EN Cooling and Ventilation Activity report on NA62-GTK project

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CERN (EN/CV)

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Agenda

- **CFD simulation on Microchannel solution for GTK**
- **Cooling unit engineering specification**

GTK Microchannel Cooling
- CFD Analysis for Hydraulic Design -

CFD team

Summary

A) Silicon Microchannel C_6F_{14} Heat Exchanger

- ❑ Present prototype (Design-0)
- ❑ Analytical model for pressure drop
- ❑ CFD model and validation against experimental data
- ❑ Performance of present prototype (Design-0)
- ❑ Performance of double inlet/outlet (Design-1)

B) General Design Guidelines

- ❑ Influence of channel geometry
- ❑ Possible alternative refrigerants

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Present prototype (Design-0)

Design operating conditions

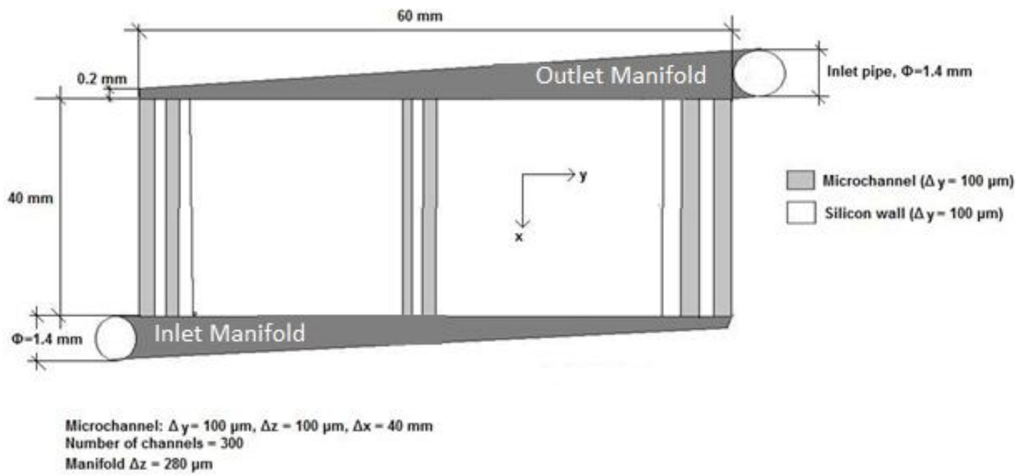
- Refrigerant C_6F_{14}, temperature = -25° C
- Max inlet/outlet temperature rise = 5 K
- Heat load = 48 W
- c_p = 975 J kg^{-1} K^{-1}

Mass flow rate
9.8 g/s

❑ The dominating thermal constraint is considered the in/out refrigerant temperature rise and not the HTC achieved inside the microchannels

Design-0 geometry

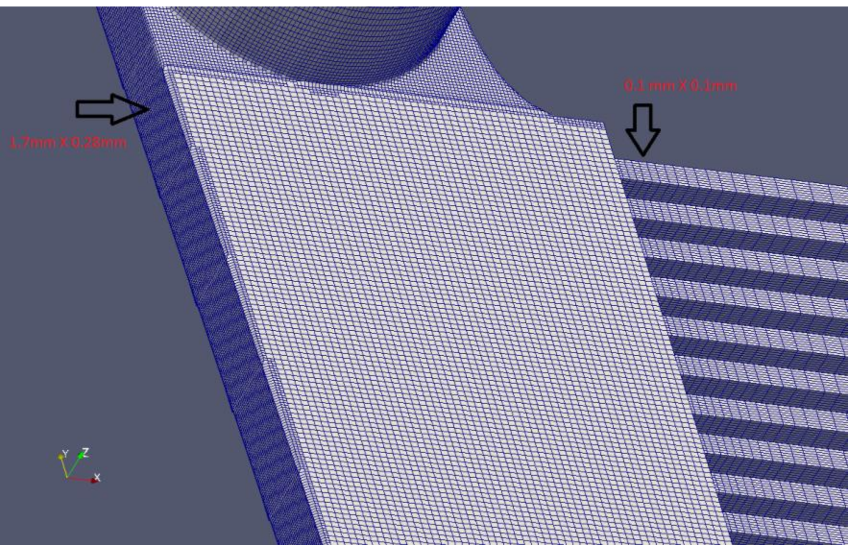
A first prototype has been manufactured and tested by CERN PH/DT

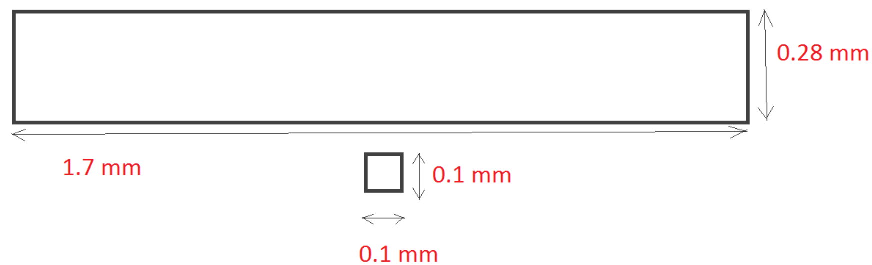


Present prototype (Design-0)

Velocity in manifolds and microchannels

Design power	Mass Flow Rate	u_m (manifold)	Re_m	u_{ch} (channel)	Re_{ch}
48 W	9.8 g/s	11.45 m/s	6882	1.81m/s	223





- ❑ The flow is laminar in the microchannels and turbulent in the manifold
- ❑ Too high manifold velocity ➡ high pressure drop + maldistribution

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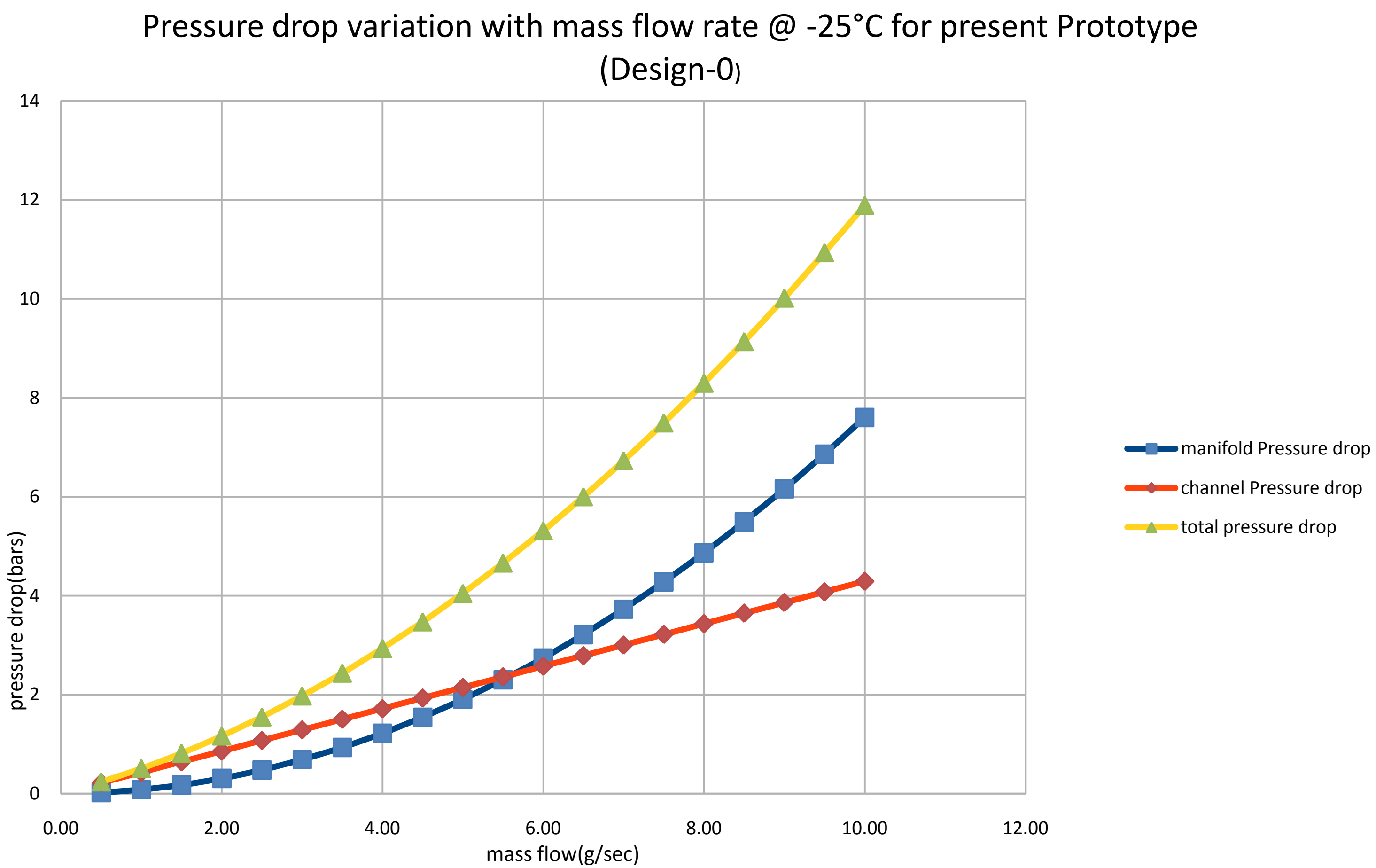
Analytical model



- ❑ Most of the pressure drop is due to the manifold

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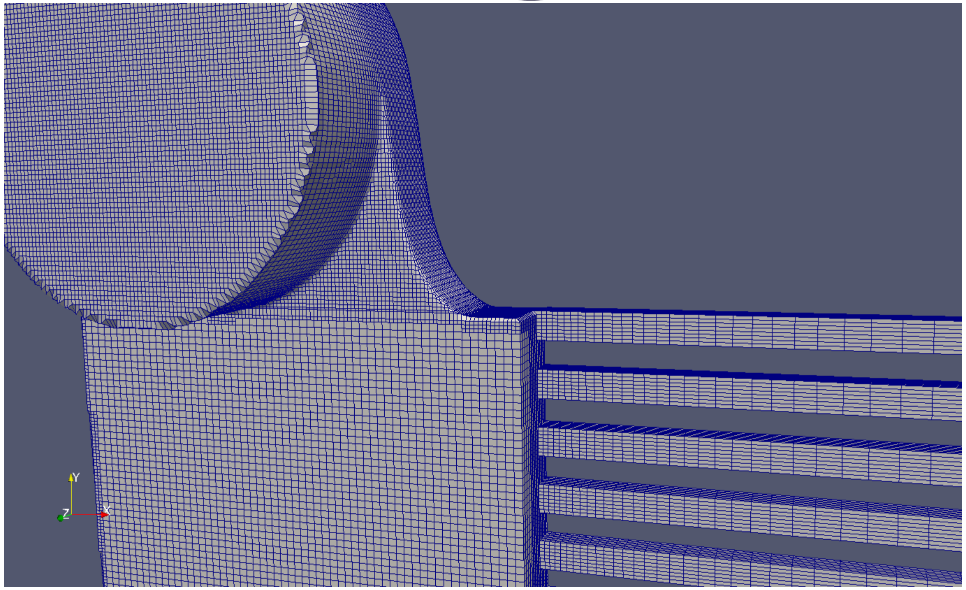
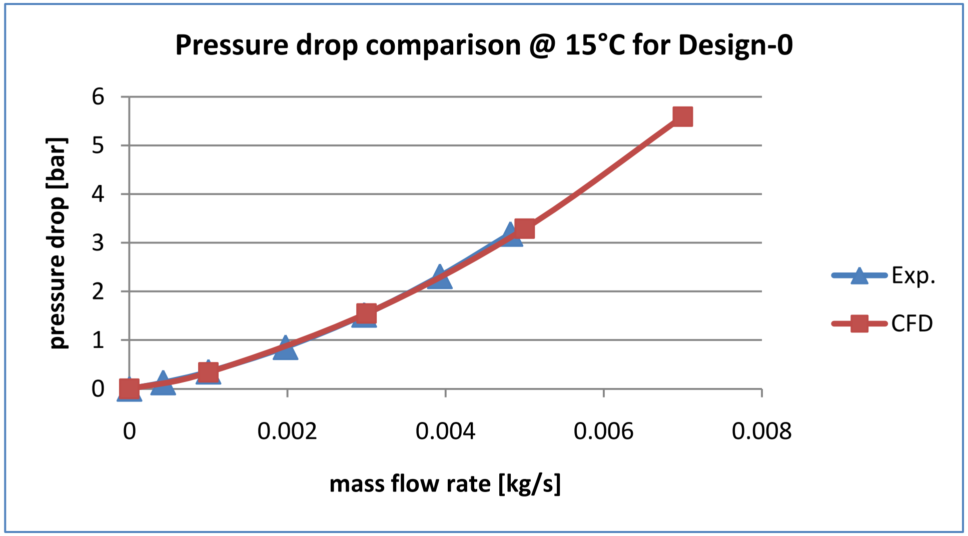
CFD model and validation



- Mesh data
  - ->No. of cells : 8.2 M
    - Hexahedra: 8.1 M
    - polyhedra: 0.1M
  - ->Mesh non-orthogonality
    - Max: 39.9
    - Average: 3.6



- The CFD model is able to predict experimental the data for the whole range of mass flow rates tested

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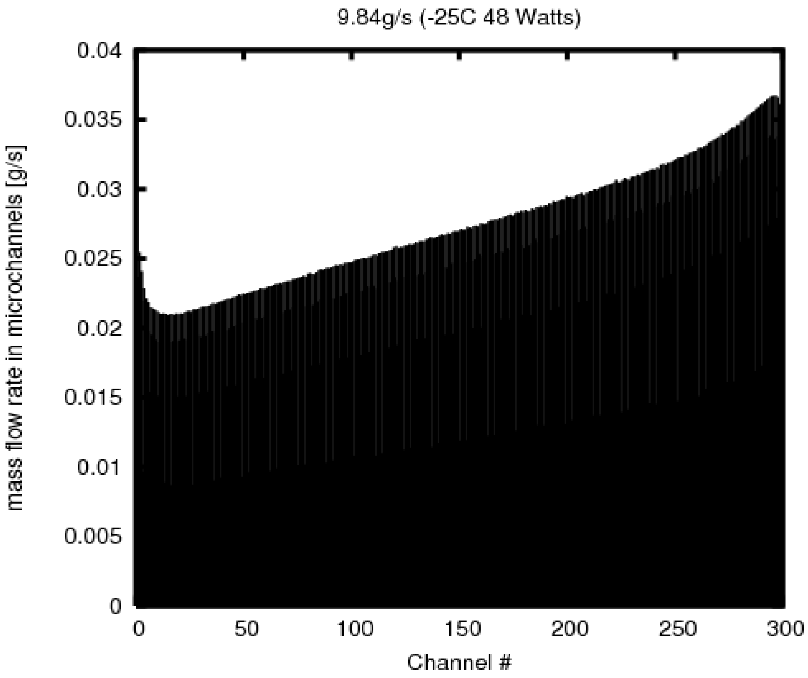
Performance of Design-0

Pressure drop

- The refrigerant pressure drop predicted by the CFD model at design working conditions is **12.2 bar**
- This value could give rise to mechanical resistance problems

Flow distribution



- The Average mass flow rate in each channel is 0.03 g/sec
- The distribution is not optimal
- The channels close to outlet are fed with almost double the mass flow rate as compared to the ones close to the inlet
- The temperature rise for the channels close to the inlet is expected to be higher then 5 K

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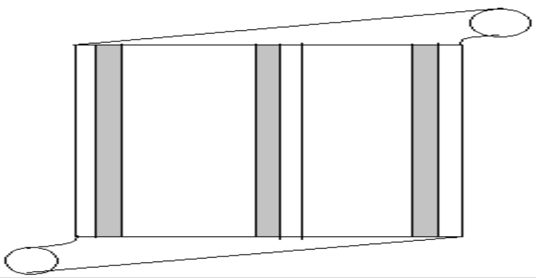
Design-1 (double inlet/outlet)

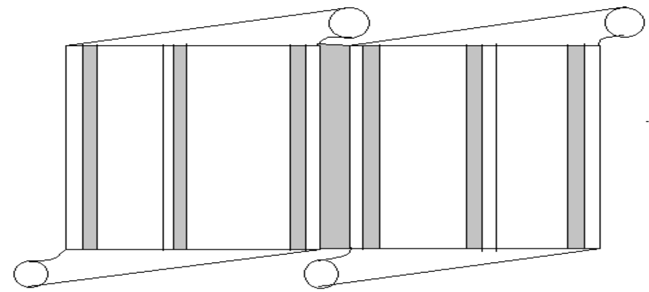
As a first step to reduce the pressure drop in the manifold without changing the Design-0 main geometry , A dual inlet/outlet solution is proposed

Geometry

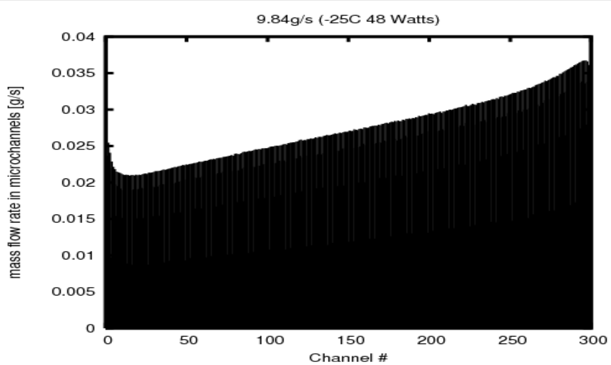
Design-0 sketch



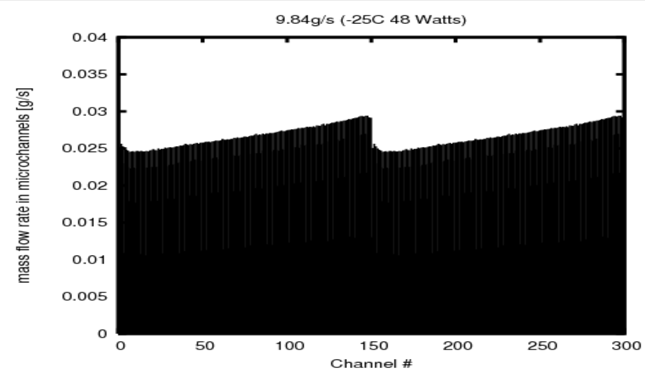
Design-1 sketch



Flow distribution & Pressure drop



$\Delta p = 12.2$ bar



$\Delta p = 5.7$ bar

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- ❑ Possible alternative refrigerants

Influence of channel geometry

- ❑The double inlet/outlet configuration is considered.
- ❑The width of the silicon wall between the channels is considered fixed (100 µm).
- ❑ The mechanical resistance of high aspect-ratio channel has to be checked.
- ❑ According to the present results, the material budget can be reduced without increasing the global pressure drop.

Pressure Drop with Perfluorohexane with dual Inlet-Outlet @-25° C with 9.84g/s for 48 Watts | 100 microns wall

Channel width	No . Of channel	Channel depth ->					
[Microns]		50	60	70	80	90	100
500.0	50	9.7 8.3	5.6	4.3	3.5	3.0	3.0 2.7
400.0	60	8.7	5.9	4.4	3.6	3.1	2.8
328.6	70	9.1	6.2	4.6	3.8	3.2	2.9
275.0	80	9.6	6.5	4.8	3.9	3.3	3.0
233.3	90	10.2	6.8	5.1	4.1	3.5	3.1
200.0	100	10.8	7.3	5.4	4.3	3.7	3.2
172.7	110	11.6	7.8	5.8	4.6	3.9	3.4
150.0	120	12.5	8.4	6.2	6.1 4.9	4.2	3.6
130.8	130	13.6	9.1	6.7	5.4	4.5	3.9
114.3	140	14.9	10.0	7.4	5.9	5.0	4.3
100.0	150	21.1 16.6	11.2	8.3	6.6	5.6	5.7 4.8

CFD Results in Red

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Possible alternative refrigerants

Fluid	Temperature[°C]	Pressure [bar]	CP[J/Kg-k]	Nu[cSt]	Density [Kg/m³]	HTC[Laminar flow with Dh=.1mm]
C6F14	-25	1	975	.81	1805.25	2008
Water	25	1	4181	.892	997	19424
Glycol[45%]	-25	1	3211	24	1080.6	
CO2	-25	18	2111	.143	1054.7	4480
Ammonia	-45	.9	4387.1	.43	696.18	22560

- ❑For HTC calculation , Nusselt number is taken as constant(=3.2).
- ❑ C_6F_{14} is the only dielectric fluid considered in the table.
- ❑ High c_p allows to reduce mass flow rate and pressure drop.
- ❑ Water displays optimal properties but can be used only above 0° C.
- ❑ Liquid CO_2 displays good properties but the saturation pressure is extremely high even at low temperature.
- ❑ Ammonia displays optimal thermodynamic properties and also a very low saturation temperature .

Pressure Drop with dual Inlet-Outlet @25°C with 2.3g/s for 48 Watts | 100 microns wall

Fluid : Water
Properties @ 25° C , 1 bar:
Cp = 4181 J/kg-K
kinematic viscosity(nu) = .892 cSt
Density =997 kg/m^3

- ❑ Water could be an optimal solution for operating conditions above 0° C
- ❑ A cooling system operating below atmospheric pressure could be designed in order to avoid leakages problems.

Channel width	No. of channel	Channel depth ->					
[microns]		50	60	70	80	90	100
500.0	50	1.38	0.90	0.65	0.51	0.42	0.36
400.0	60	1.49	0.97	0.70	0.55	0.45	0.38
328.6	70	1.61	1.05	0.76	0.59	0.48	0.41
275.0	80	1.76	1.15	0.83	0.64	0.52	0.44
233.3	90	1.92	1.26	0.91	0.70	0.57	0.48
200.0	100	2.12	1.39	1.01	0.78	0.63	0.53
172.7	110	2.35	1.55	1.12	0.86	0.70	0.59
150.0	120	2.63	1.74	1.26	0.97	0.79	0.66
130.8	130	2.97	1.98	1.43	1.11	0.90	0.75
114.3	140	3.38	2.27	1.65	1.28	1.03	0.86
100.0	150	3.90	2.63	1.92	1.49	1.21	1.01

Pressure Drop with dual Inlet-Outlet @-25°C with 3g/s for 48 Watts | 100 microns wall

Fluid : Glycol 45% solution
Properties @ -25° C :
Cp = 3211 J/kg-K
kinematic viscosity(nu) = 24 cSt
Density =1080.6 kg/m^3
Freezing Point = -30.5° C

- ❑ Glycol cannot be used to employ water in microchannels below 0° C, because the viscosity is extremely high.

Channel width	No. of channel	Channel depth ->					
[microns]		50	60	70	80	90	100
500.0	50	42.59	25.55	16.67	11.56	8.40	6.34
400.0	60	46.40	28.06	18.45	12.89	9.43	7.16
328.6	70	50.78	30.96	20.51	14.44	10.65	8.14
275.0	80	55.86	34.35	22.94	16.27	12.08	9.30
233.3	90	61.78	38.32	25.81	18.45	13.80	10.69
200.0	100	68.74	43.03	29.22	21.05	15.86	12.37
172.7	110	77.00	48.65	33.33	24.20	18.37	14.43
150.0	120	86.90	55.45	38.32	28.06	21.46	16.97
130.8	130	98.90	63.74	44.46	32.83	25.29	20.15
114.3	140	113.64	74.01	52.11	38.80	30.13	24.17
100.0	150	131.98	86.90	61.78	46.40	36.31	29.33

Pressure Drop with dual Inlet-Outlet @-25°C and 18 bars with 4.5g/s for 48 Watts | 100 microns

Fluid : Carbon Dioxide
Properties @ -25° C , 18bars :
Cp =2111 J/kg-K
kinematic viscosity(nu) = 0.143cSt
Density =1054.7 kg/m^3

❑ The pressure drop with liquid CO_2 is extremely low, but this is useless since the saturation pressure of CO_2 is high(16.8 bars @ -25° C).

Channel width	No. of channel	Channel depth ->					
[microns]		50	60	70	80	90	100
500.0	50	1.05	0.90	0.82	0.77	0.74	0.73
400.0	60	1.08	0.92	0.83	0.79	0.75	0.73
328.6	70	1.12	0.95	0.85	0.80	0.77	0.74
275.0	80	1.17	0.98	0.87	0.82	0.78	0.75
233.3	90	1.22	1.01	0.90	0.83	0.79	0.77
200.0	100	1.28	1.05	0.93	0.86	0.81	0.78
172.7	110	1.36	1.10	0.97	0.89	0.83	0.80
150.0	120	1.45	1.16	1.01	0.92	0.86	0.82
130.8	130	1.55	1.24	1.07	0.96	0.90	0.85
114.3	140	1.68	1.33	1.14	1.02	0.94	0.89
100.0	150	1.85	1.45	1.22	1.08	0.99	0.93

Pressure Drop with dual Inlet-Outlet @-45°C with 2.19g/s for 48 Watts | 100 microns wall

Fluid : Ammonia
Properties @ -45° C , 0.9 bar :
Cp =4387.1 J/kg-K
kinematic viscosity(nu) = 0.43cSt
Density =696.18 kg/m^3

- ❑ Ammonia could be an optimal solution for operating conditions below 0° C
- ❑ A cooling system operating below -35° C and below atmospheric pressure could be designed in order to avoid leakages problems.

Channel width	No. of channel	Channel depth ->					
[microns]		50	60	70	80	90	100
500.0	50	0.80	0.57	0.46	0.39	0.35	0.32
400.0	60	0.85	0.61	0.48	0.41	0.36	0.33
328.6	70	0.91	0.65	0.51	0.43	0.38	0.35
275.0	80	0.97	0.69	0.54	0.45	0.40	0.36
233.3	90	1.05	0.74	0.58	0.48	0.42	0.38
200.0	100	1.14	0.80	0.62	0.52	0.45	0.40
172.7	110	1.25	0.88	0.68	0.56	0.48	0.43
150.0	120	1.38	0.97	0.74	0.61	0.52	0.46
130.8	130	1.54	1.08	0.82	0.67	0.57	0.50
114.3	140	1.73	1.21	0.92	0.75	0.63	0.56
100.0	150	1.97	1.38	1.05	0.85	0.72	0.62

Conclusions

- The velocity in the manifold of the present prototype is too high, therefore the total pressure drop is high (i.e. ~12 bar) and the flow distribution is not uniform.
- Before improving the channels design, the manifold design must be fixed.
- Adopting double inlets/outlets allow to half the pressured drop and improve the flow distribution without changing the overall manifold geometry.
- Neglecting possible mechanical resistance problems, the material budget could be further decreased by adopting high aspect ratio channels.
- From the hydraulic point of view, liquid ammonia at around -40° C would allow to operate a microchannel heat exchanger below the atmospheric pressure thus avoiding mechanical resistance and leakages problems.