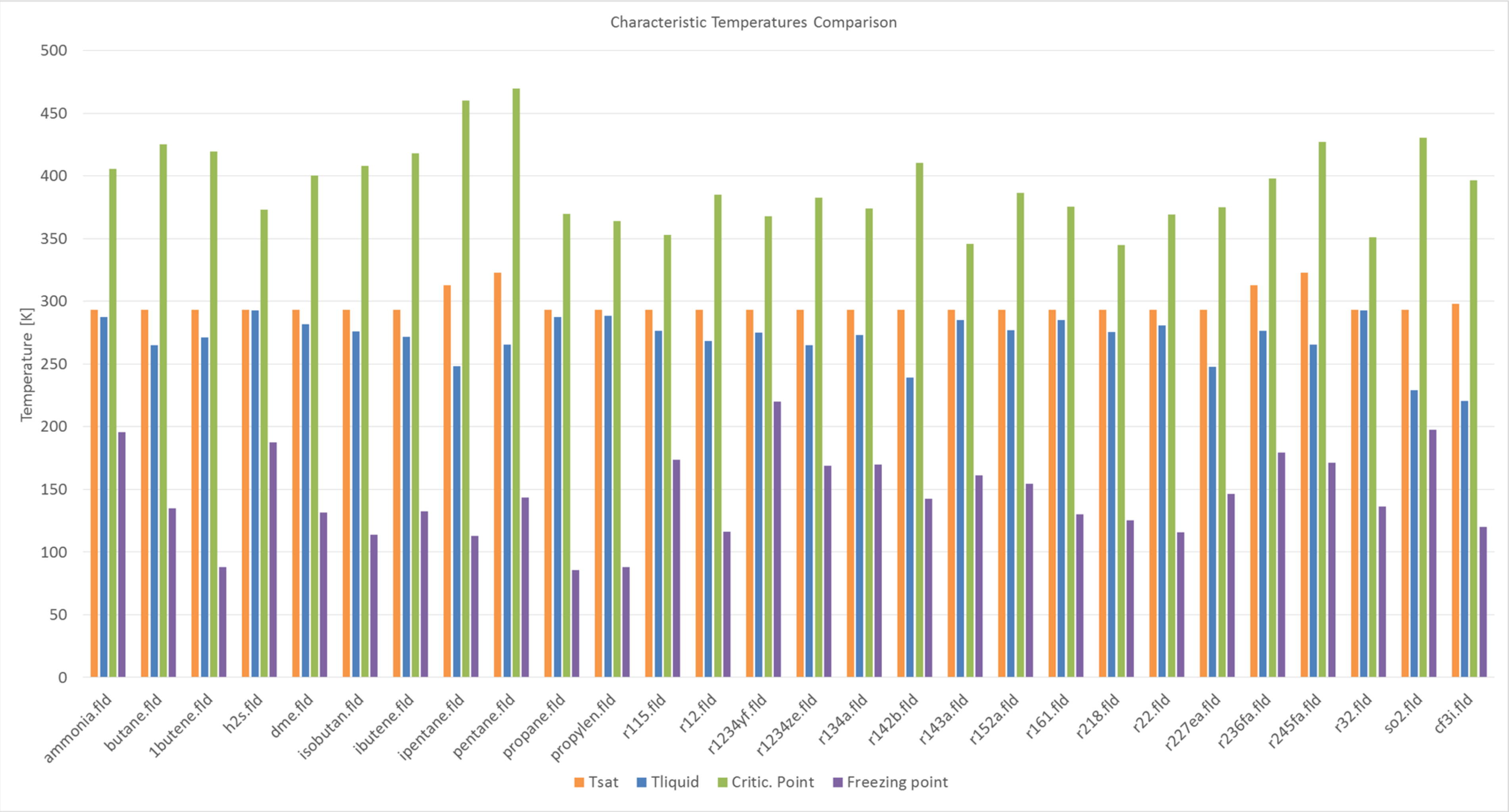
Working fluid study results



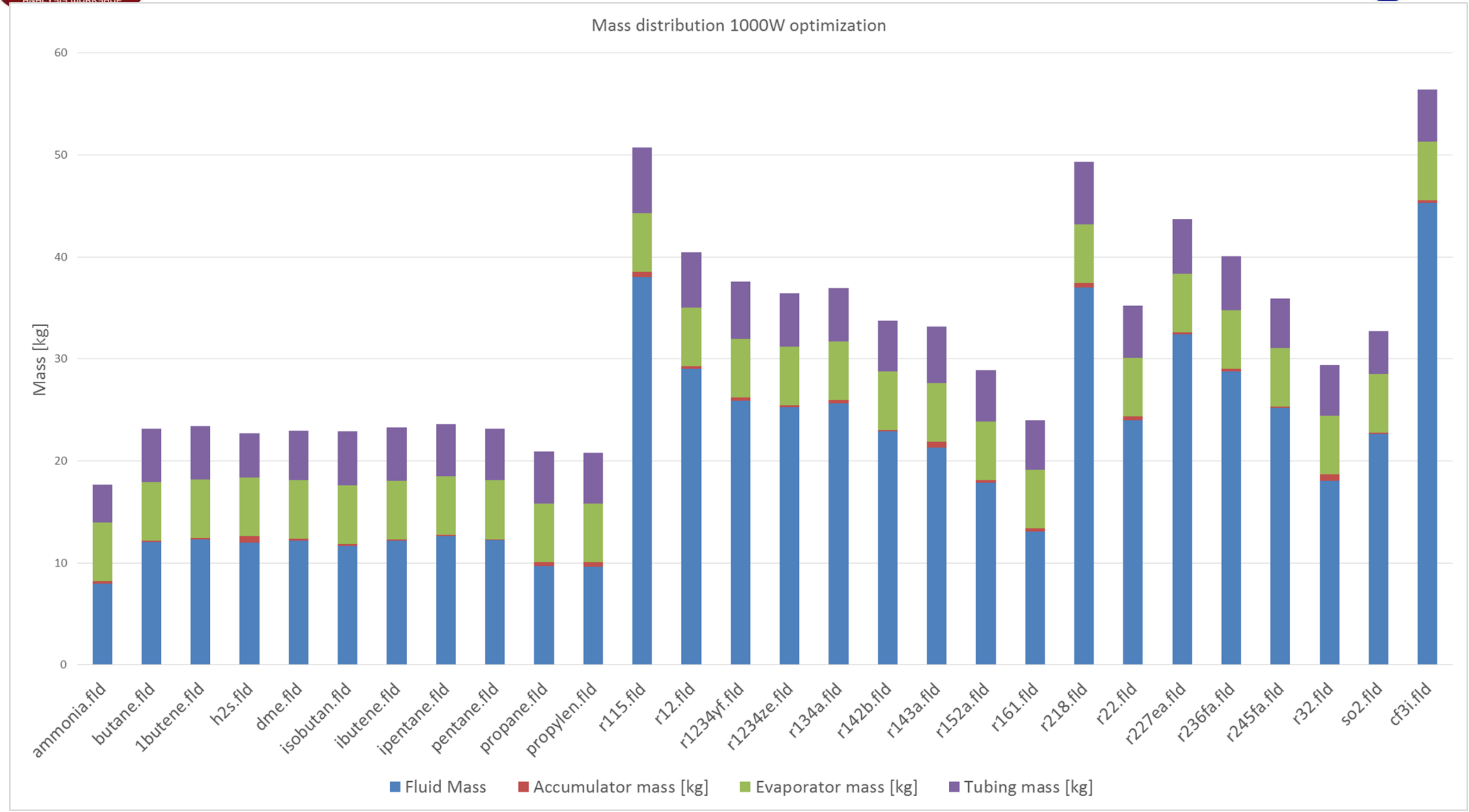
Working fluid study results



Working fluid study results



Working fluid study results



Conclusions

Fluid	Weight [kg]	Mass flow rate [ml/min]	Freezing temperature [K]	Critical Point [K]	Health	Flammability	Instability/reactivity	Al compatability	Titanium compatability	316 St S compatibility	Applications
ammonia	17.7	100.0	195.5	405.4	3	1	0	EXCELLENT	GOOD	EXCELLENT	Heat pipes
butane	23.2	200.0	134.9	425.1	1	4	0	EXCELLENT	EXCELLENT	EXCELLENT	Heat pipes
1-butene	23.4	200.0	87.8	419.3	1	4	0	EXCELLENT	?	EXCELLENT	?
Hydrogen Sulfide	22.7	200.0	187.7	373.1	4	4	0	POOR	GOOD	POOR	?
Dimethyl ether	23.0	200.0	131.7	400.4	1	4	1	POOR	?	POOR	?
Isobutane	22.9	200.0	113.7	407.8	1	4	0	EXCELLENT	?	EXCELLENT	Heat pipes
Isobutene	23.3	200.0	132.4	418.1	1	4	0	EXCELLENT	?	EXCELLENT	?
Isopentane	23.6	200.0	112.7	460.4	1	4	0	EXCELLENT	?	EXCELLENT	Heat pumps
pentane	23.1	200.0	143.5	469.7	1	4	0	EXCELLENT	?	GOOD	Heat pipes
propane	20.9	200.0	85.5	369.9	2	4	0	EXCELLENT	EXCELLENT	EXCELLENT	Heat pipes
propylene	20.8	200.0	88.0	364.2	1	4	1	EXCELLENT	?	EXCELLENT	Heat pipes

Considering:

- **Model results**
- **Critical and freezing temperatures**
- **Toxicity, flammability, instability**
- **Material compatibility, applications heritage**

The chosen working fluid for the loop is AMMONIA

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