ITk Pixel outer endcap cooling system: BabyDEMO test summary

OEC Integration Workshop - Frascati

January 31st, 2024

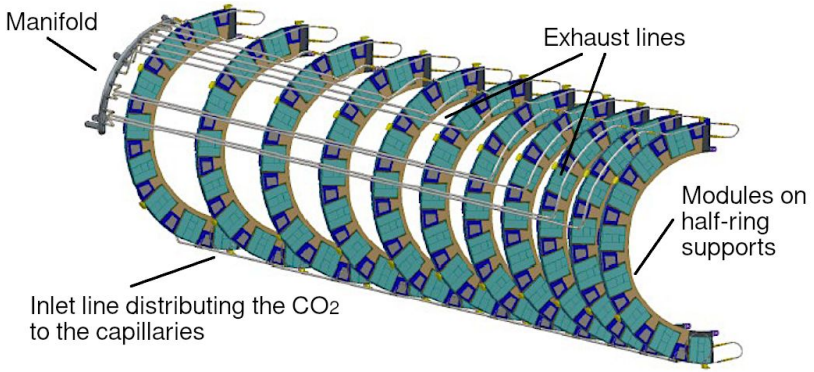
Alex Bitadze, Attilio Andreazza, **Sonia Carrà,** Andrea Capsoni, Simone Coelli, Lidia Dell'Asta, Danilo Giugni, Paul Kemp-Russell, Fabrizio Sabatini, Ennio Viscione, Daniele Viganò

INFN MILANO

ATLAS EXPERIMENT

Pixel outer endcap specification

- Detector working temperature: -35 C
- PP1 temperature: -40 C
- **Total pressure drop: 10 bar**
- **Layer 2, 3 and 4** with increasing thermal load, and progressive larger CO_2 flow



Layer	Evaporator on each layer	Power/evap. [W]	Flow/evaporator [g/s]	Total flow [g/s]
4	9	304	3.04	30.4
3	8	257	2.57	23.1
2	11	187	1.87	22.4

- **Capillary with ID 0.6 mm**
- **Exhaust line have different ID: 3 mm in L2 and L3, 4 mm in L4**

Measurements at BabyDEMO

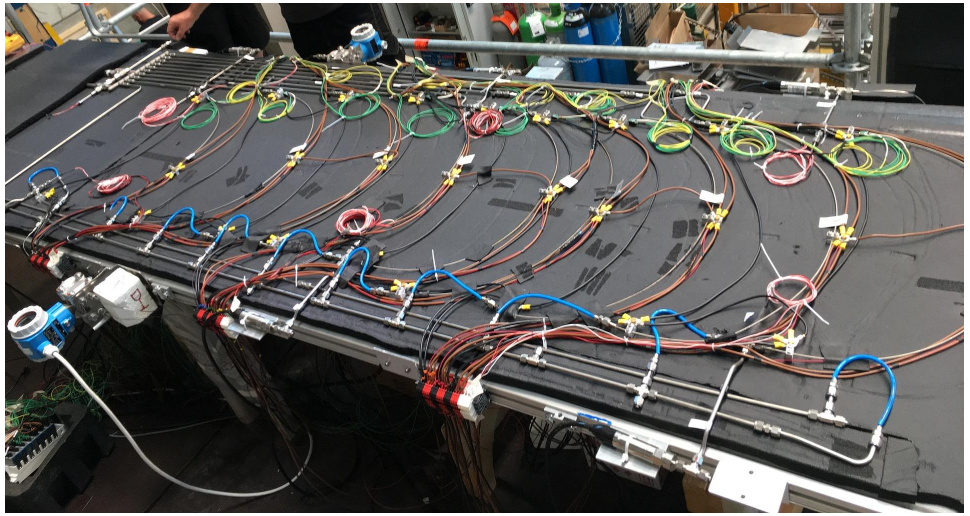
Many thanks to Joao Noite for his support!

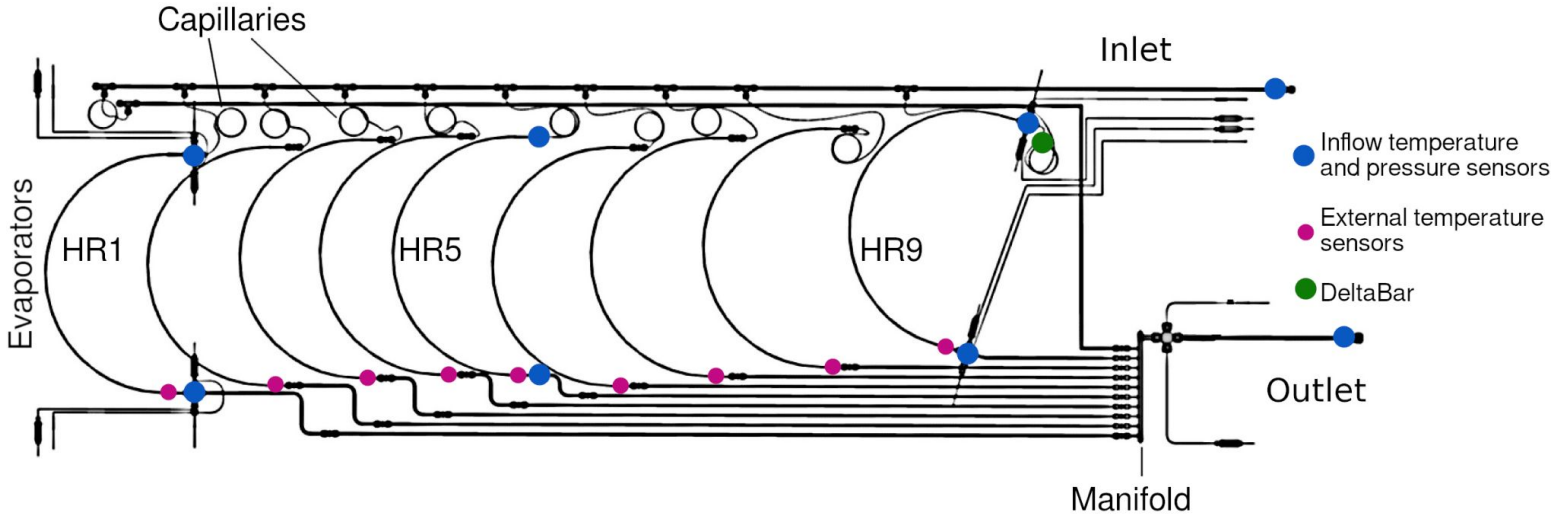
Collecting the presentations on EDMS: AT2-IP-EN-0046

- June and July 2022, **full Layer 4 mockup**
  - many different test conditions:
    - capillaries with different ID
    - flow: nominal 30 g/s, scan from 10 g/s to 40 g/s
    - T setpoint: nominal -40 C, -35 C, -20 C, 0 C
    - thermal load: nominal 300 W/evaporator, no power, nominal +20% (400W/evaporator)
  - links to previous presentation: design - preliminary results - ITk week presentation - dry-out study
- November 2023, **one loop mockup for Layer 2 and Layer 3**
  - many different test conditions:
    - T setpoint: nominal -40 C, -20 C, 0 C, +15 C
    - flow, Layer 2: nominal 1.8 g/s, 1.4 g/s, 2.2 g/s; Layer 3: nominal 2.6 g/s, 2 g/s, 3 g/s
    - thermal load, Layer 2: nominal 187 W, no power, nominal +20% (224 W);
      Layer 3: nominal 257 W, no power, nominal +20% (308 W)
  - link to preliminary study with TRACI - BD summary at ITk cooling meeting
- **Presenting just a selection of the results at nominal working conditions**

Setup for Layer 4

- **Full Layer 4, flat mockup**
- **Exhaust line pipe with ID 4.55 mm** (4 mm in final detector) due to availability at the time
- **Capillary with ID 0.6 mm**, sizing done at BabyDEMO (90 cm gives 9.33 bar)





Result for Layer 4 [1]

Data at nominal conditions:

- total flow is 30 g/s
- PP1 T -40 C
- reporting ΔP both at nominal power and power +20%

Length of exhaust lines in the Layer 4 prototype:

- L_{exh} HR1 = 236 cm
- L_{exh} HR5 = 147 cm
- L_{exh} HR9 = 35 cm

	300 W/evaporator ΔP [bar]	400 W/evaporator ΔP [bar]
Capillary [HR9]	9.33	9.31
Evaporator [HR1]	0.81	1.04
Evaporator [HR5]	0.82	1.04
Evaporator [HR9]	0.85	1.12
Exh. line + manifold [HR1]	0.49	0.50
Exh. line + manifold [HR5]	0.40	0.37
Exh. line + manifold [HR9]	0.41	0.36

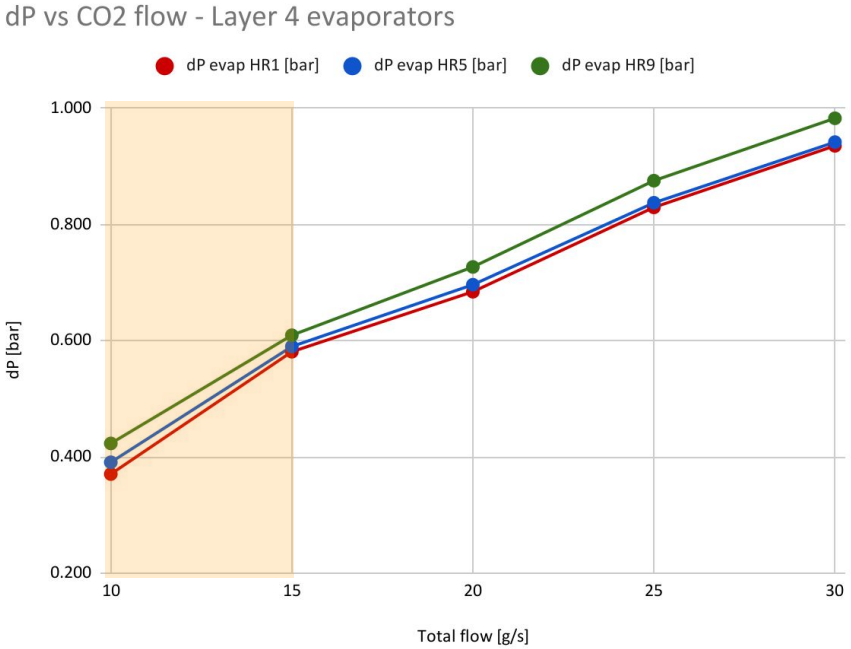
Capillary to be size to reach 10 bar total ΔP

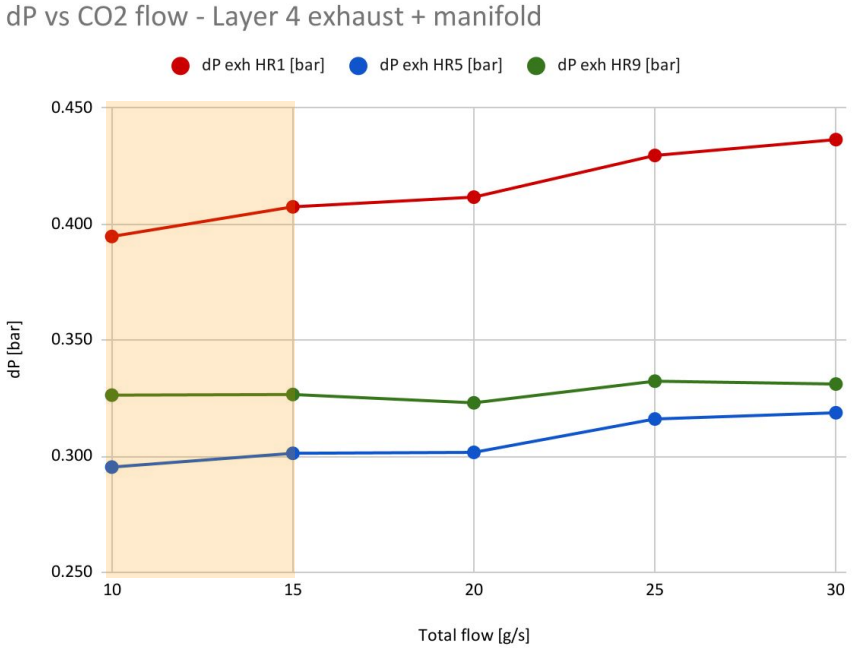
Result for Layer 4 [2]

Pressure drop in evaporators (left) and exhaust lines + manifold (right) for decreasing CO_2 flow.

Total flow range from 30 g/s (nominal) to 10 g/s, PP1 T -40 C and 300 W/evaporator

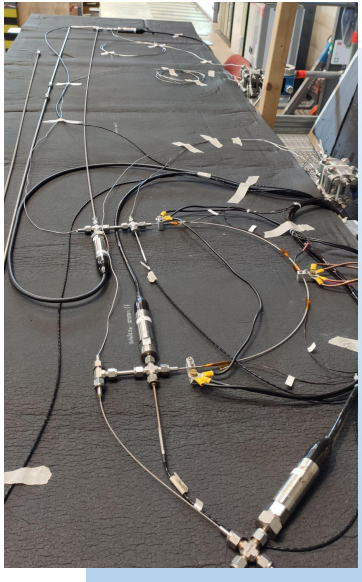
Dry-out condition for flow below 15 g/s

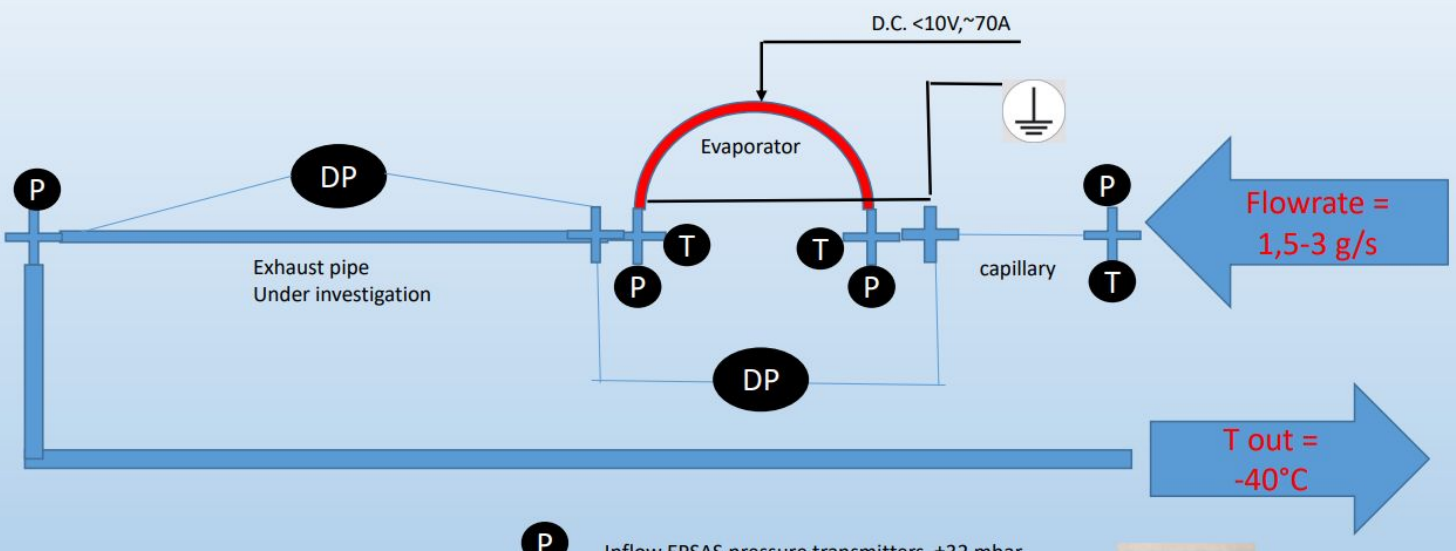




Setup for Layer 2 and Layer 3

- **One loop only,** same set up Layer 2 and Layer 3 but different evaporator and capillary length
- All pipe ID as foreseen in the final detector design





Exhaust pipes
Under investigation:
ID3mm/OD4mm

P Inflow EPSAS pressure transmitters, ±32 mbar

T Inflow temperature: PT100 (4 wire) with 1.5 mm tip

DP DeltaBar ENDRES+HAUSER PMD75 +/- 500mbar

DeltaBar ENDRES+HAUSER PMD75 +/- 16bar

Results for Layer 2

Result at nominal conditions:

- flow 1.8 ± 0.1 g/s
- CO_2 set point -40C

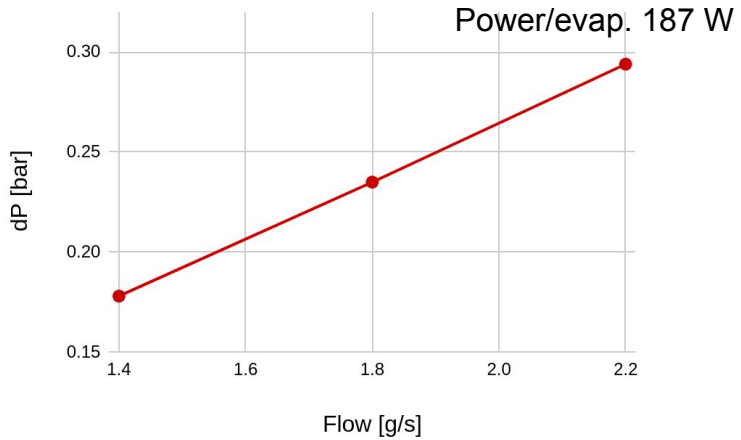
Capillary length: 55 cm

	187 W/evaporator ΔP [bar]	224 W/evaporator ΔP [bar]
Capillary	5.62	5.58
Evaporator	0.235	0.277
Exhaust line	0.145	0.172

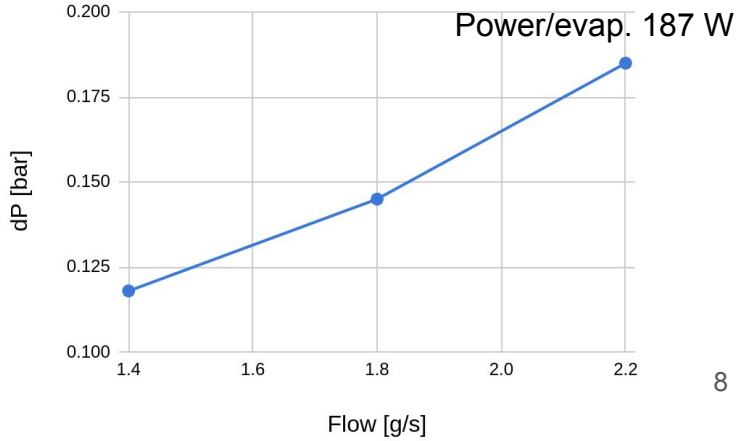
Capillary to be size to reach 10 bar total ΔP

Pressure drop as function of the flow

dP vs CO2 flow - Layer 2 evaporator



dP vs CO2 flow - Layer 2 exhaust line



Results for Layer 3

Result at nominal conditions:

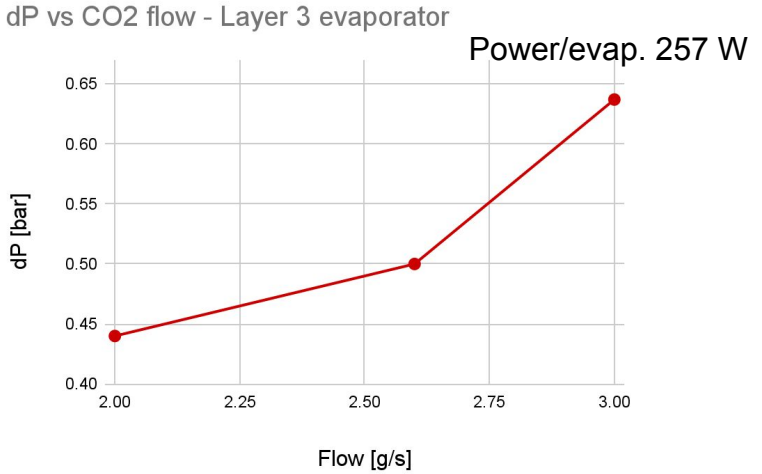
- flow 2.6 ± 0.1 g/s
- CO_2 set point -40C

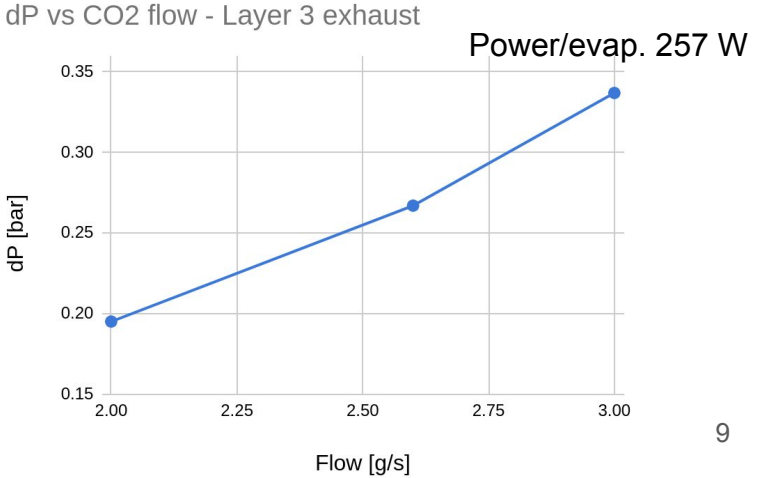
Capillary length: 29 cm

	257 W/evaporator ΔP [bar]	308 W/evaporator ΔP [bar]
Capillary	7.14	6.89
Evaporator	0.50	0.60
Exhaust line	0.267	0.327

Capillary to be size to reach 10 bar total ΔP

Pressure drop as function of the flow





Conclusions

- **Full Layer 4 prototype** measurement at BD:
  - proving the stability of the system in all working condition
  - first sizing of the capillary, ID 0.6 mm chosen over ID 0.8 mm in order to provide reasonable length for all the layers
- **One loop Layer 2 and Layer 3** measurement at BD:
  - detailed study of the exhaust lines, ID3mm/OD4mm proven to be suitable for both the layers
- **Pressure drop:**
  - target is to reach **10 bar of total pressure drop** in each Layer and capillaries to be sized accordingly
  - full set of measurements, compared with FLUDY simulation, allows to estimate proper capillary sizing for all the layers
    → discussed in the next talk by Lidia Dell'Asta

Summary of the pressure drop measurements

Pressure drop and capillary sizing will be discussed in detail in the talk by Lidia Dell'Asta

Nominal power

	Evaporator ΔP [bar]	Longest exhaust line ΔP [bar]	Manifold ΔP [bar]
Layer 2	0.235	0.145	0.45 → estimated
Layer 3	0.50	0.267	0.45 → estimated
Layer 4	0.83 → average of three evaporators	0.08 → estimated from data and simulations comparison	0.45 → estimated from data and simulations comparison

Power +20%

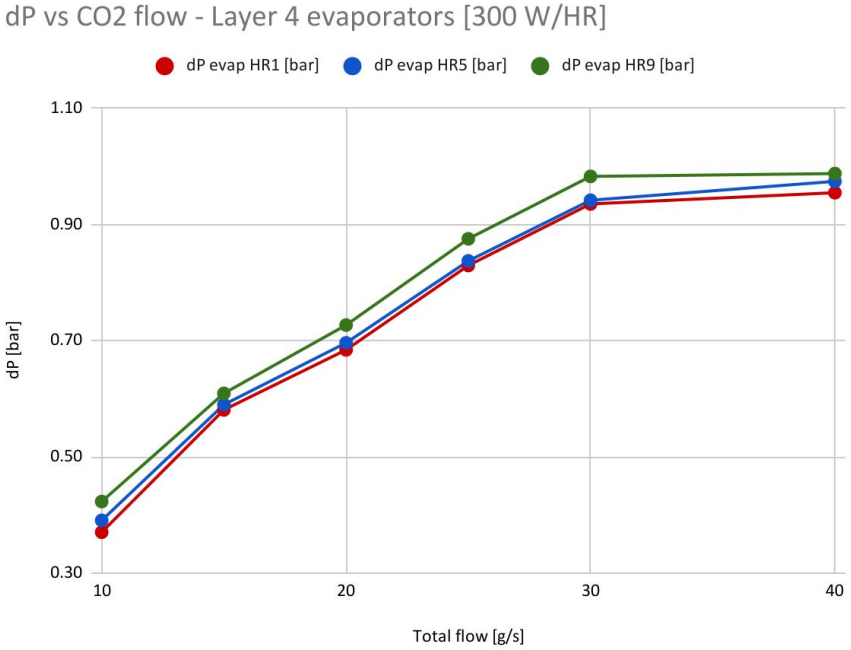
	Evaporator ΔP [bar]	Longest exhaust line ΔP [bar]	Manifold ΔP [bar]
Layer 2	0.277	0.172	0.44 → estimated
Layer 3	0.60	0.327	0.44 → estimated
Layer 4	1.07 → average of three evaporators	0.12 → estimated from data and simulations comparison	0.44 → estimated from data and simulations comparison

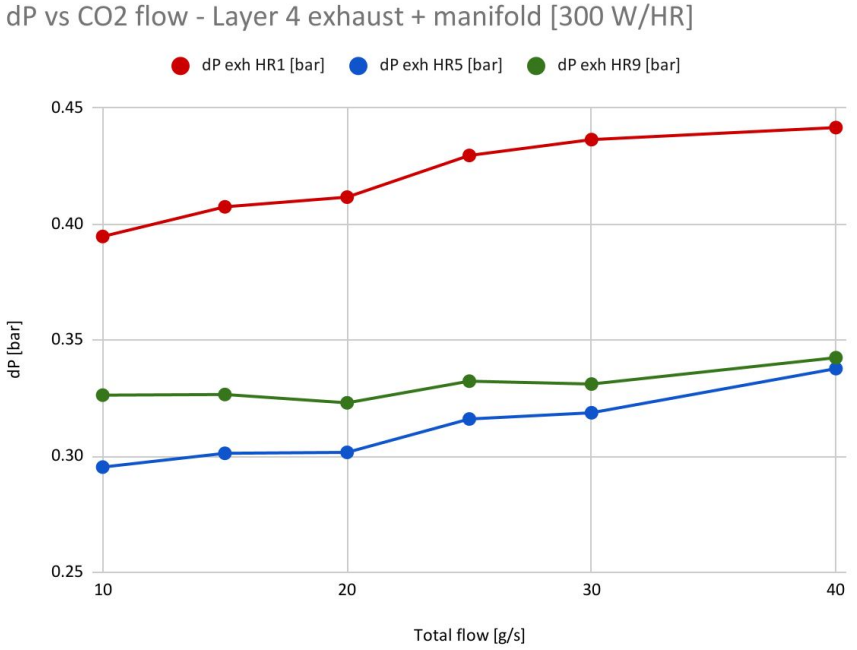
Backup

Additional material: Layer 4 ΔP vs flow

Layer 4 - ΔP vs flow at nom. power, T_{set} = -40 C

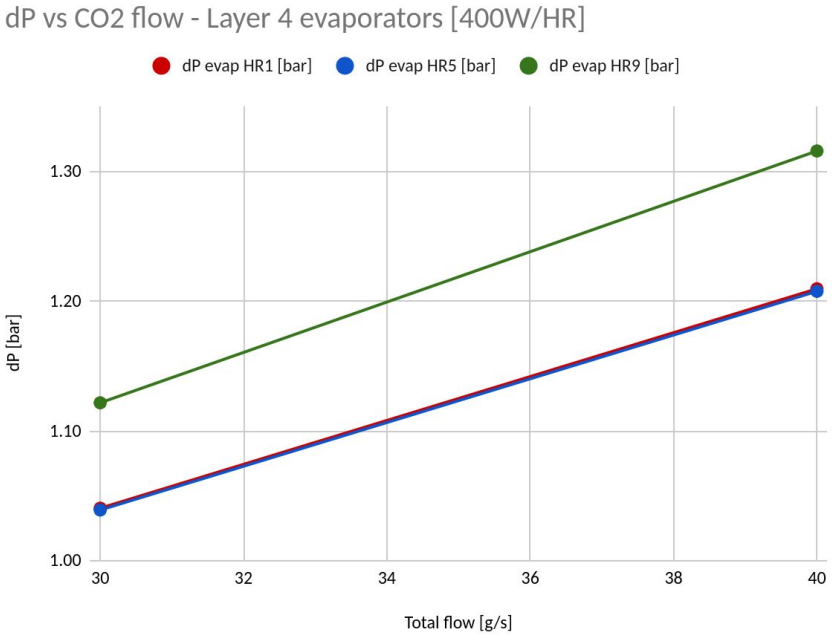
Compare to the slide in the main body, a point at 40 g/s from a different data taking day is also added.

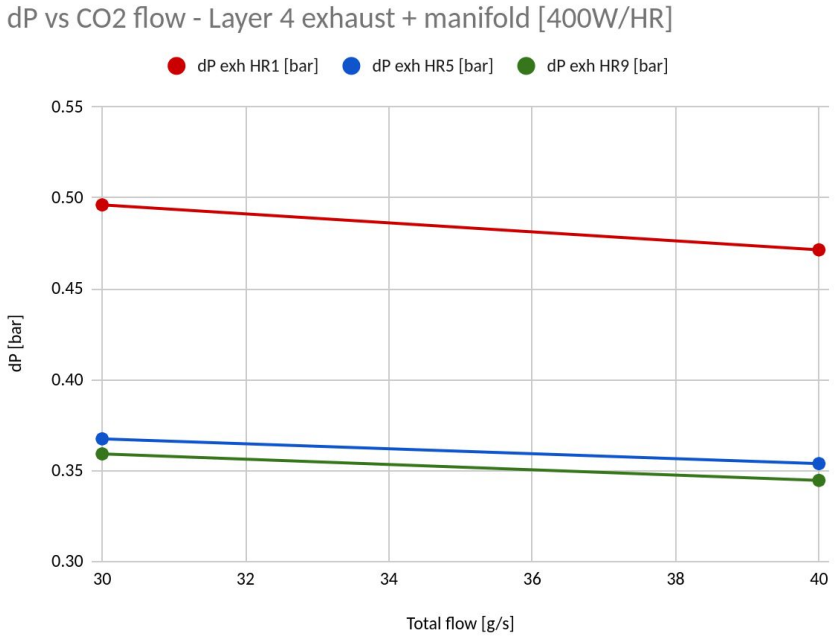




Layer 4 - ΔP vs flow at power +20%, T_{set} = -40 C

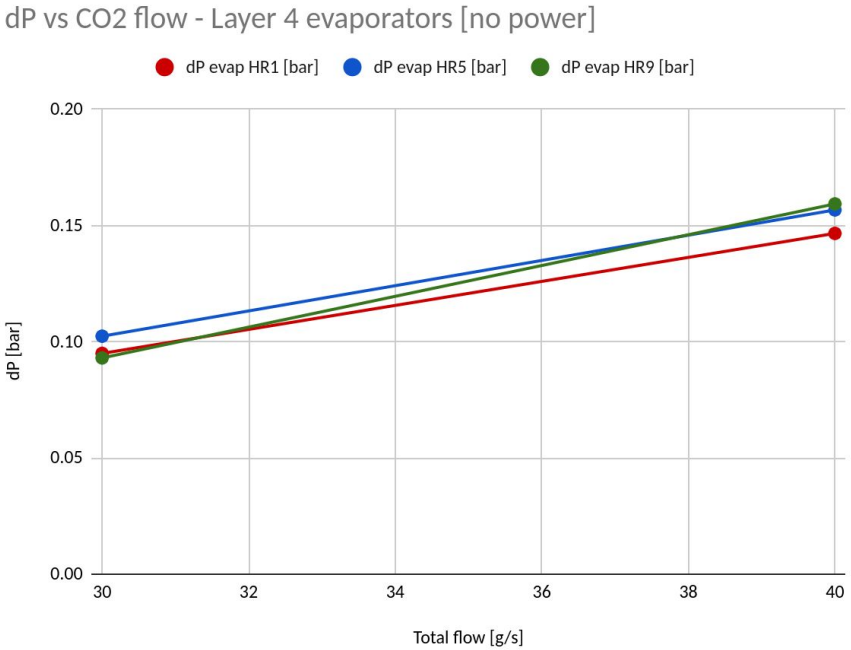
Only two flow points available for this configuration.

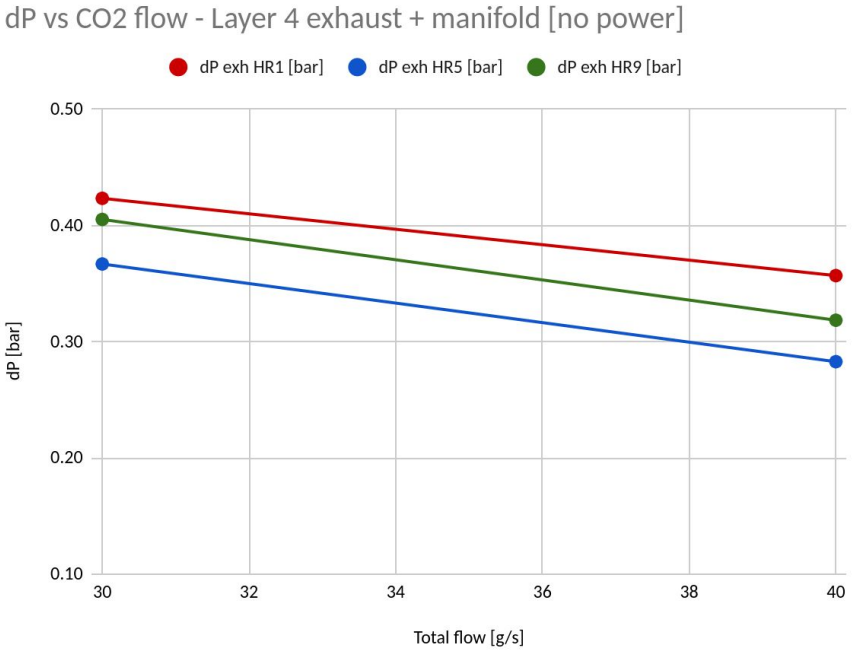




Layer 4 - ΔP vs flow with no power, T_{set} = -40 C

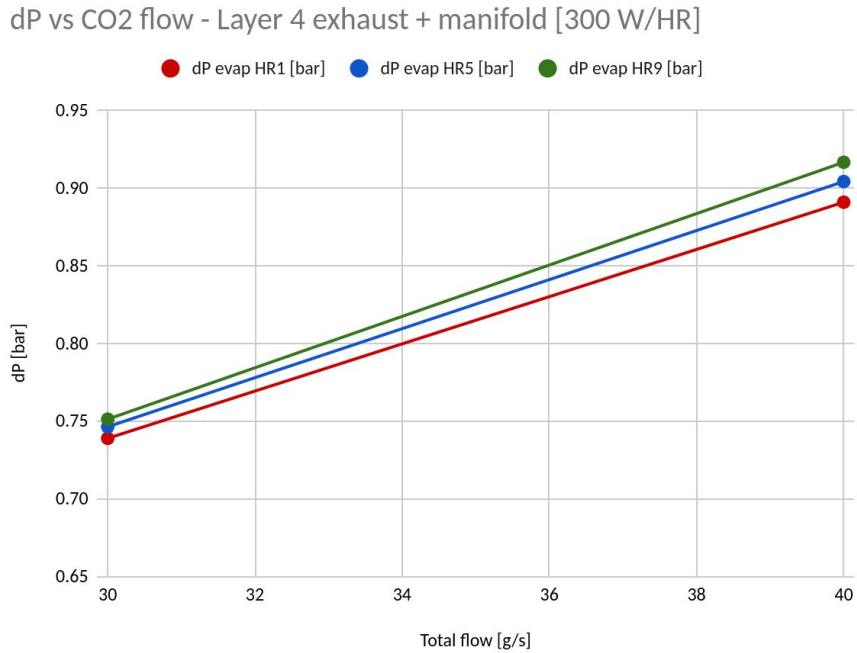
Only two flow points available for this configuration.

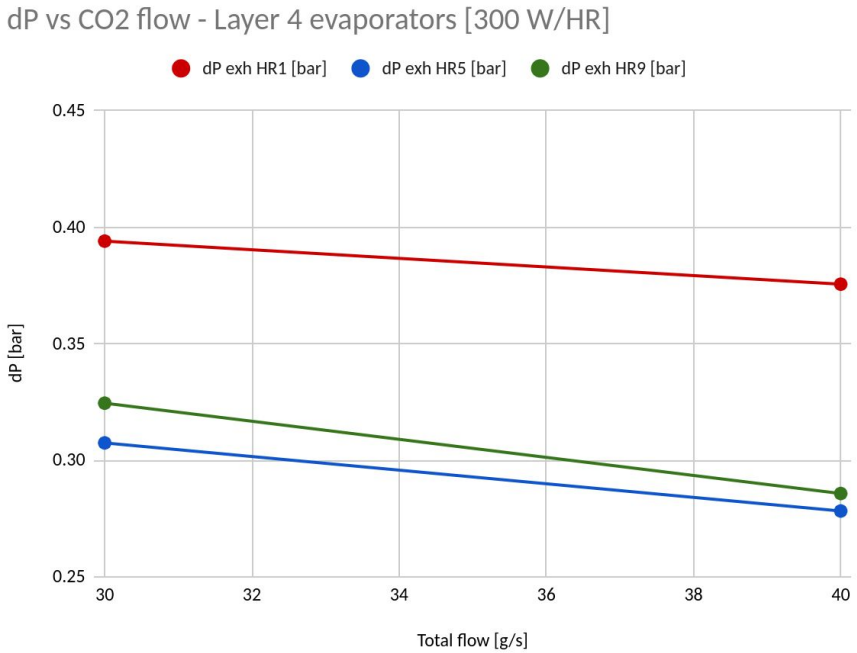




Layer 4 - ΔP vs flow at nom. power, T_{set} = -35 C

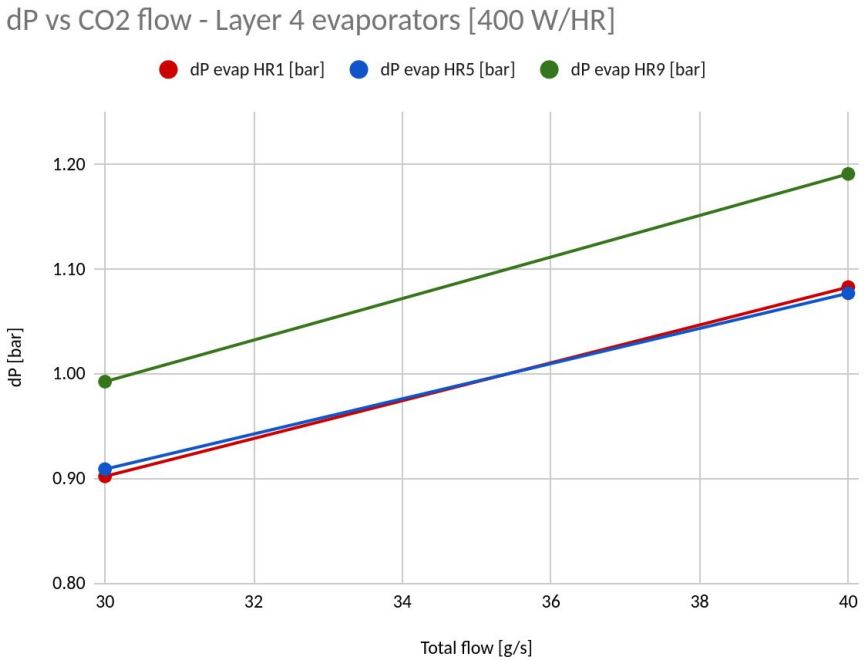
Only two flow points available for this configuration.

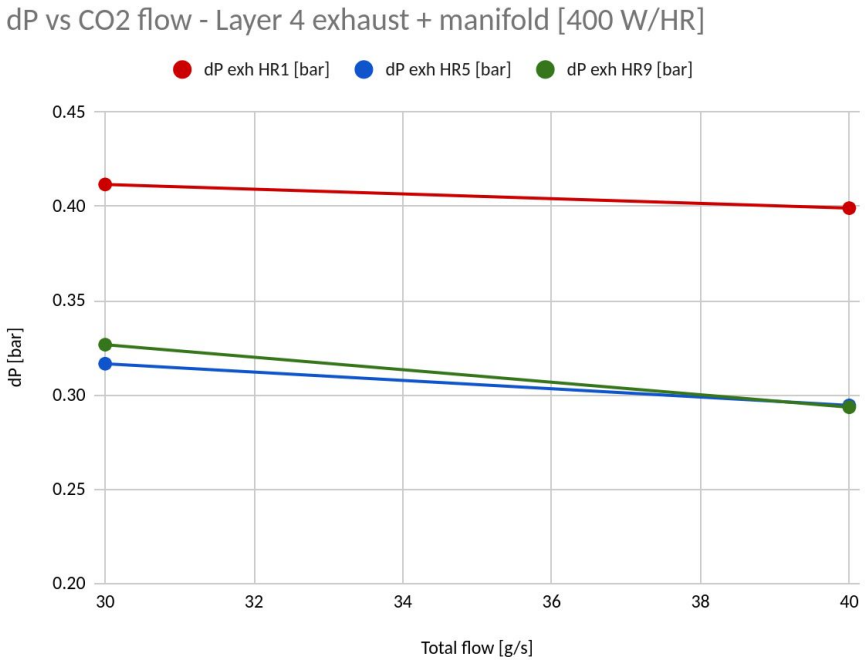




Layer 4 - ΔP vs flow at power +20%, T_{set} = -35 C

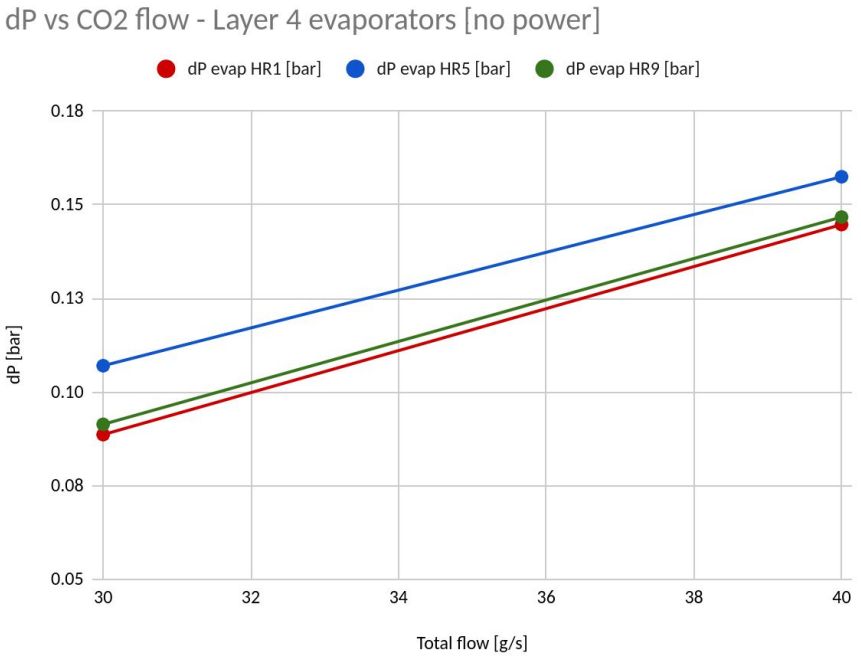
Only two flow points available for this configuration.

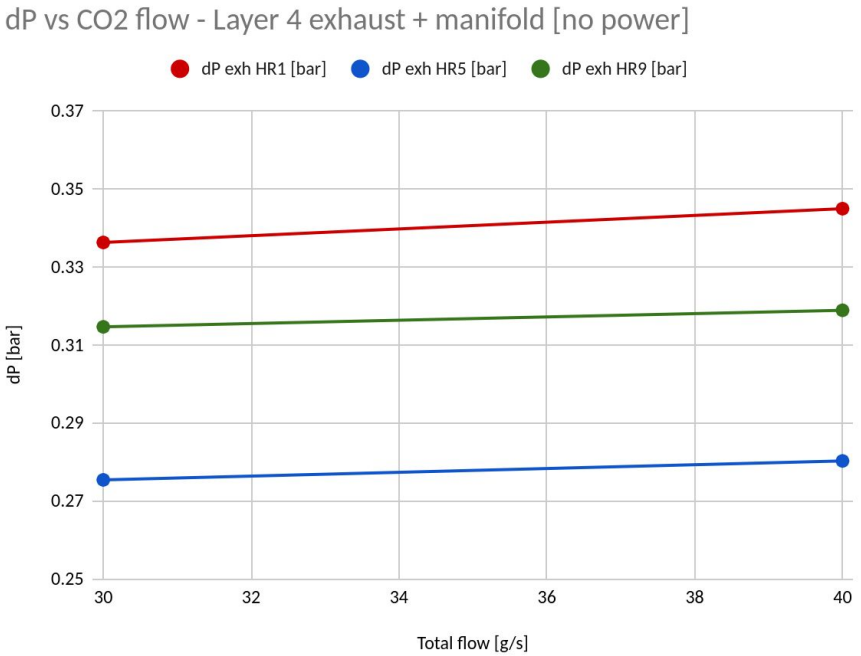




Layer 4 - ΔP vs flow with no power, T_{set} = -35 C

Only two flow points available for this configuration.



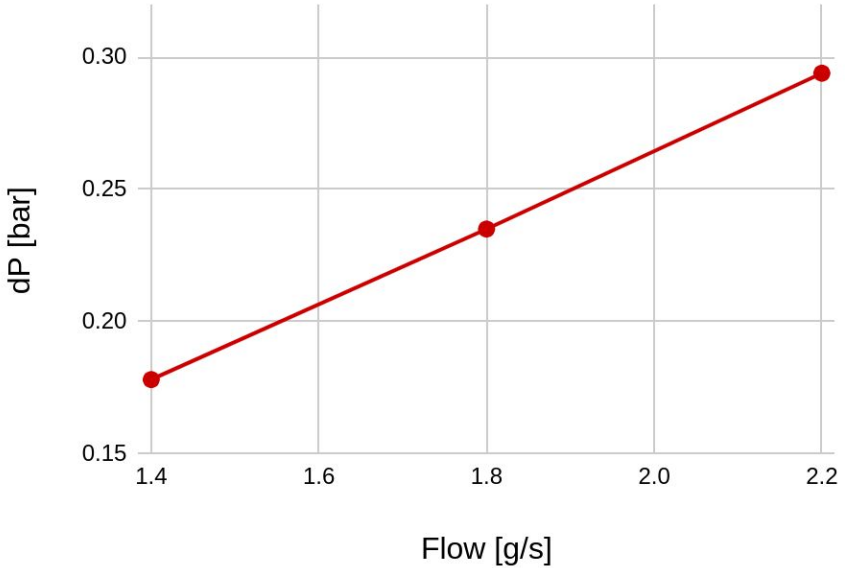


Additional material: Layer 2 ΔP vs flow

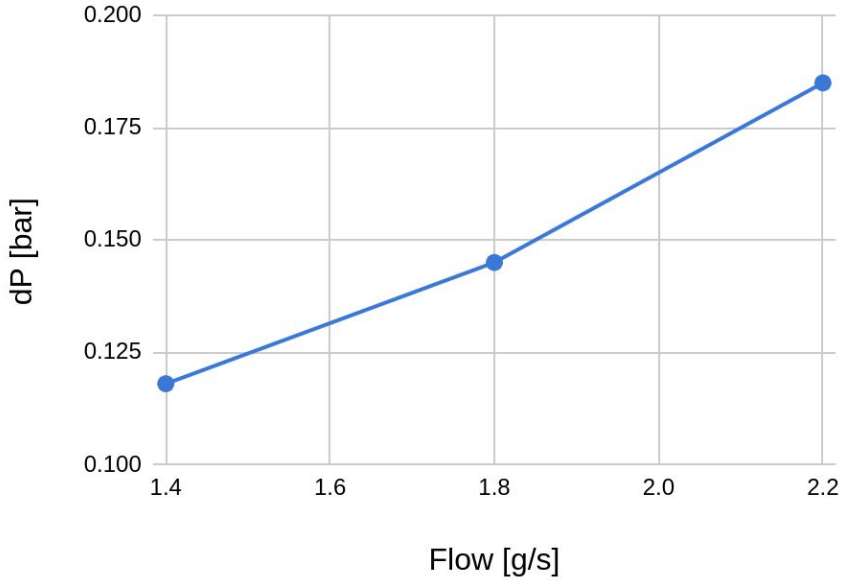
Layer 2 - ΔP vs flow at nom. power, T_{set} = -40 C

Same plots shown in slide 8, reporting them for easier comparison

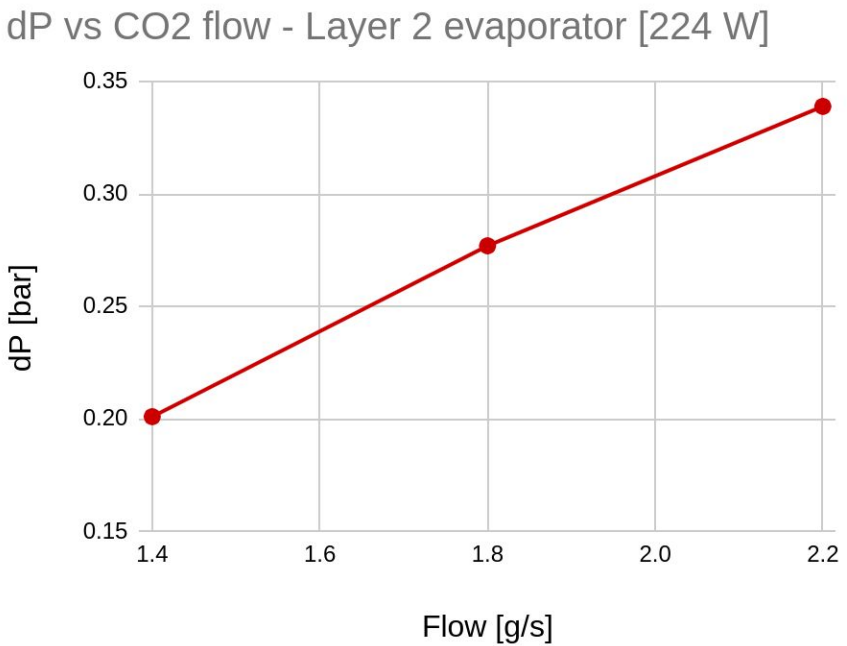
dP vs CO2 flow - Layer 2 evaporator

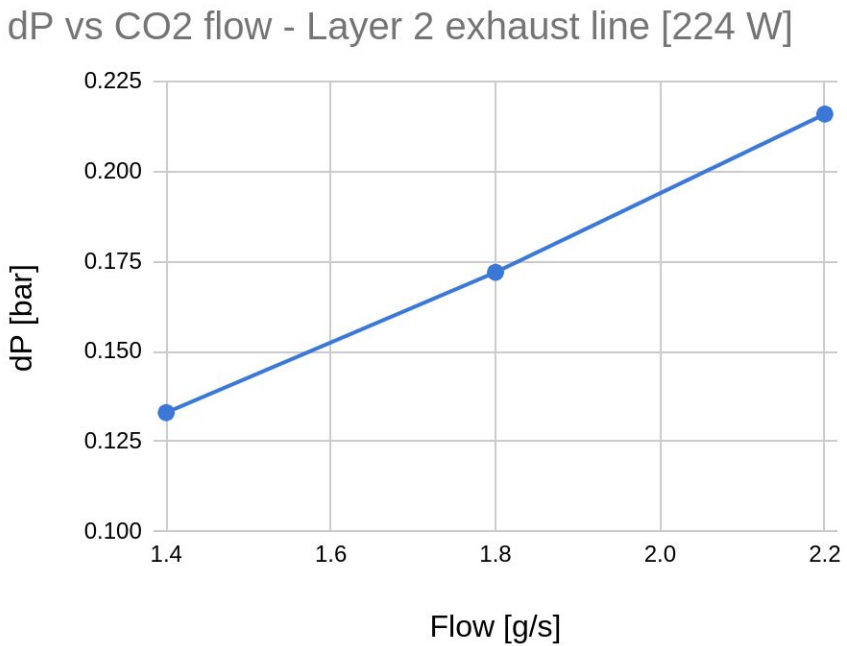


dP vs CO2 flow - Layer 2 exhaust line

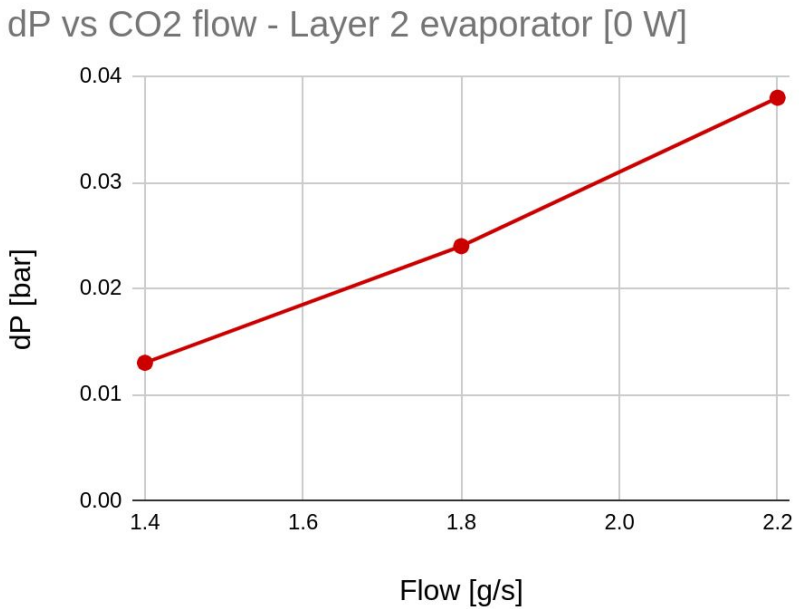


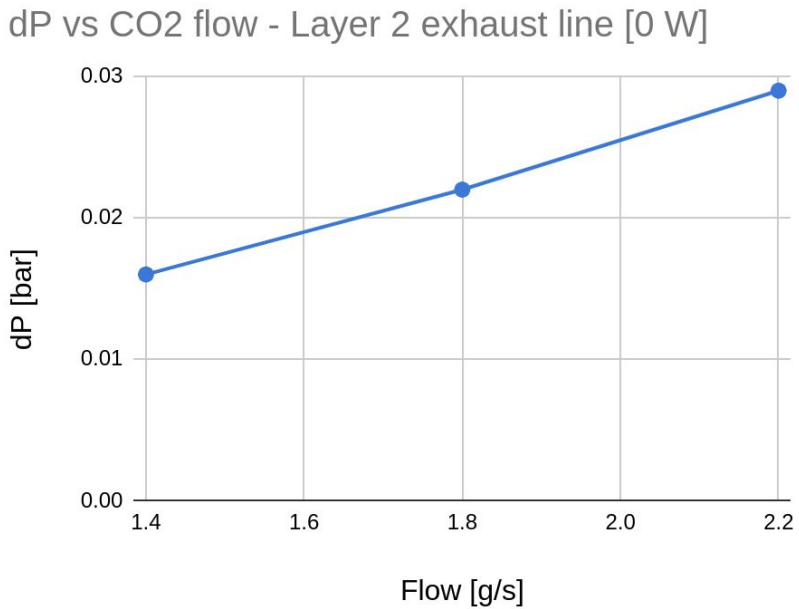
Layer 2 - ΔP vs flow at power +20%, T_{set} = -40 C



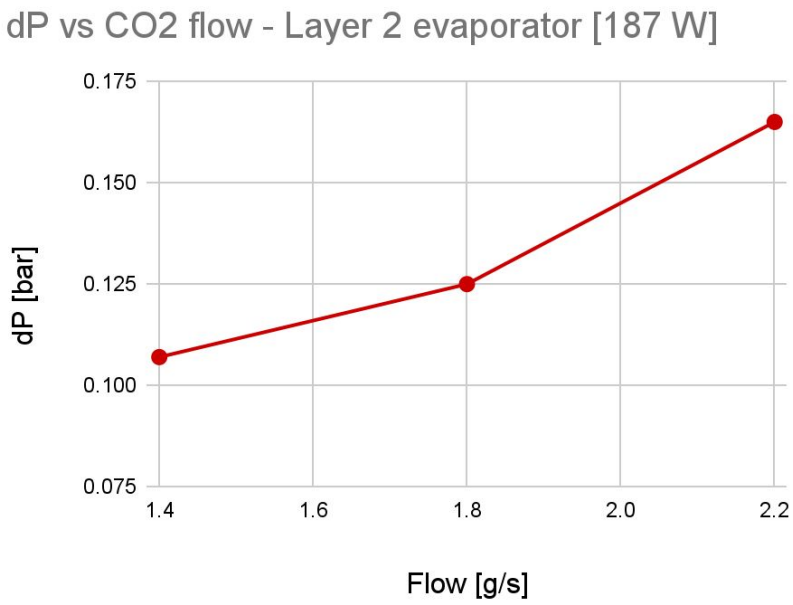


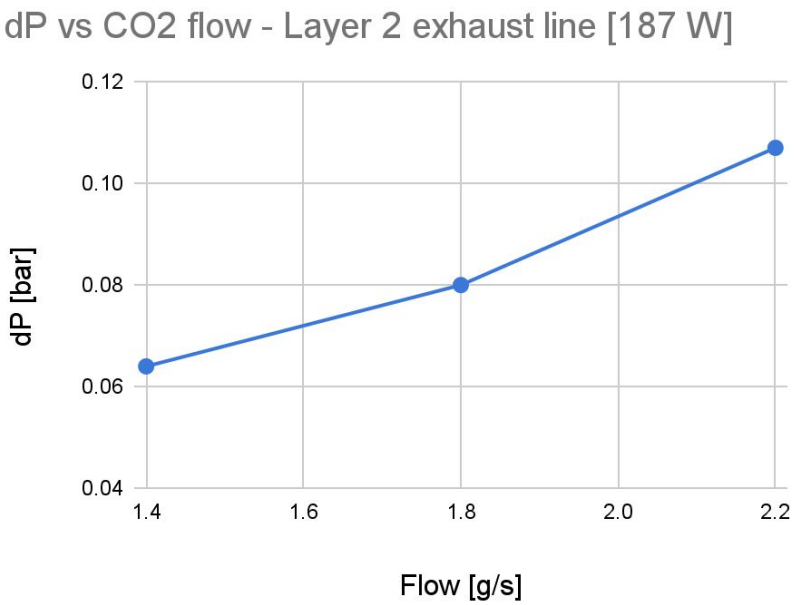
Layer 2 - ΔP vs flow with no power, T_{set} = -40 C



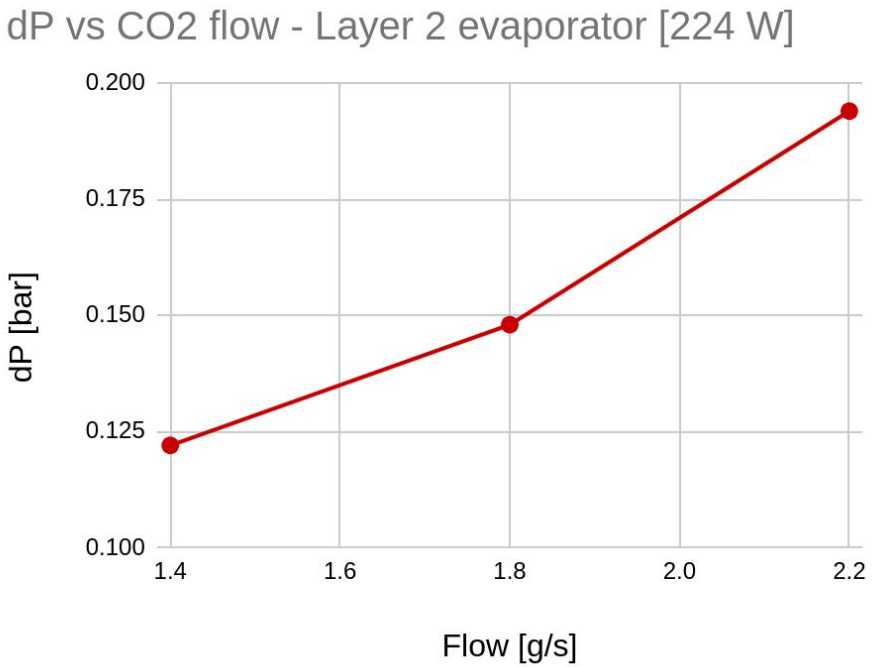


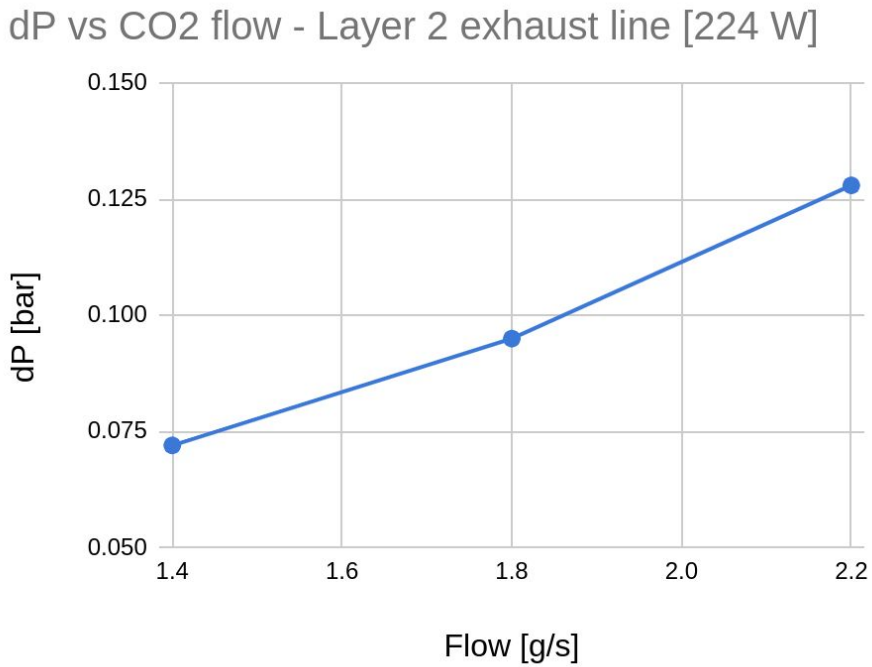
Layer 2 - ΔP vs flow at nom. power, T_{set} = -20 C



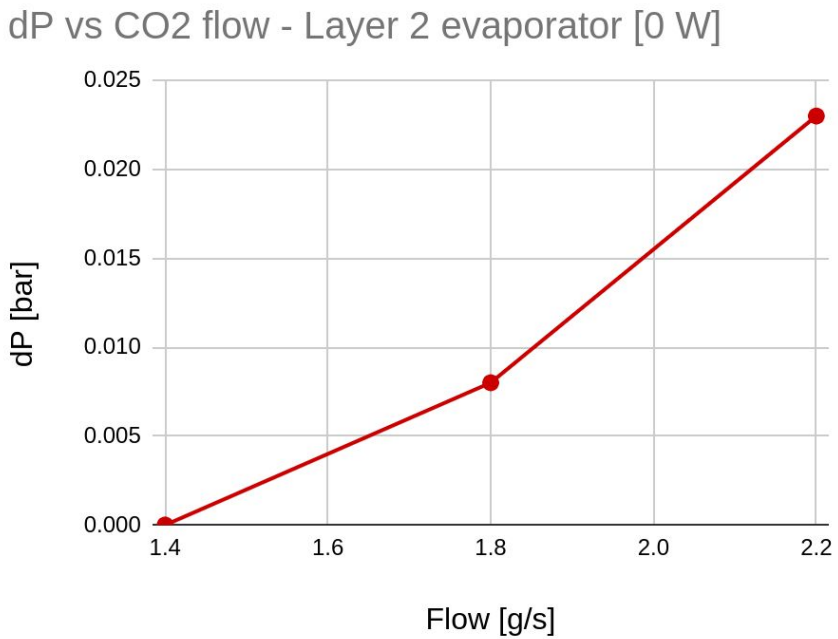


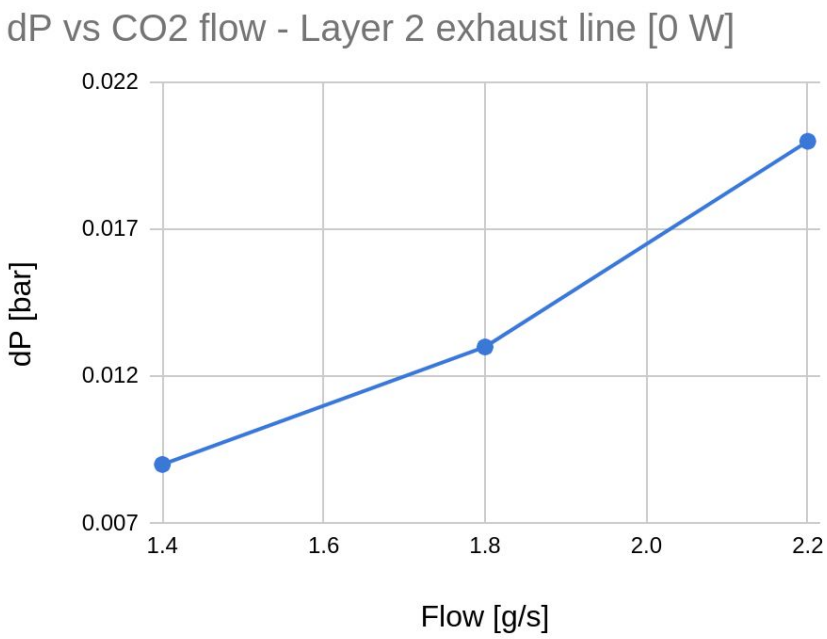
Layer 2 - ΔP vs flow at power +20%, T_{set} = -20 C



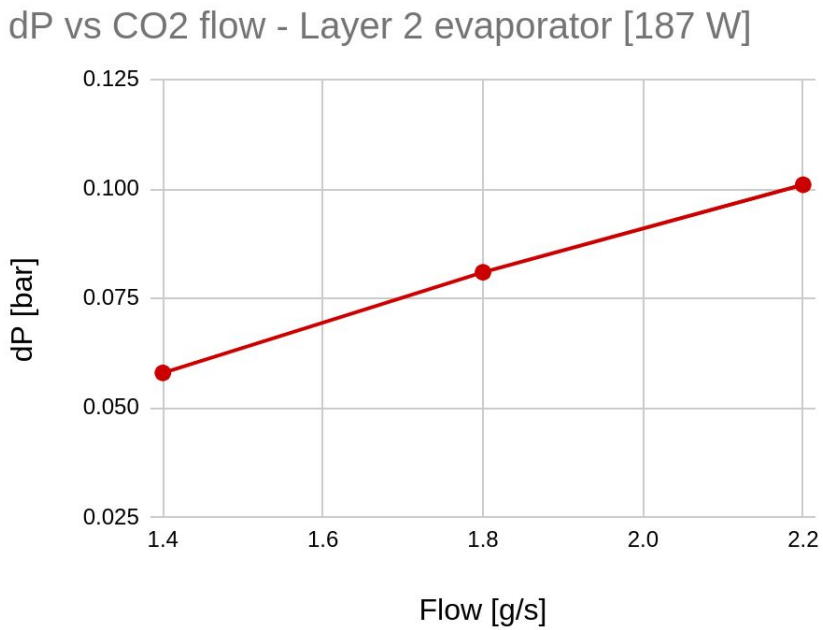


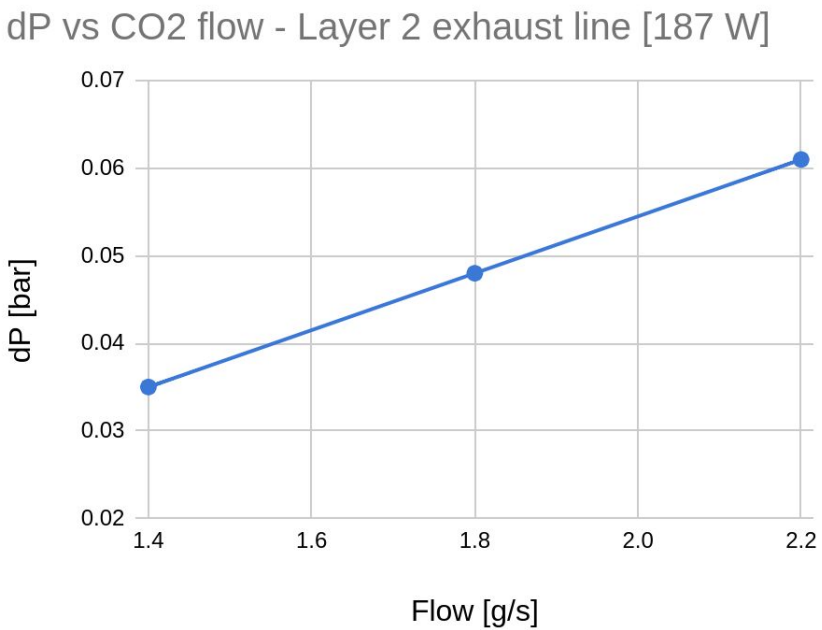
Layer 2 - ΔP vs flow with no power, T_{set} = -20 C



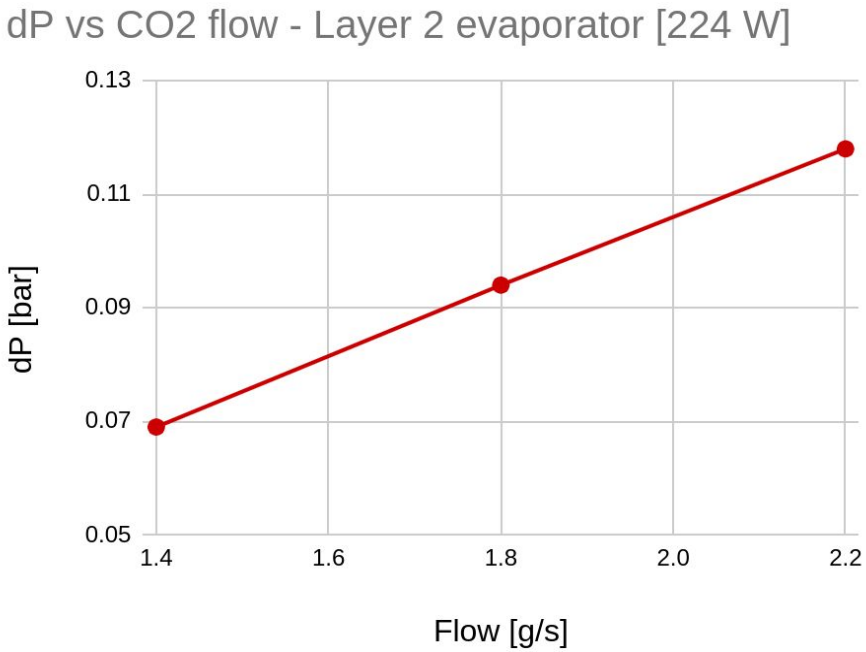


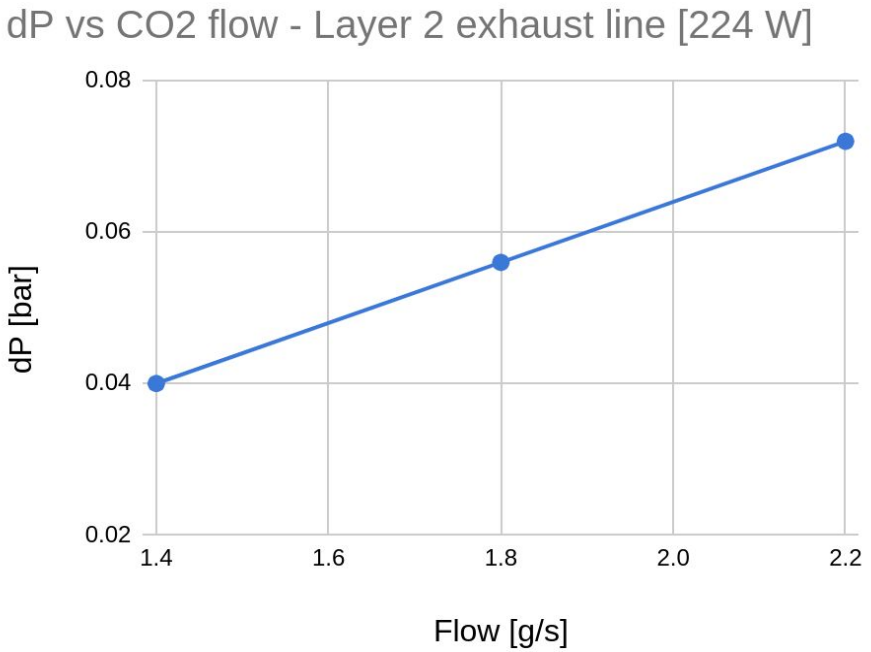
Layer 2 - ΔP vs flow at nom. power, T_{set} = 0 C



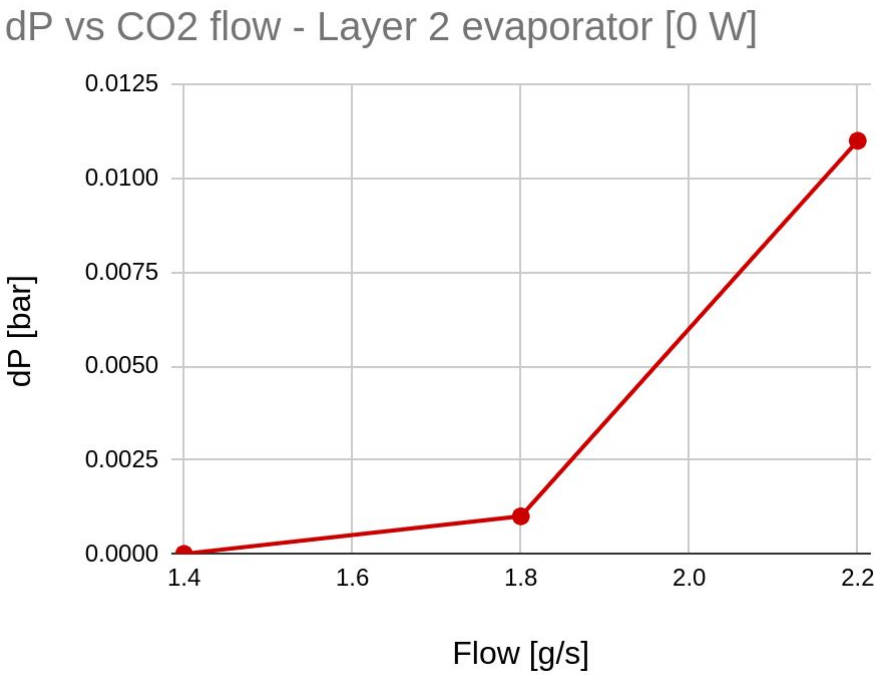


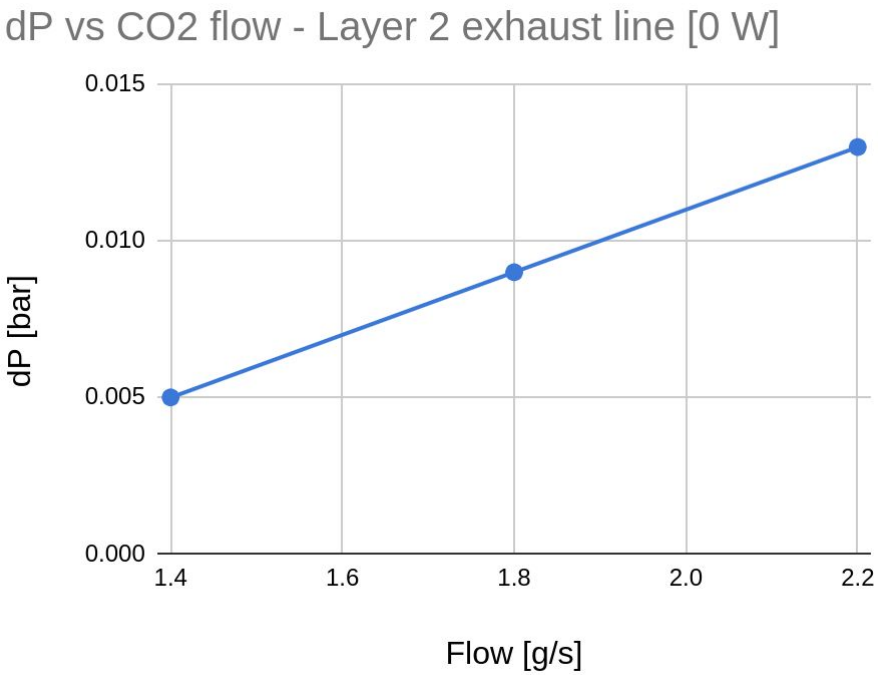
Layer 2 - ΔP vs flow at power +20%, T_{set} = 0 C



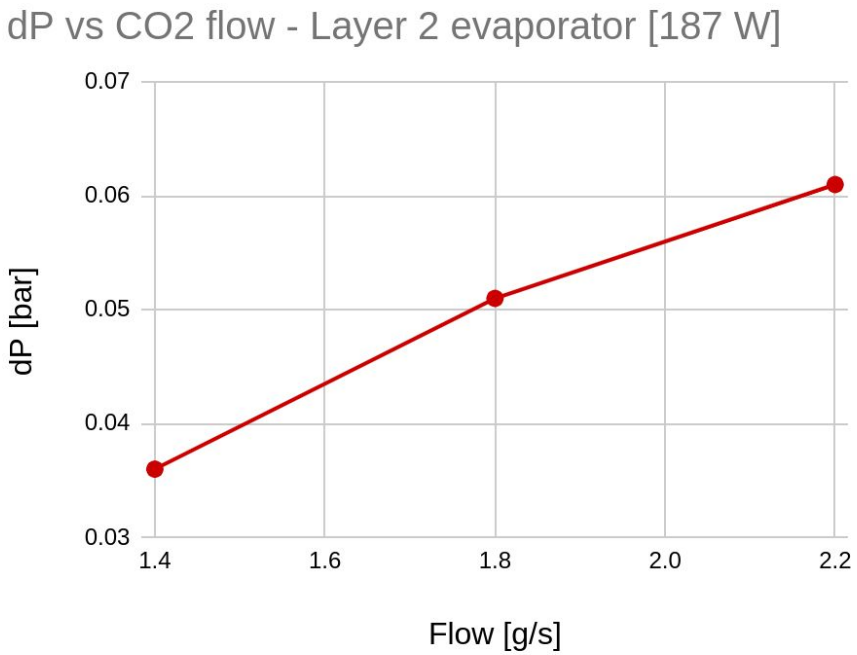


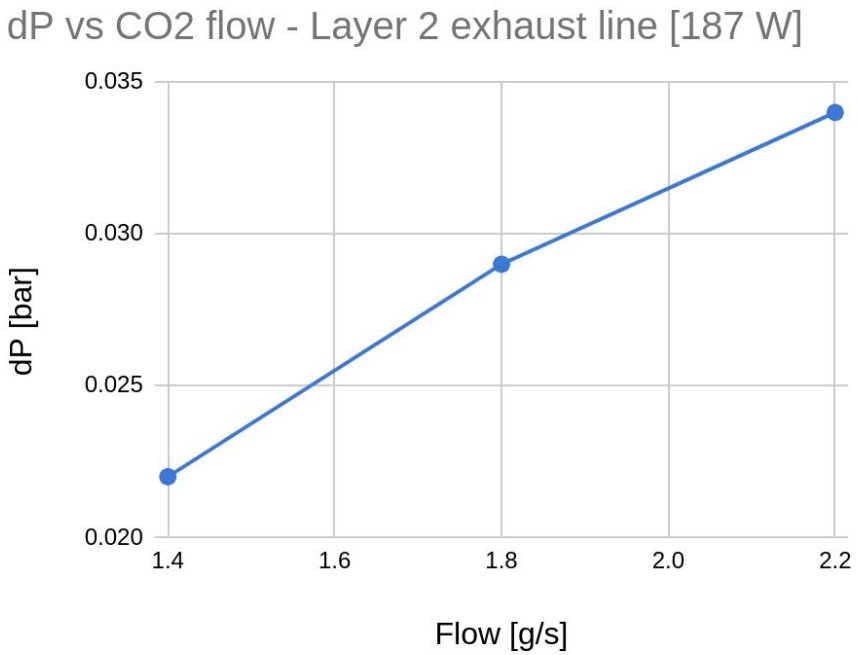
Layer 2 - ΔP vs flow with no power, T_{set} = 0 C



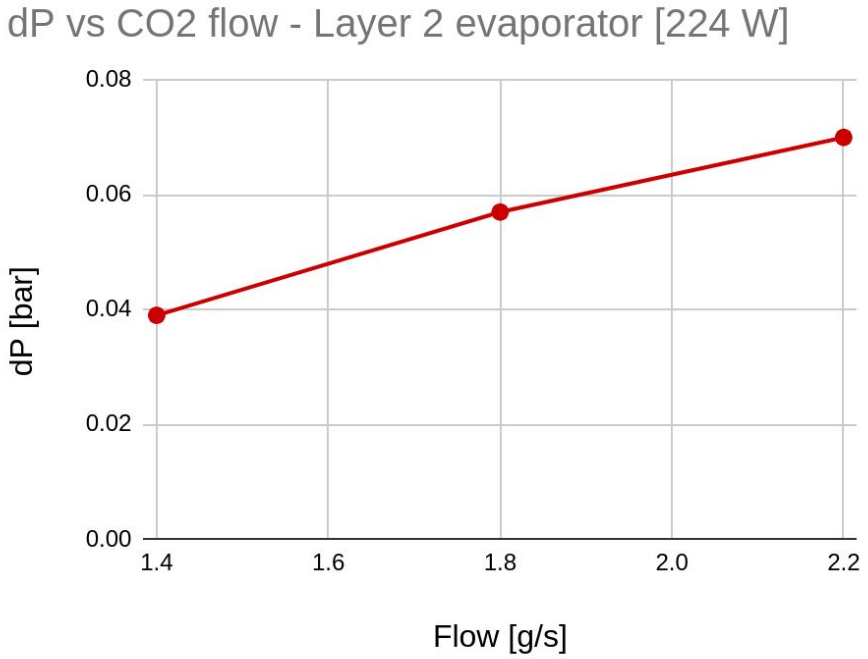


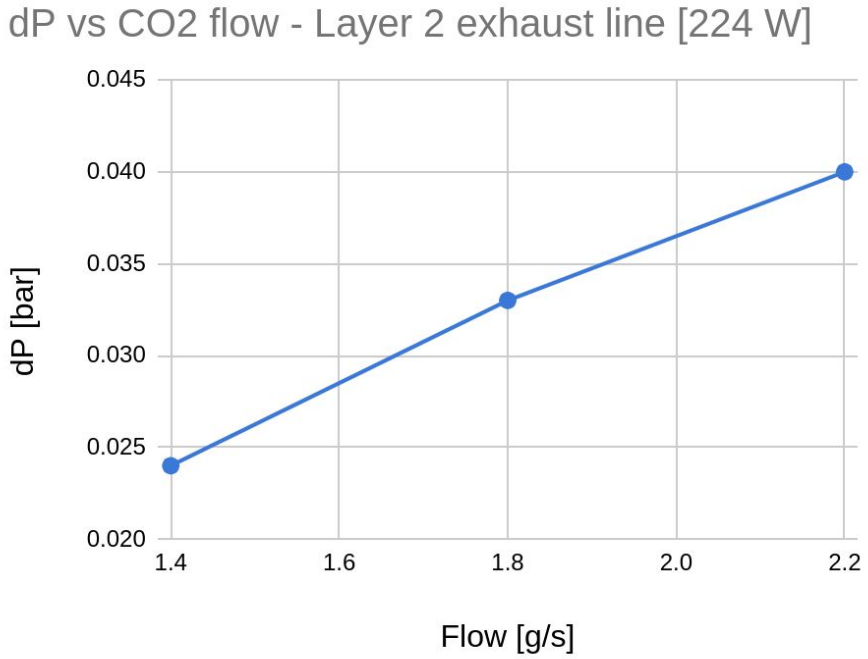
Layer 2 - ΔP vs flow at nom. power, T_{set} = 15 C





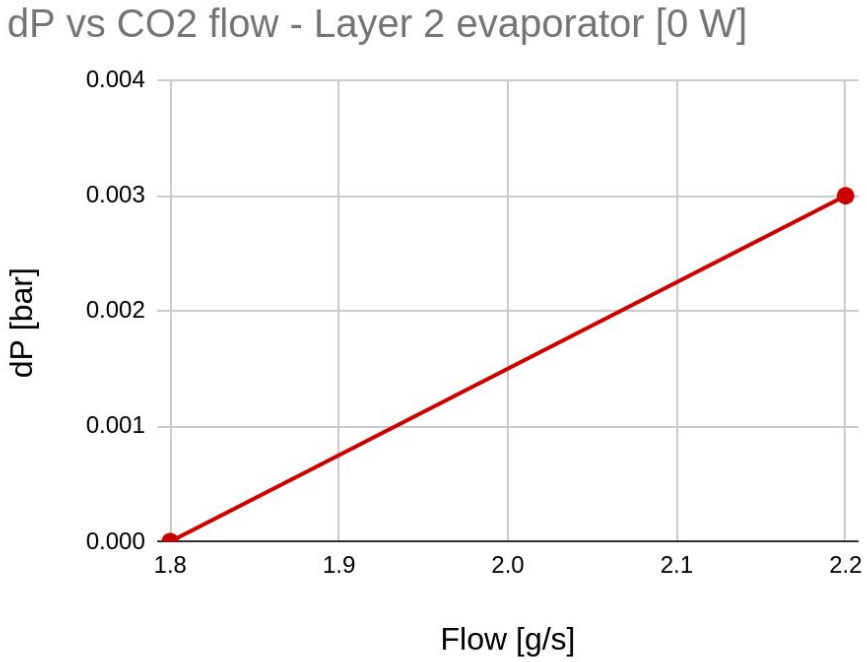
Layer 2 - ΔP vs flow at power +20%, T_{set} = 15 C

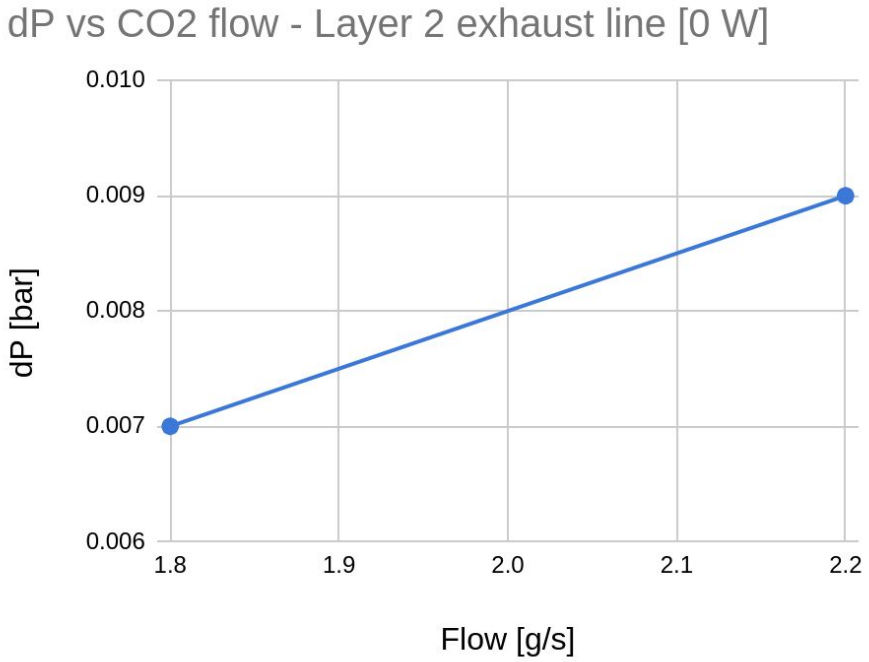




Layer 2 - ΔP vs flow with no power, T_{set} = 15 C

Only two flow points available for this configuration.

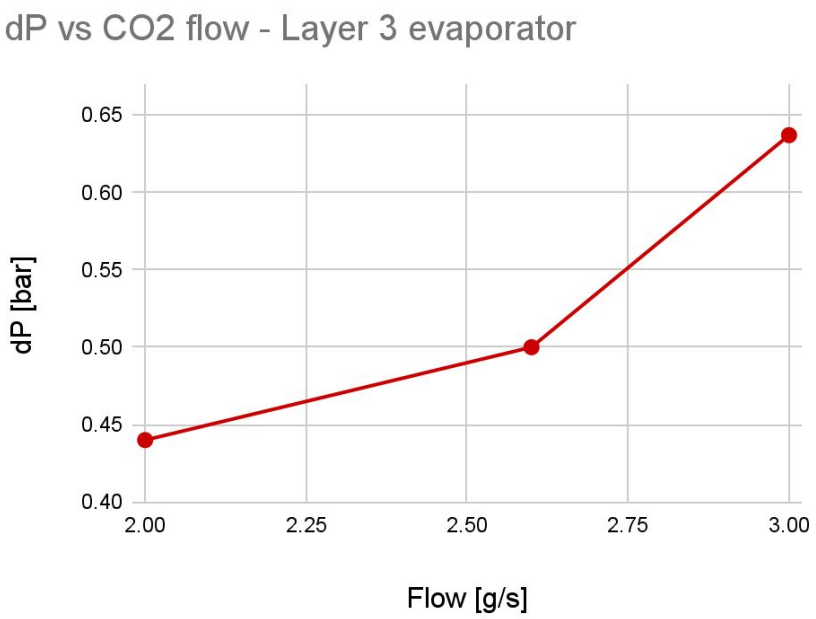


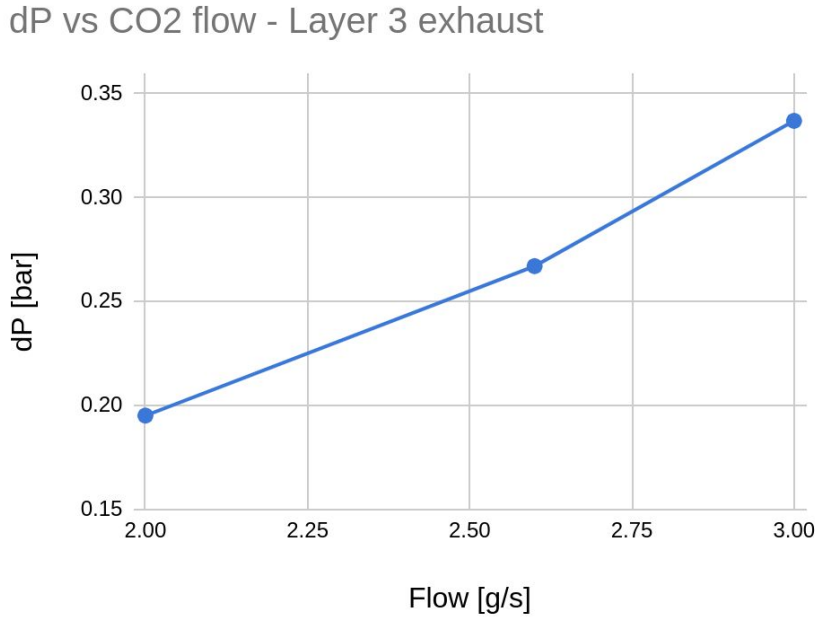


Additional material: Layer 3 ΔP vs flow

Layer 3 - ΔP vs flow at nom. power, T_{set} = -40 C

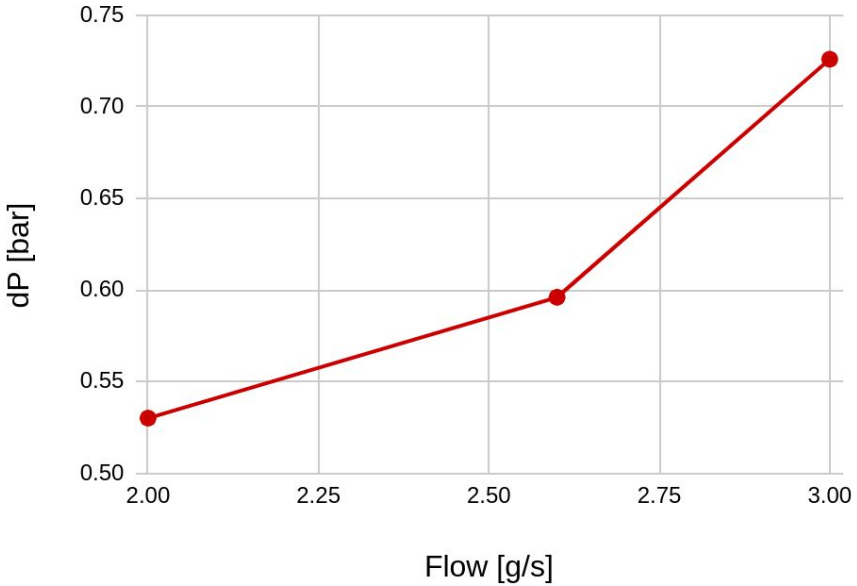
Same plots shown in slide 9, reporting them for easier comparison.



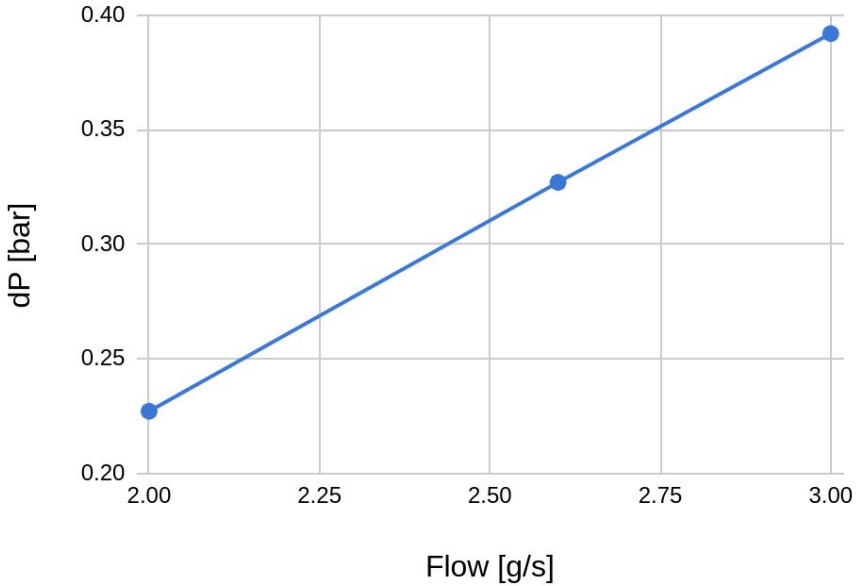


Layer 3 - ΔP vs flow at power +20%, T_{set} = -40 C

dP vs CO2 flow - Layer 3 evaporator [308 W]



dP vs CO2 flow - Layer 3 exhaust [308 W]

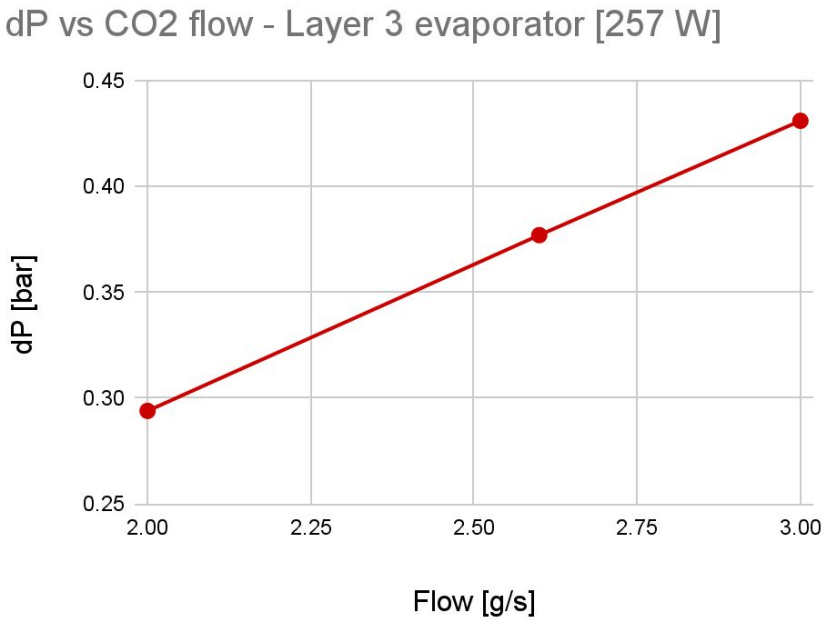


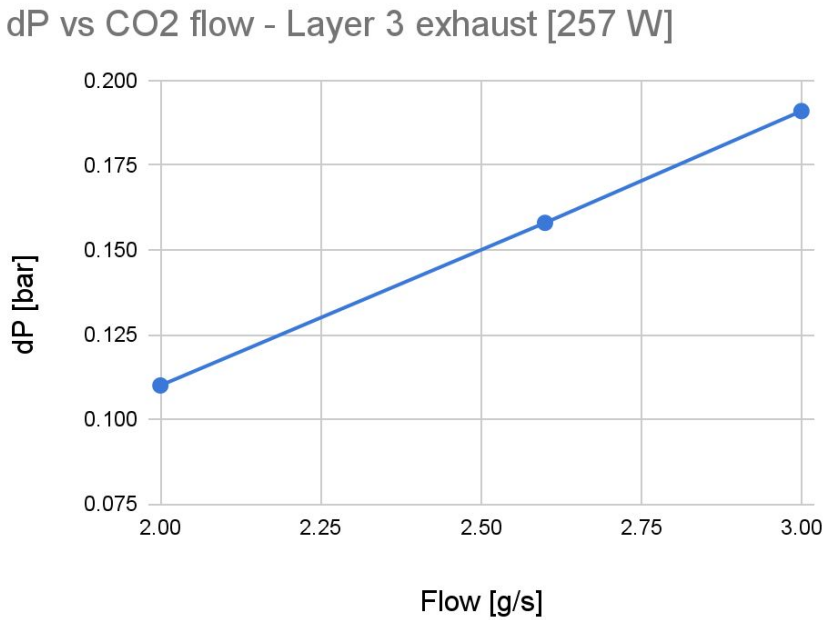
Layer 3 - ΔP vs flow with no power, T_{set} = -40 C

Note that the flow scan is not available with no power in this configuration, so the pressure drop for the 2.6 ± 0.1 g/s flow are reported

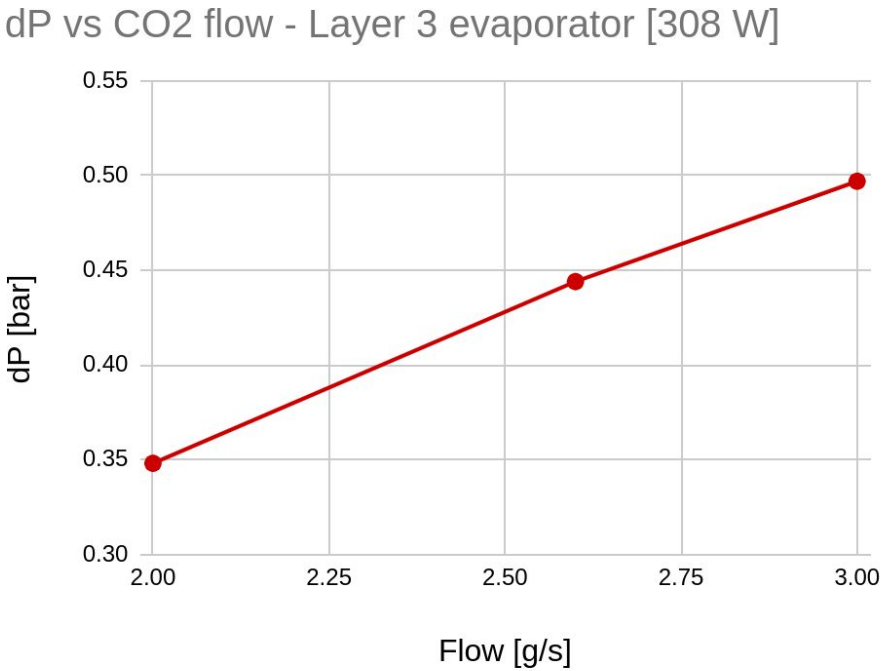
	Pressure drop [bar]
Capillary	7.64
Evaporator	0.101
Exhaust line	0.013

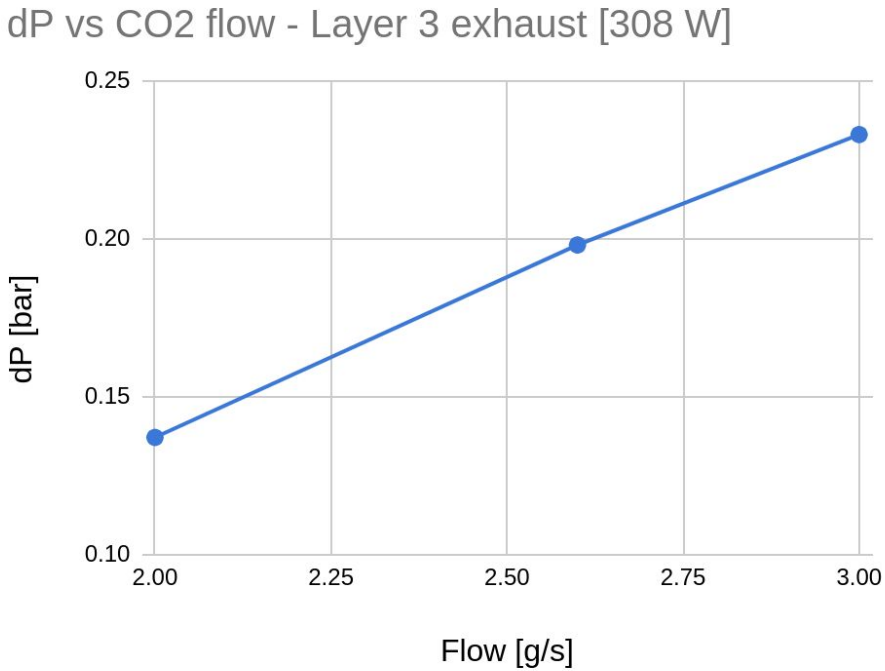
Layer 3 - ΔP vs flow at nom. power, T_{set} = -20 C





Layer 3 - ΔP vs flow at power +20%, T_{set} = -20 C



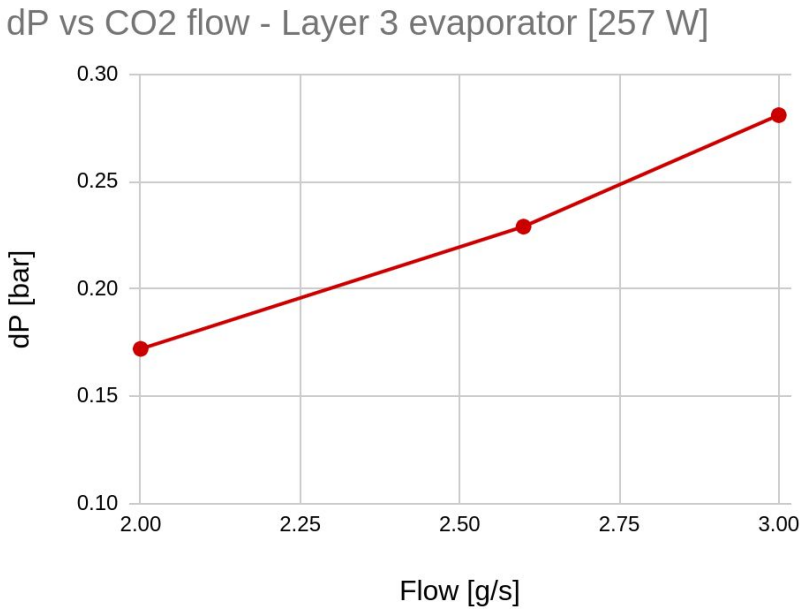


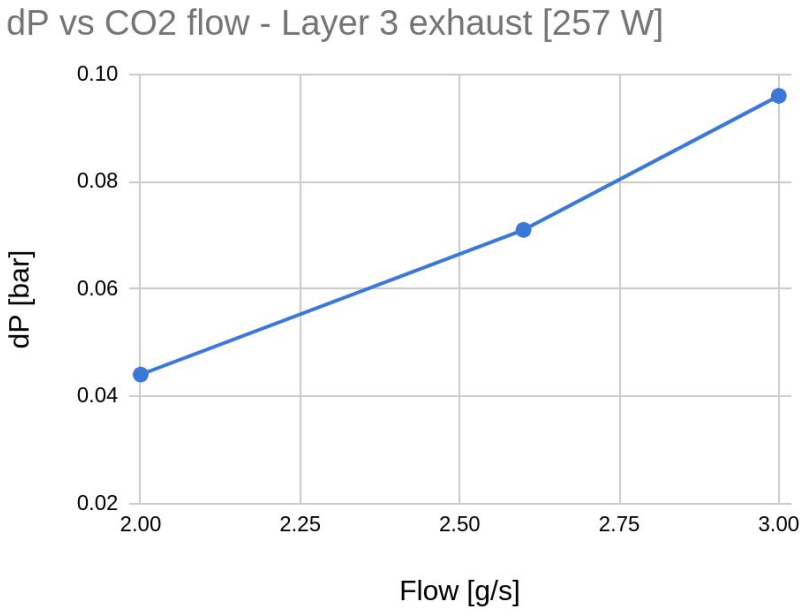
Layer 3 - ΔP vs flow with no power, T_{set} = -20 C

Note that the flow scan is not available with no power in this configuration, so the pressure drop for the 2.6 ± 0.1 g/s flow are reported

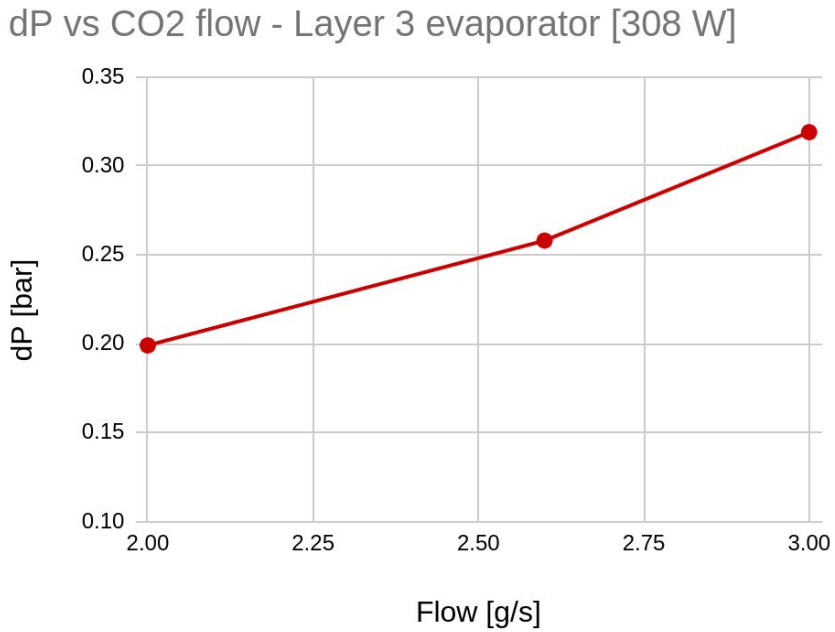
	Pressure drop [bar]
Capillary	7.49
Evaporator	0.071
Exhaust line	0.001

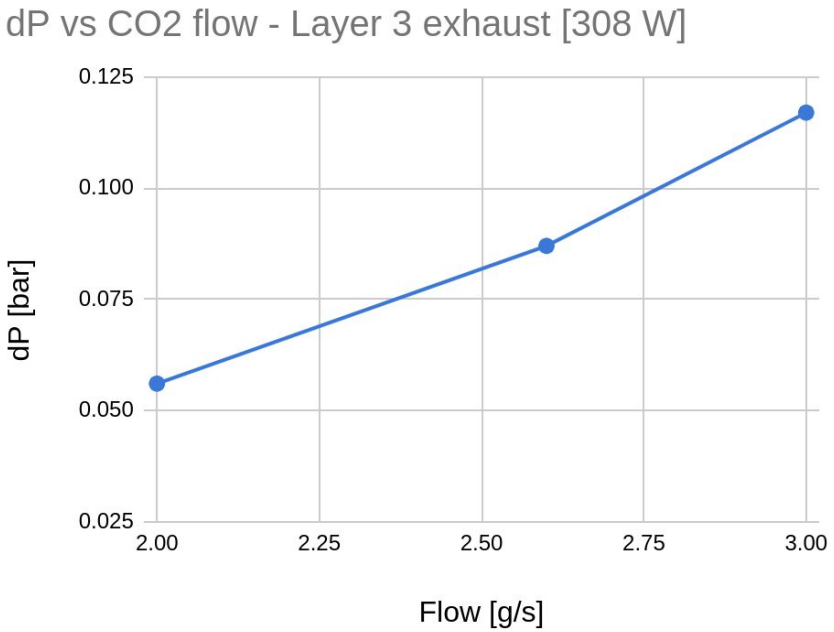
Layer 3 - ΔP vs flow at nom. power, T_{set} = 0 C





Layer 3 - ΔP vs flow at power +20%, T_{set} = 0 C





Layer 3 - ΔP at T_{set} = 15 C

Flow scan is not available at this temperature, showing the pressure drop for the nominal flow 2.6 ± 0.1 g/s with nominal power and power +20%

	Pressure drop [bar]	
	257 W	**308 W**
Capillary	8.42	8.37
Evaporator	0.165	0.171
Exhaust line	0.036	0.039