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Detector Technologies

Progress towards the design of Phase-2 CO2 cooling systems

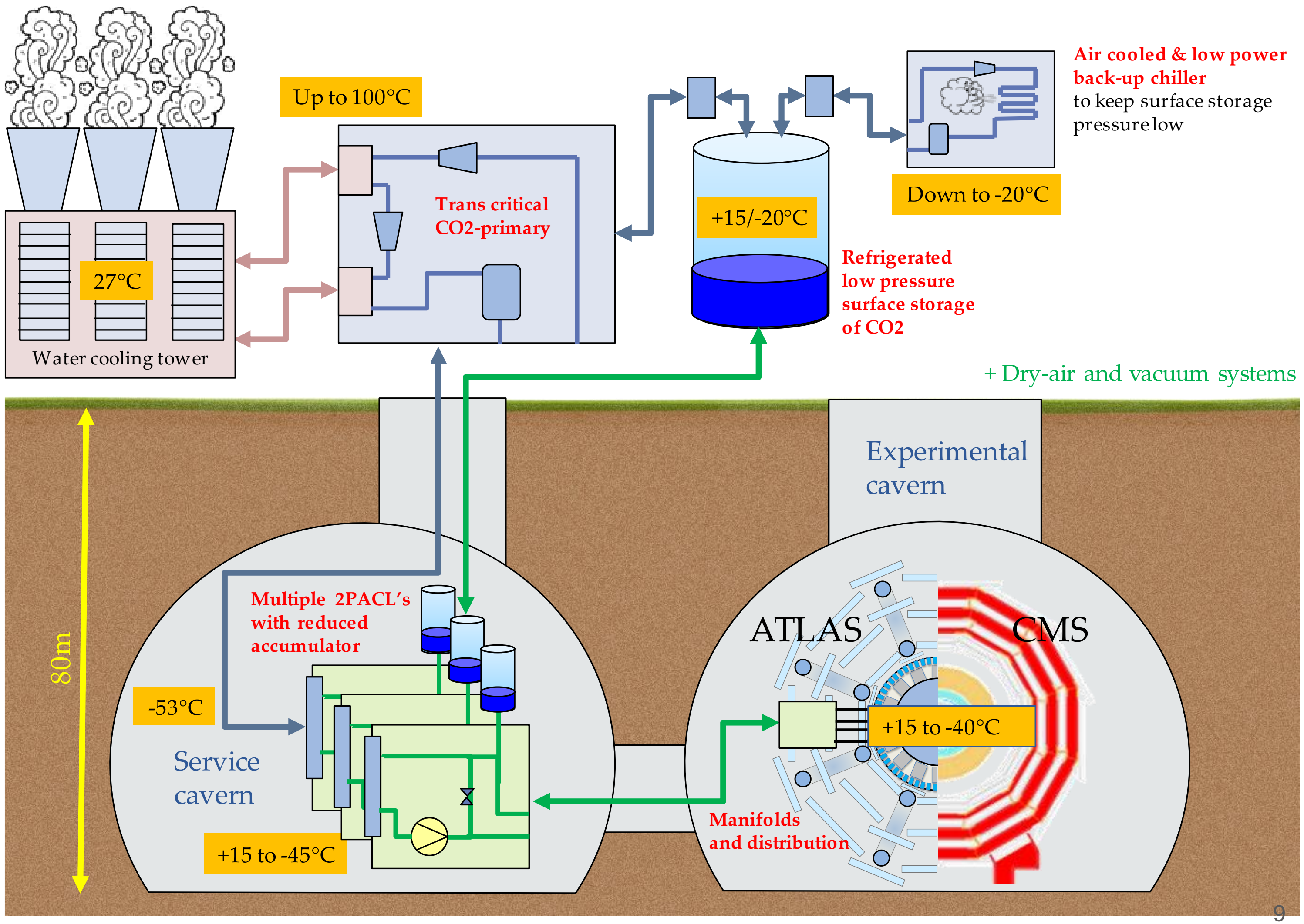
31st May 2023

Y. Herpin, K. Sliwa

On behalf of EP-DT-FS section

Introduction and Background

Phase 2 CO2 cooling systems



- The 2PACL cooling plants are located in USA-15 / USC-55
- Detector evaporator loops are connected via manifolds and concentric transfer lines to the 2PACL plants
- The 2PACL plants are cooled by the primary R744 which is located on the surface
- The primary R744 plants are cooled by water from the towers and air cooling
- Surface storage of CO_2 to control the charges of the underground 2PACL plants
  - Optimize accumulator volume in the caverns
  - Level control is important

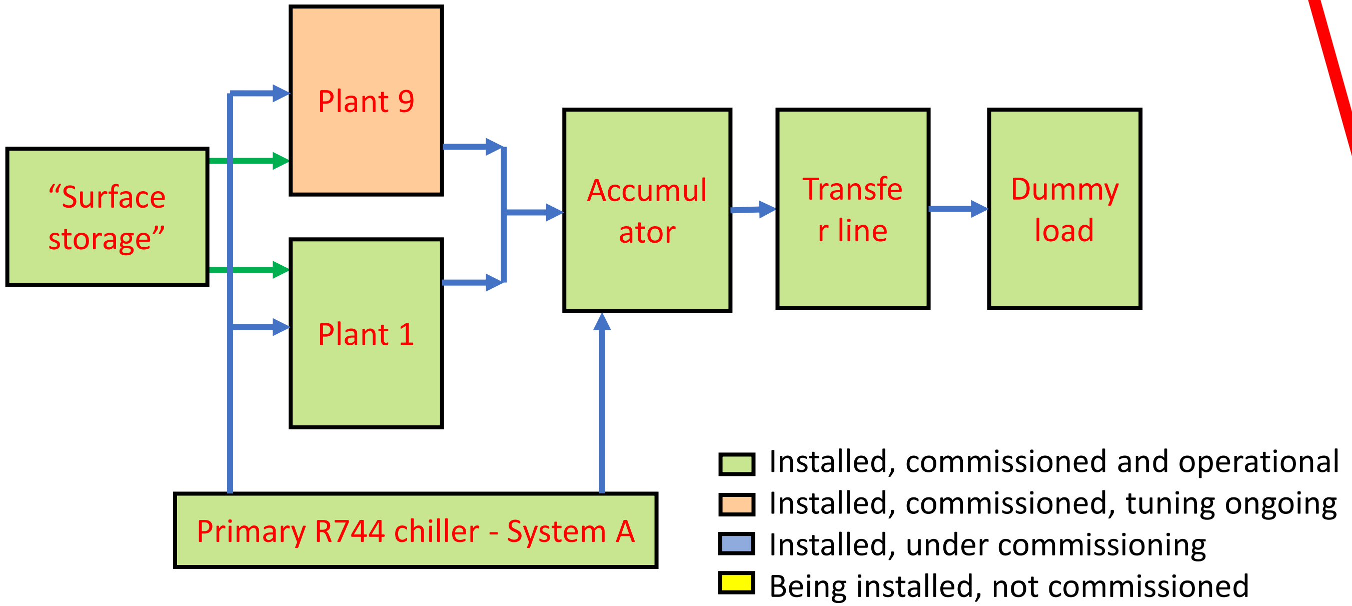
DEMO prototype cooling system

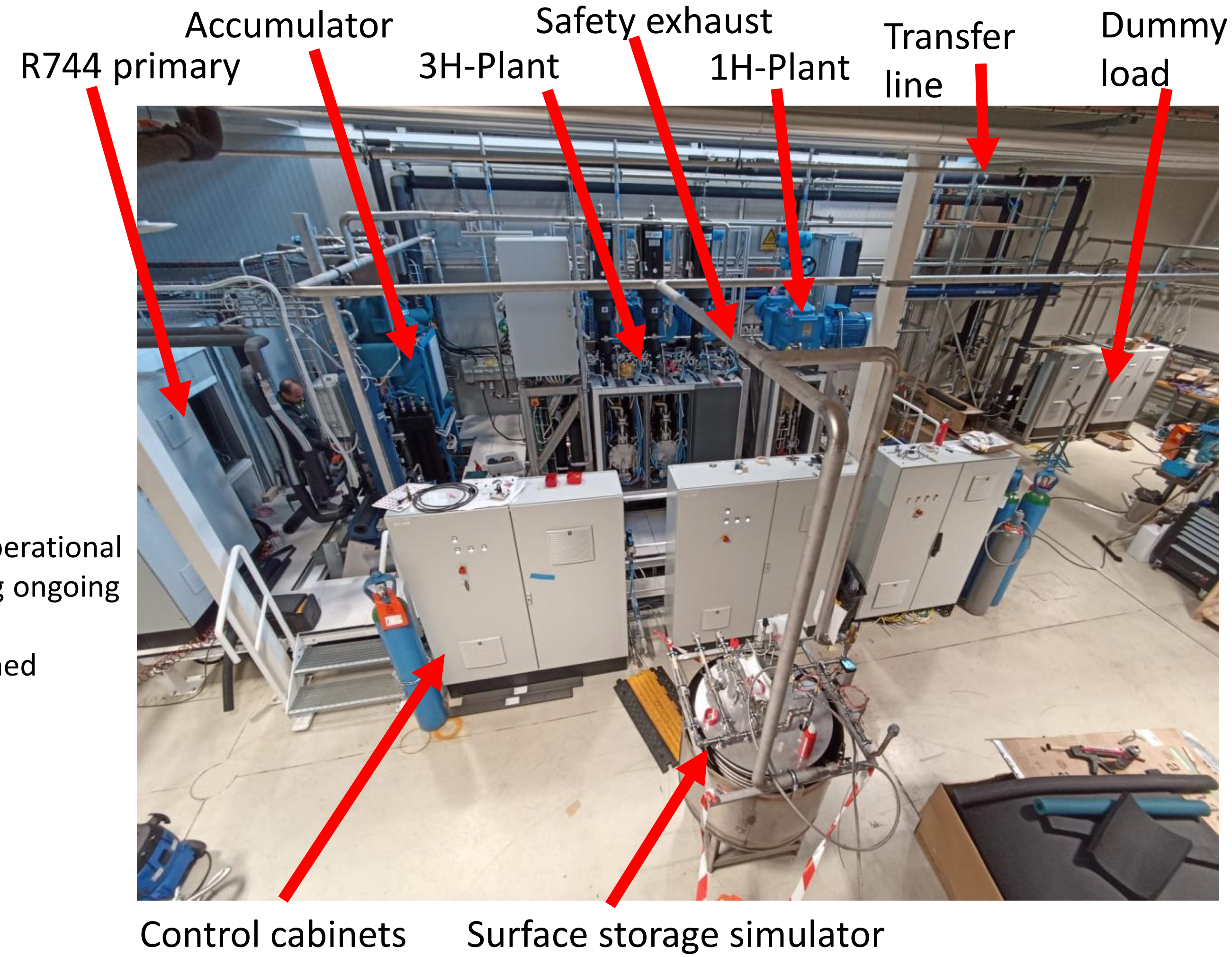
- DEMO is a full-scale prototype of Phase 2 2PACL CO_2 cooling system
- DEMO specs
  - 428 L accumulator
  - 3-head plant → 1.58 kg/s
  - 100 kW dummy load
  - -45°C on Accumulator
  - -50°C on R744 chiller evaporator
  - 1-head backup plant

- DEMO goals:
  - Demonstrate the new method of accumulator flow-through (2PACL-FT)
  - Demonstrate the proper selection of components
    - Heat exchangers, valves, pipe sizes, etc.
  - Demonstrate specific design updates
    - Surface storage interaction
    - A reliable accumulator level control

DEMO is a modular system

Each block (Module/subsystem) has its own control cabinet and a dedicate control PCO . Each module can be operated independently and partly tested

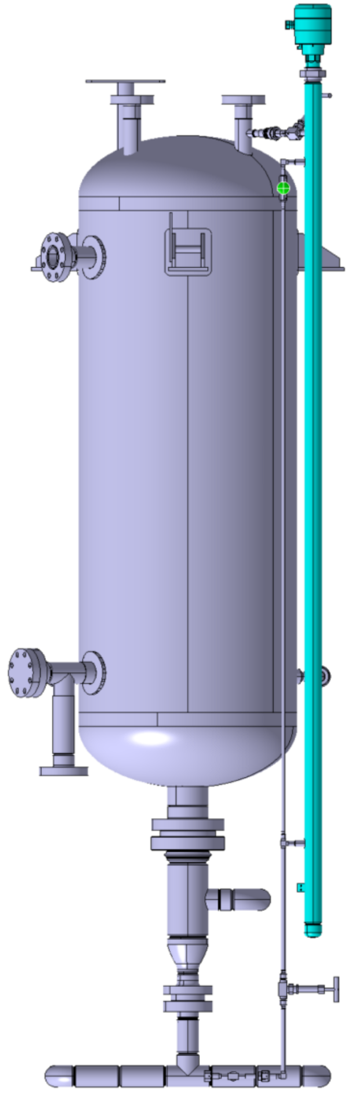




Demo commissioning results

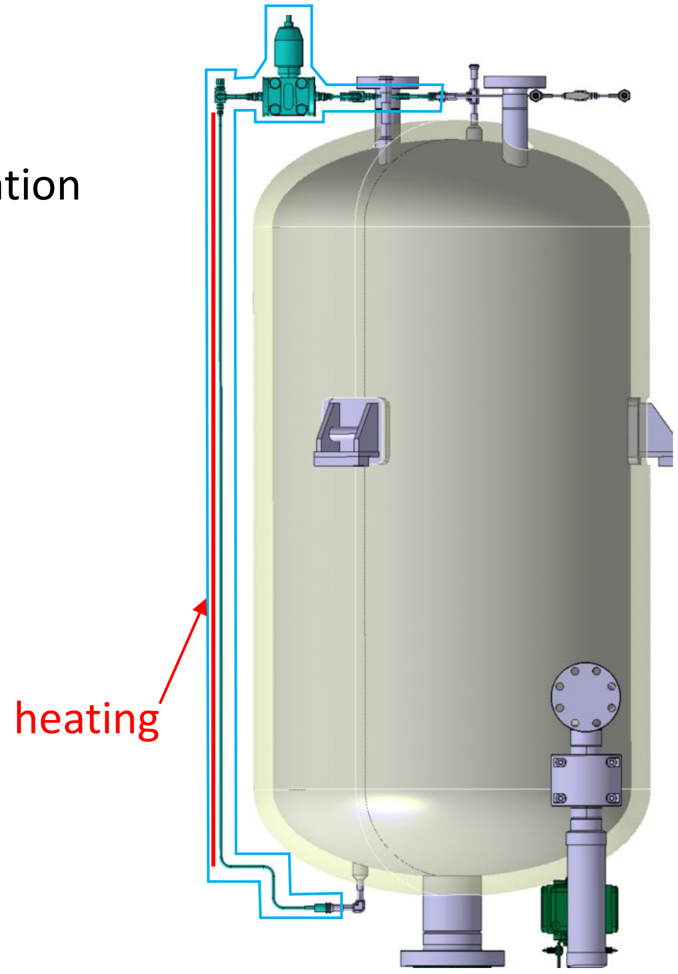
Level measurement and control

Radar vs DP measurement



- Require temperature calibration
  - Time consuming
- Complex configuration
- Level error due to different temperature in the side pipe/vessel during set point change

Radar measurement



- No calibration needed
  - Level determined by calculating static head on each side
- Smaller side pipe
  - Less expensive
- Small heating to ensure gas phase in the side pipe
  - More accurate

DP measurement

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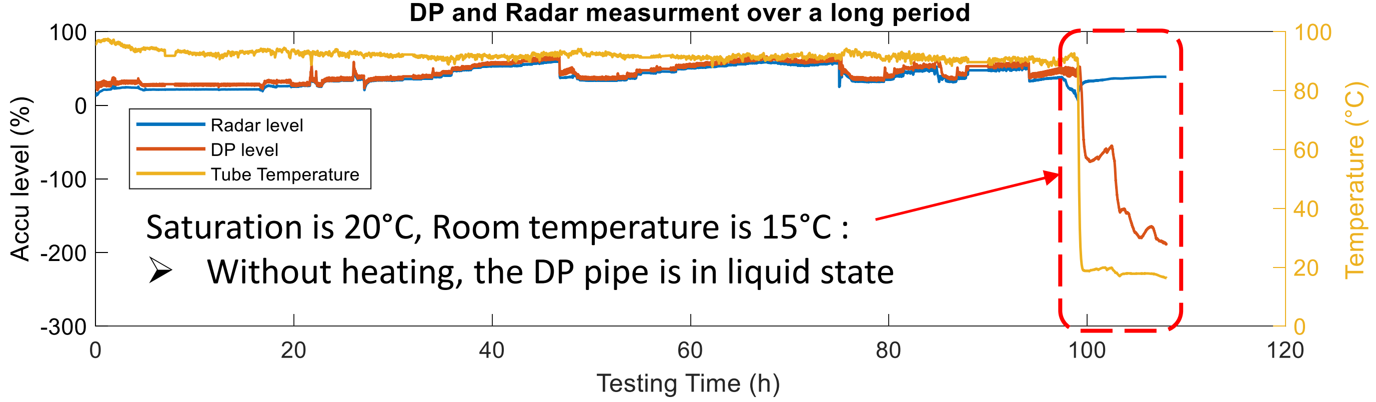
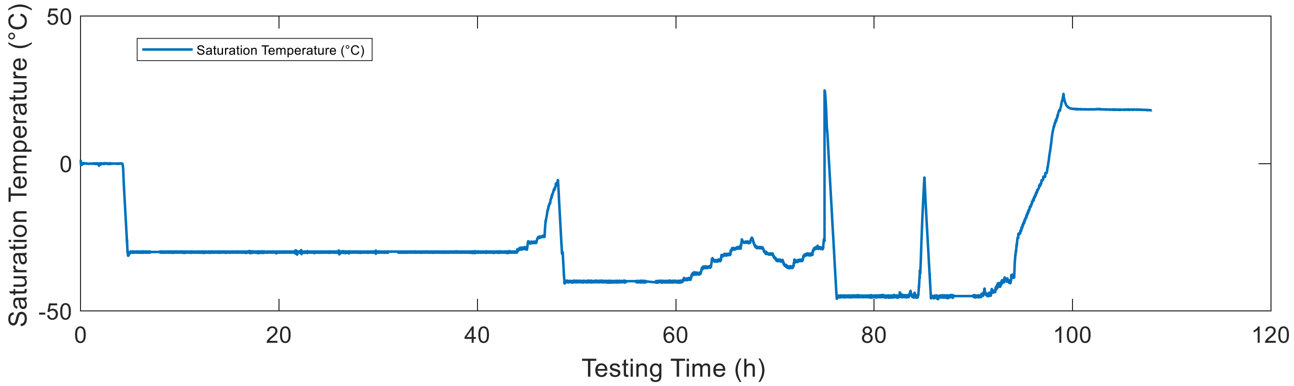
DP level sensor development

DP sensor test results :

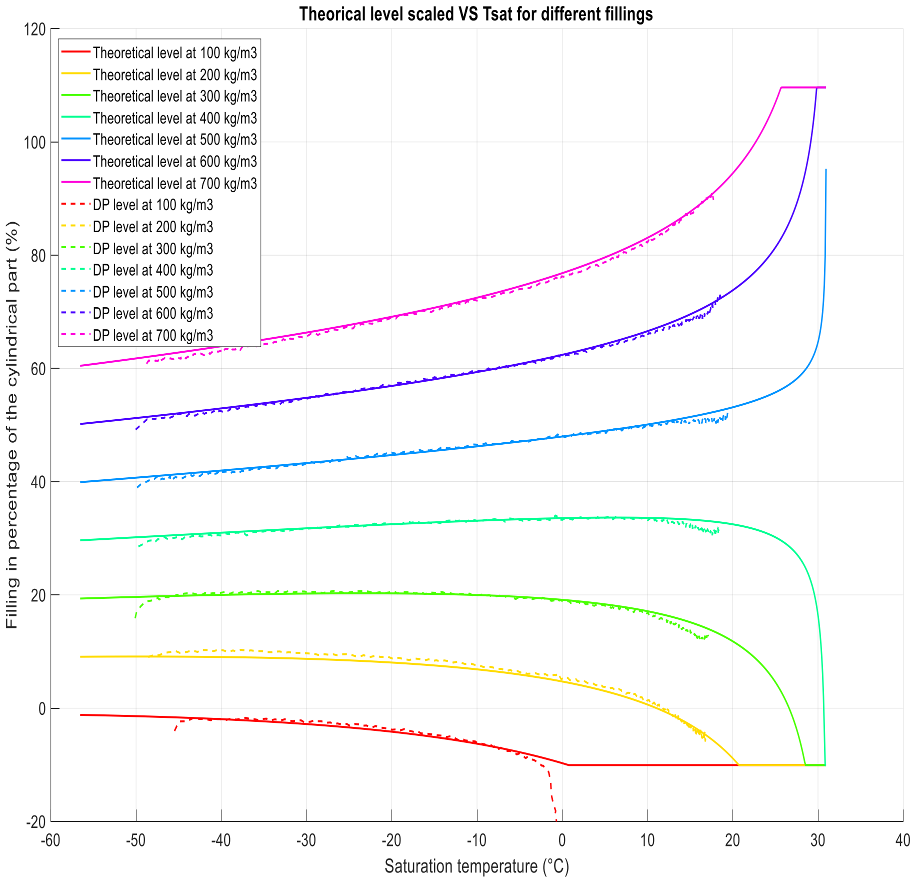
- Small heating power is added to ensure **gas phase is in the DP tube**
- DP pipe connection should be away from the CO_2 flow





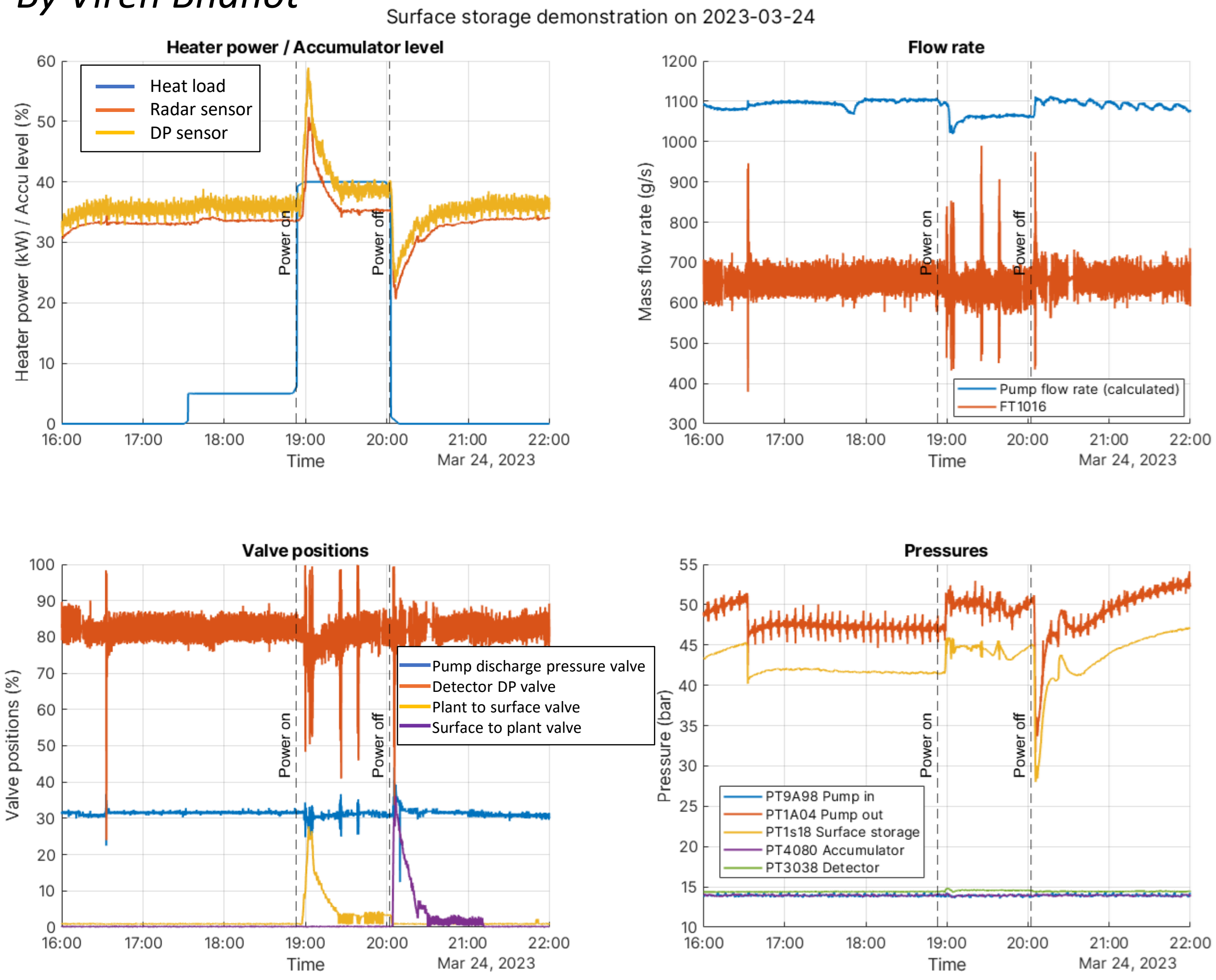
Precise comparison with theorical level based on accumulator filling has been performed

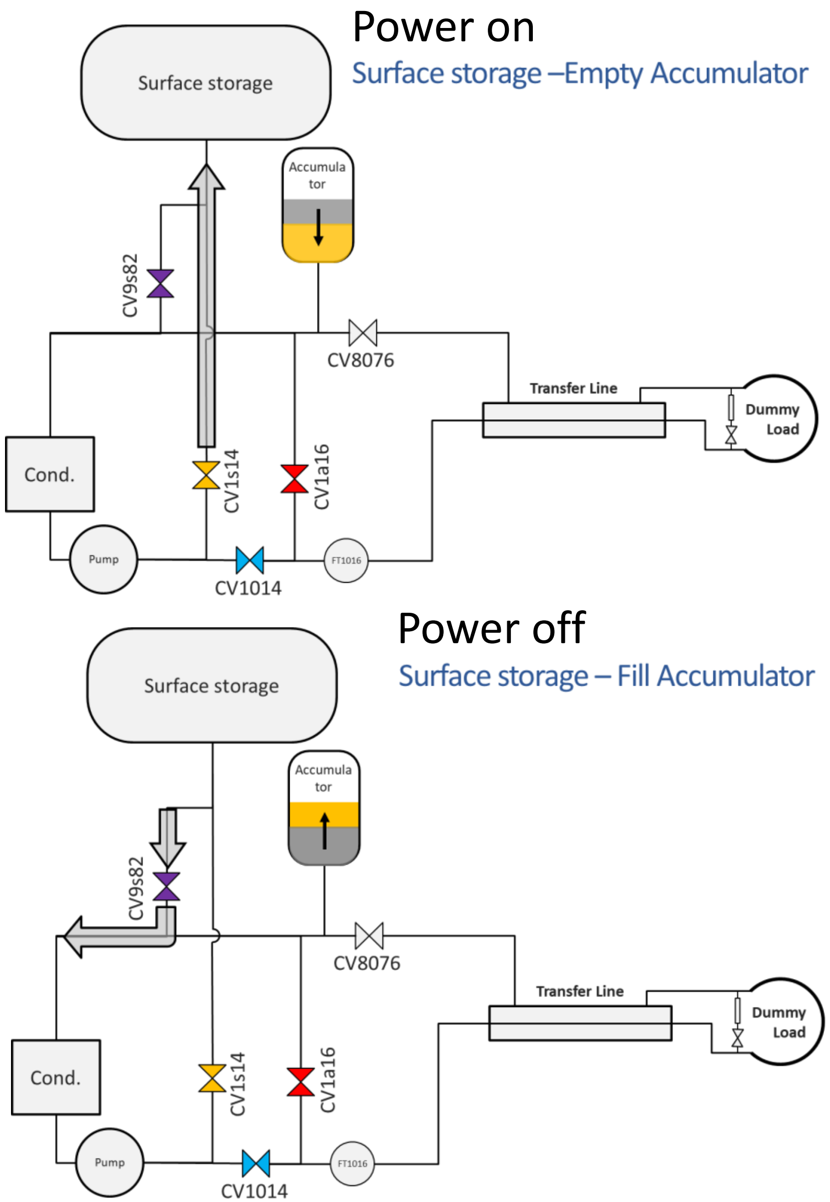
➢ DP level calculation is accurate



Surface storage operation

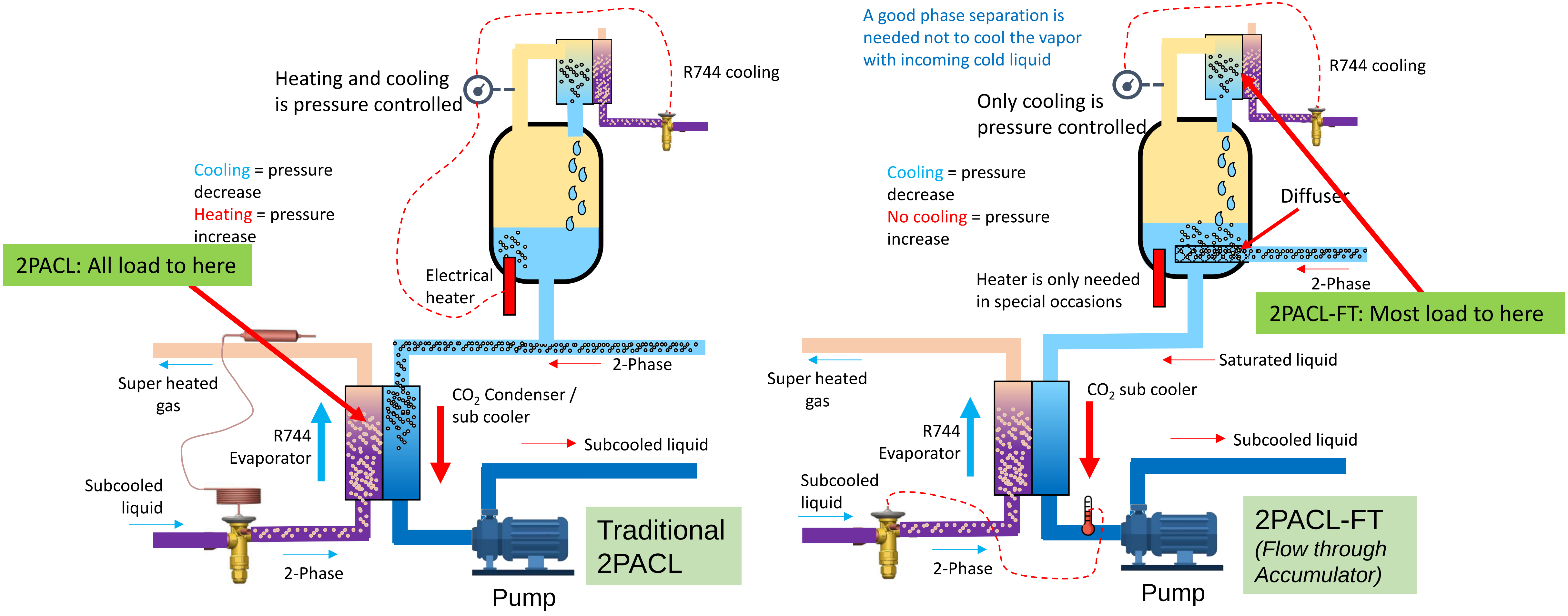
By Viren Bhanot





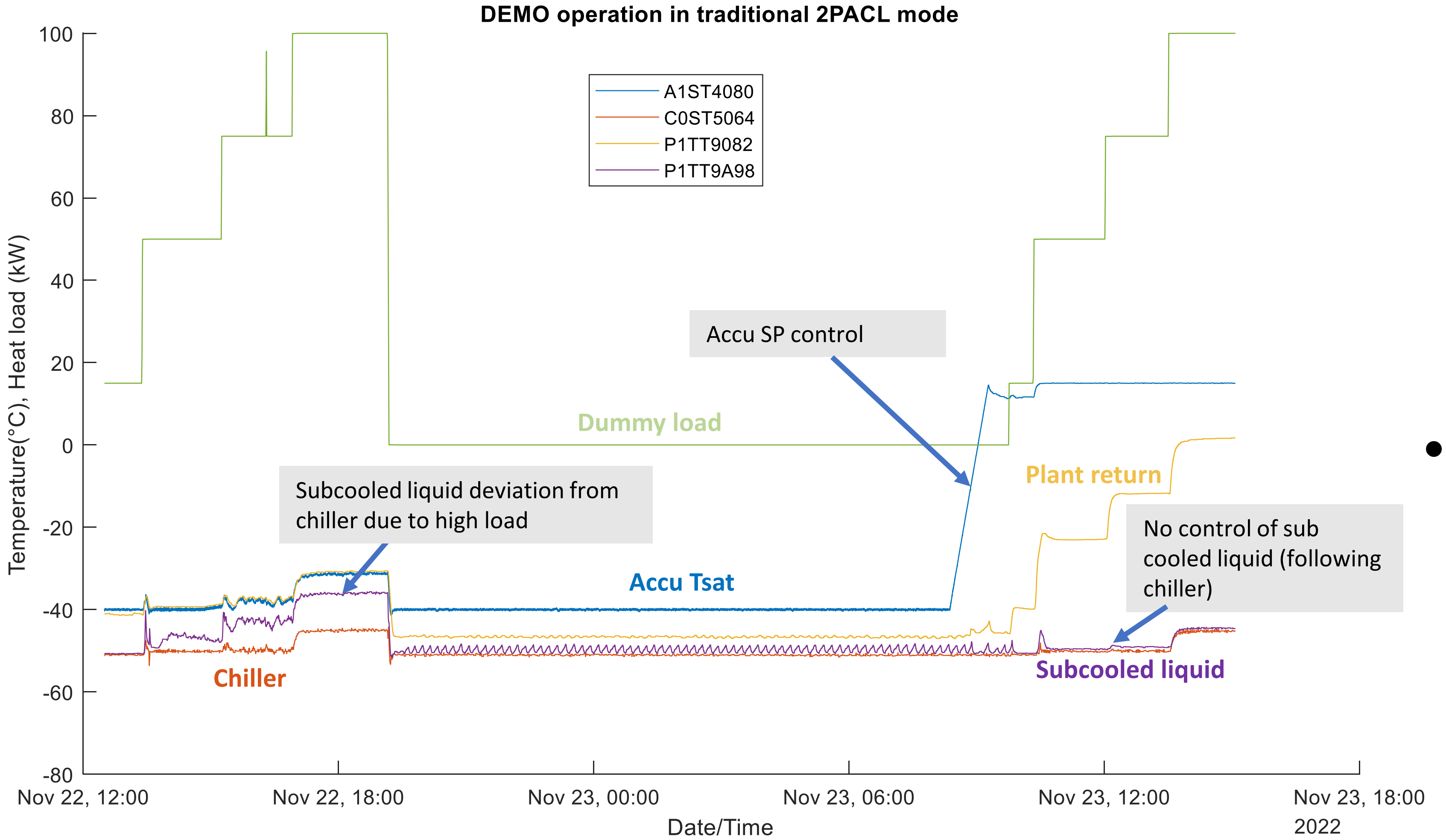
Flow-through

Traditional 2PACL vs 2PACL-FT



2PACL-FT => Demonstrate the new concept and show that the accumulator can handle the full system load capacity

Typical system behavior in traditional 2PACL mode



- The traditional 2PACL works well but is harder to control than the 2PACL-FT

- Risk of cold drift at high temperature

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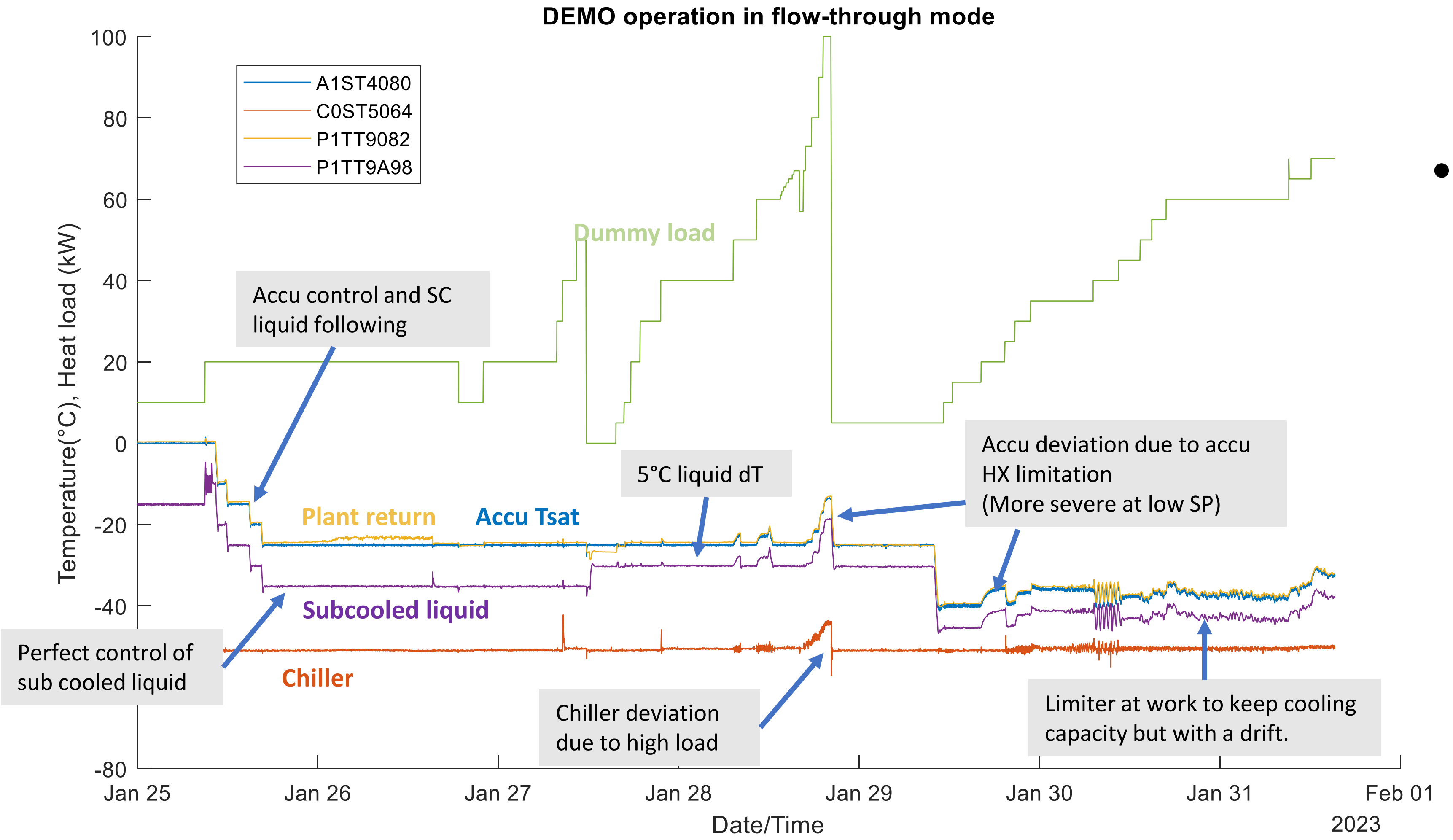
Typical system behavior in 2PACL-FT mode

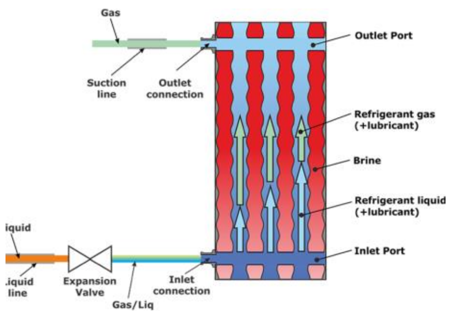


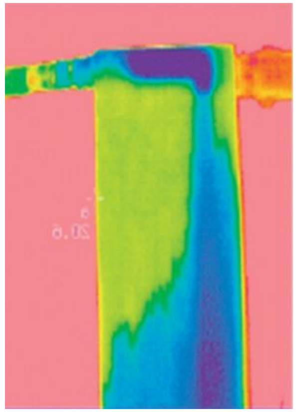
- 2PACL-FT mode shows a very stable and easy to control system
- It has a very good liquid temperature controllability so that at high temperature set-points there is no risk of cold drift anymore
  - Very good experience with a liquid dT of only 5°C

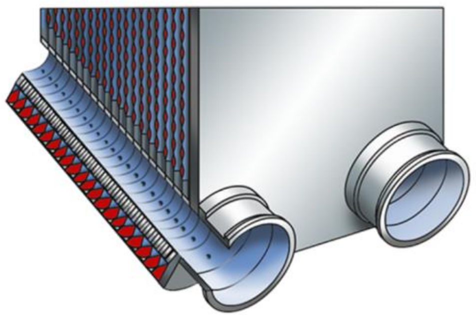
Condenser capacity test

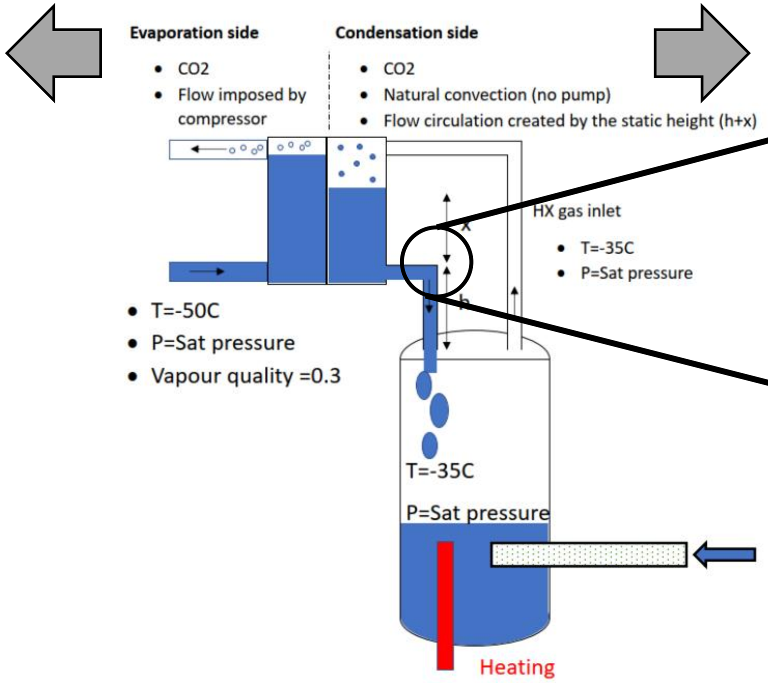
Cooling capacity too small…
Why ?

Cause n°2: Maldistribution

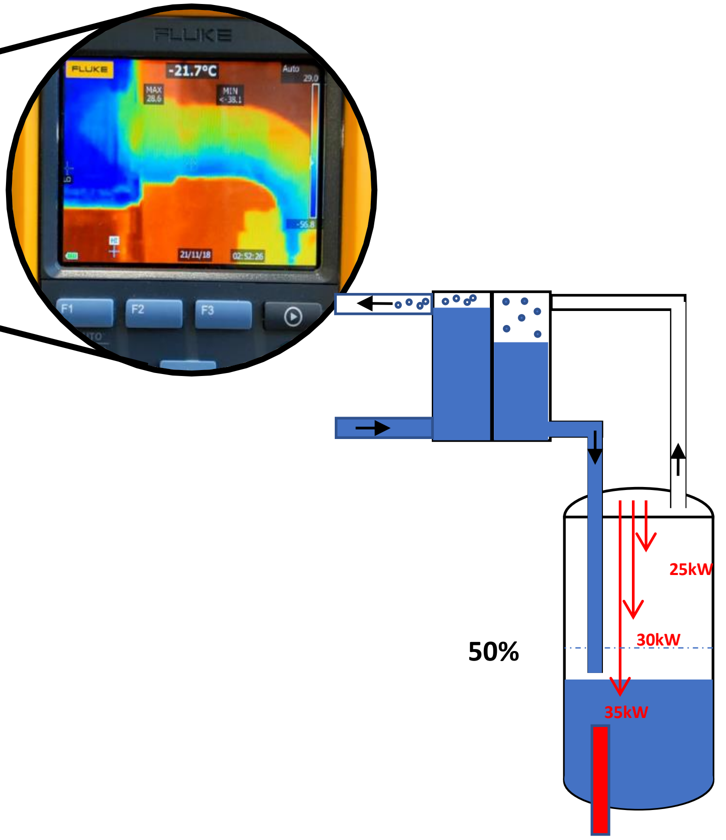






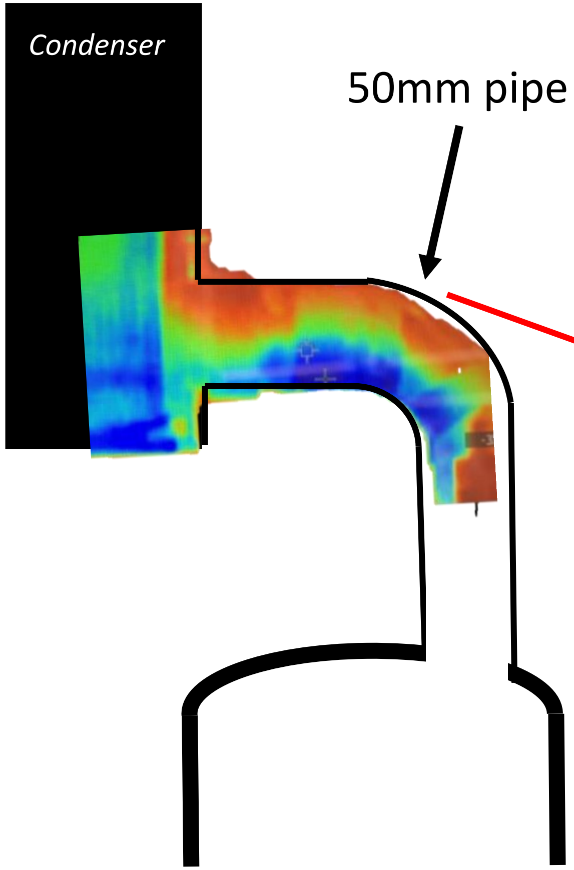


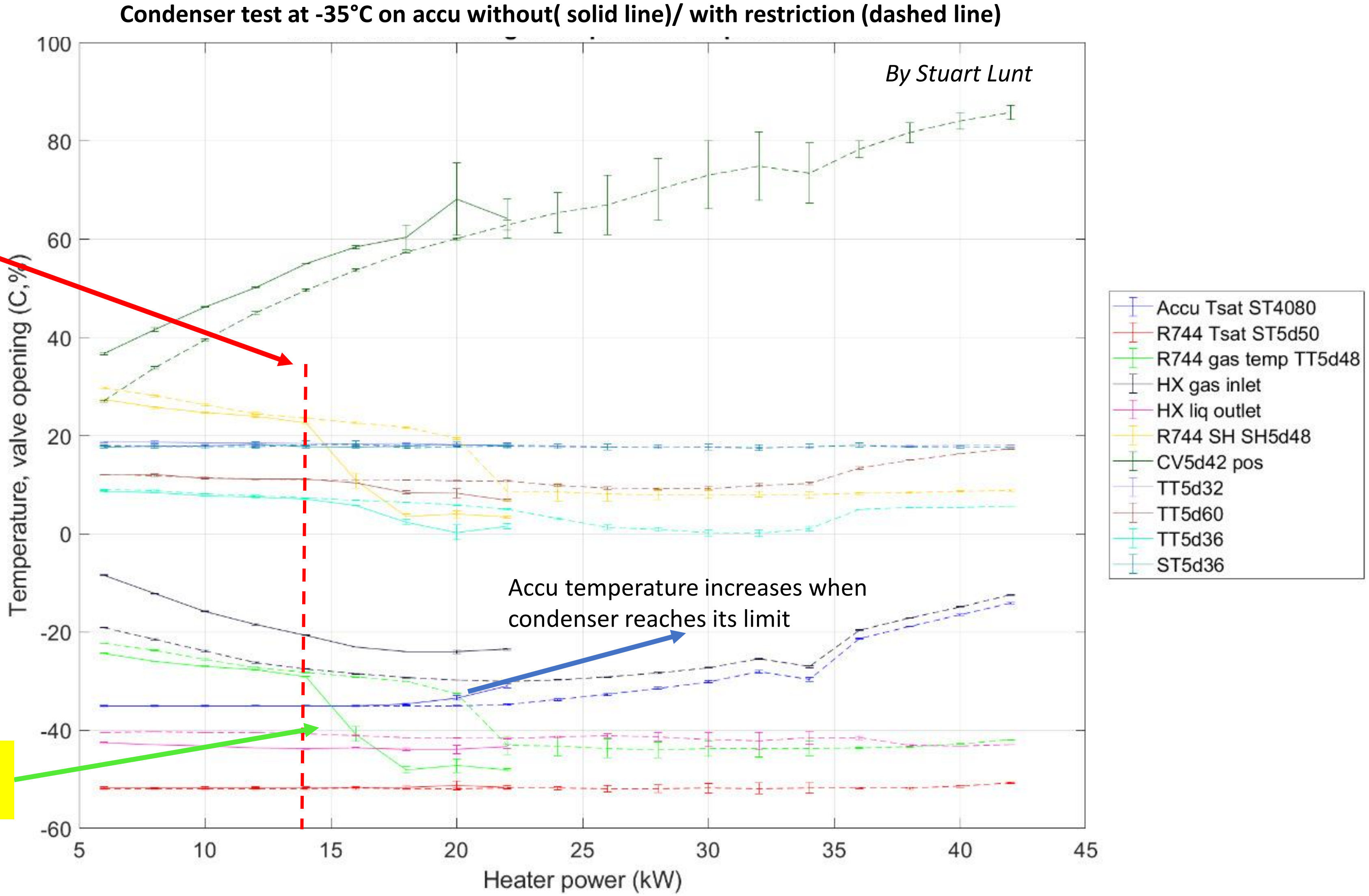
Cause n°1: natural convection flow too small



A large drawback discovered in the early accumulator testing:

Our standard way of cooling the accumulators was far from optimal



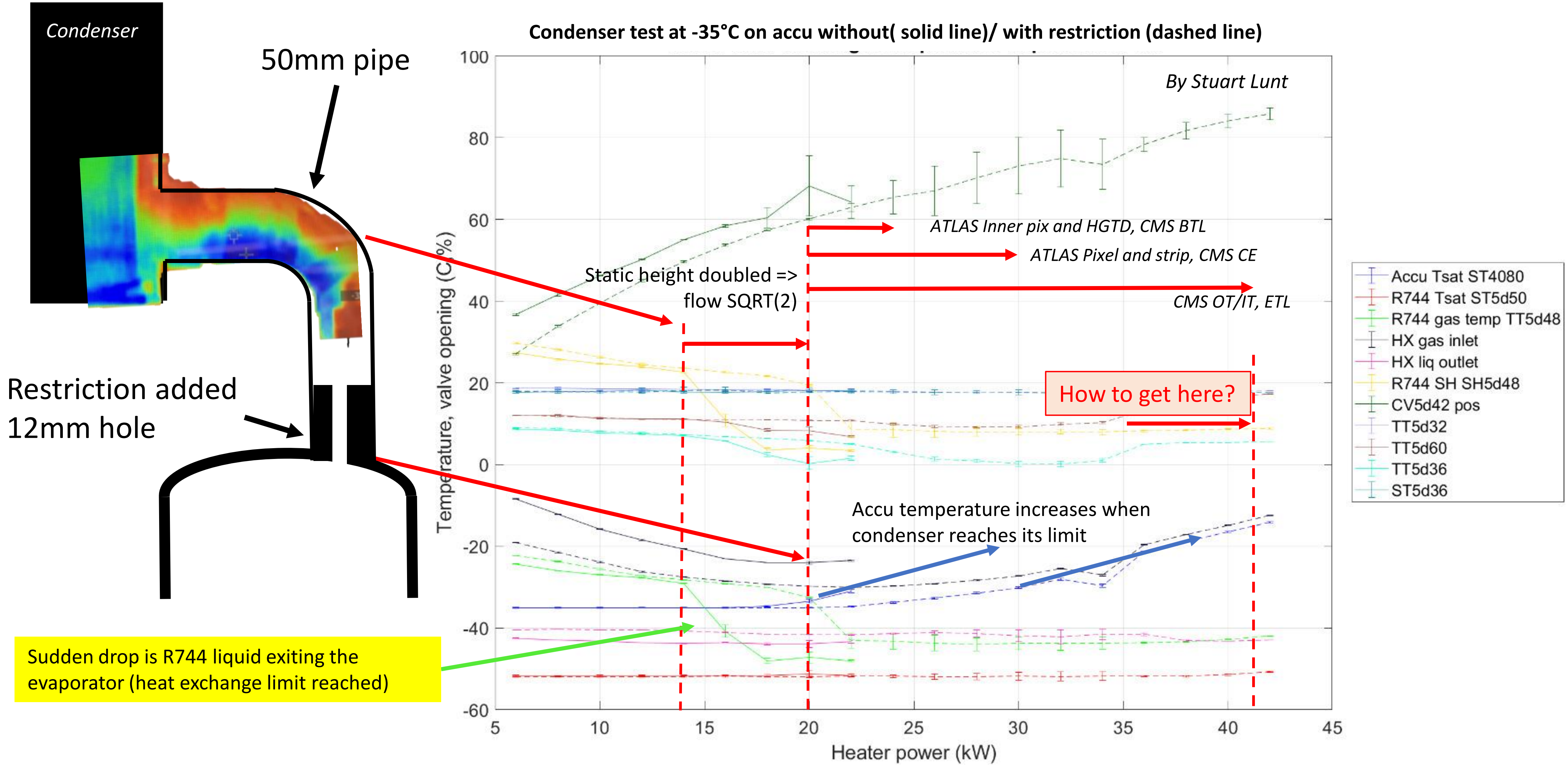


Sudden drop is R744 liquid exiting the evaporator (heat exchange limit reached)

Note: We have 2 heat exchangers, so each taking half of the capacity

A large drawback discovered in the early accumulator testing:

Our standard way of cooling the accumulators was far from optimal



Note: We have 2 heat exchangers, so each taking half of the capacity

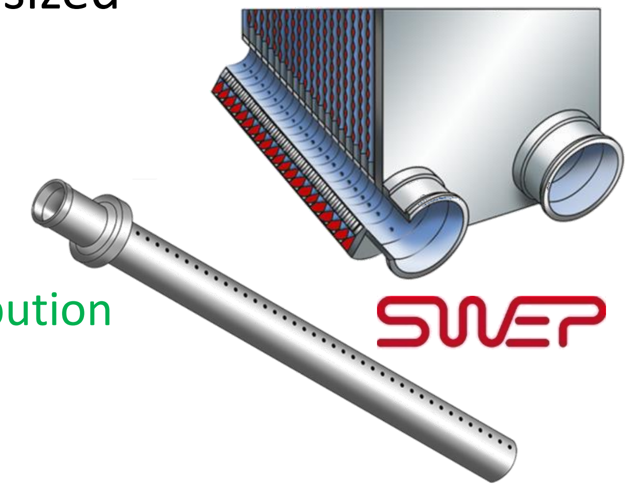
Heat exchanger redesign

- At the time the heat exchangers were under-sized as we were afraid of maldistribution

- During testing we observed a much worse maldistribution than expected
  - Beside the lack of CO_2 convection the maldistribution was another cause of the lack of performance

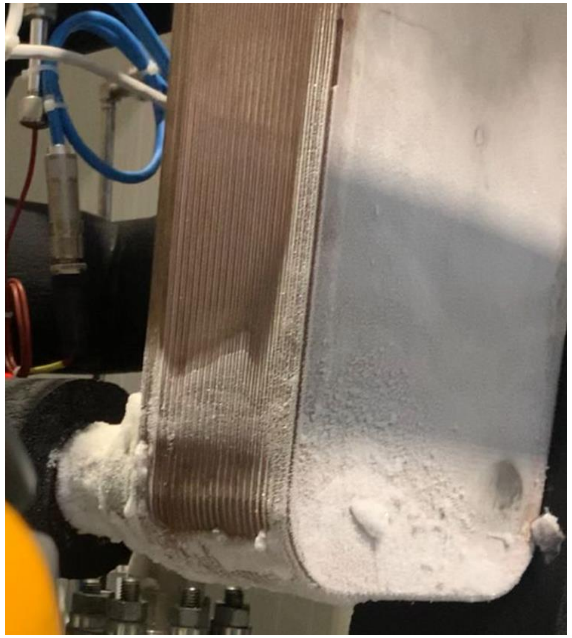
- Discussions with SWEP (the heat exchanger manufacturer) has lead to a design change by including a so-called Q-pipe. This is a method used in many of their evaporators, but not yet implemented in the high pressure CO_2 product line

- A self made prototype Q-pipe was installed in 1 of the 2 heat exchangers to study the improved behavior



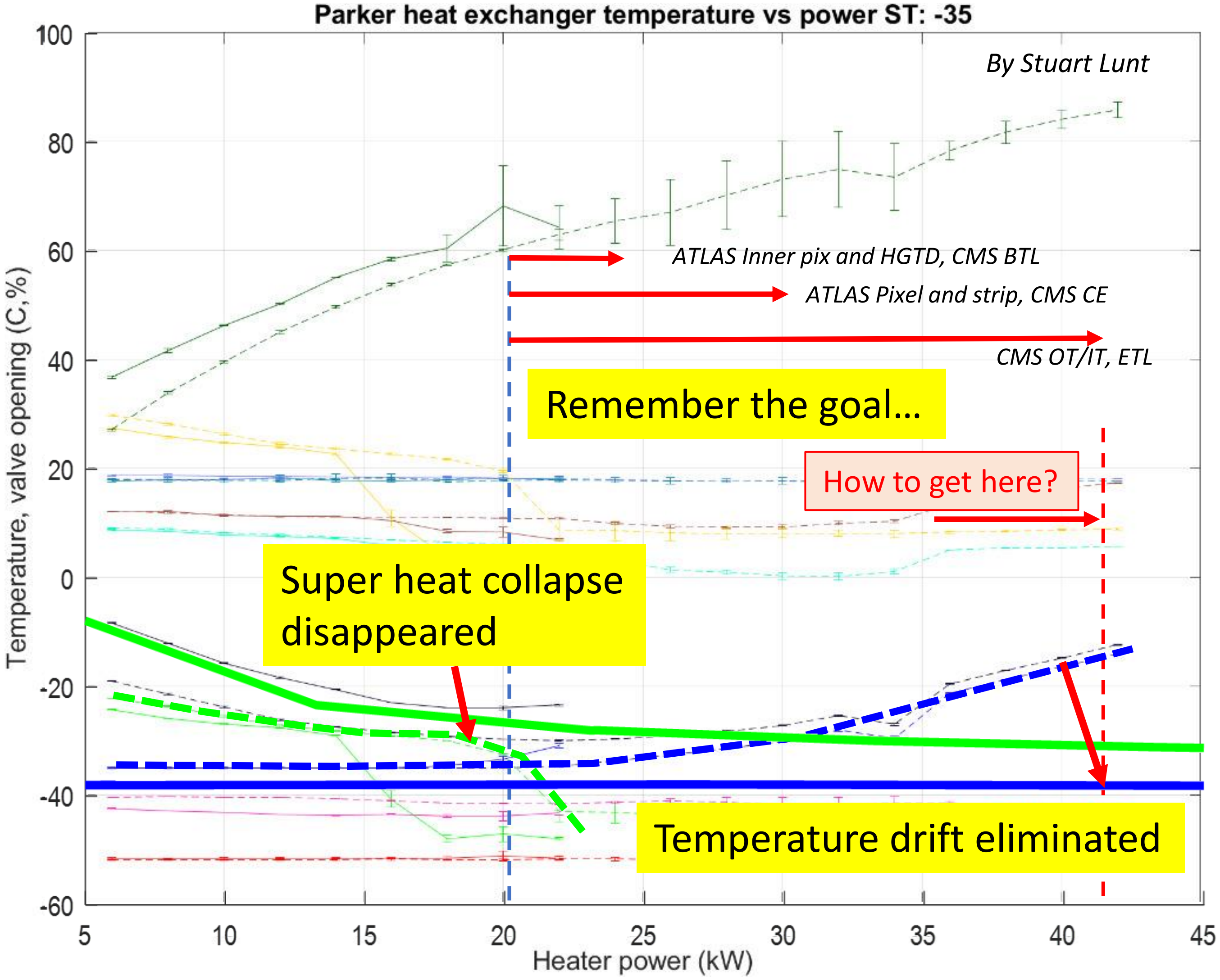
Q-pipe, a distribution spray tube

Yann Herpin



Liquid flow mainly goes to the back of the HEX

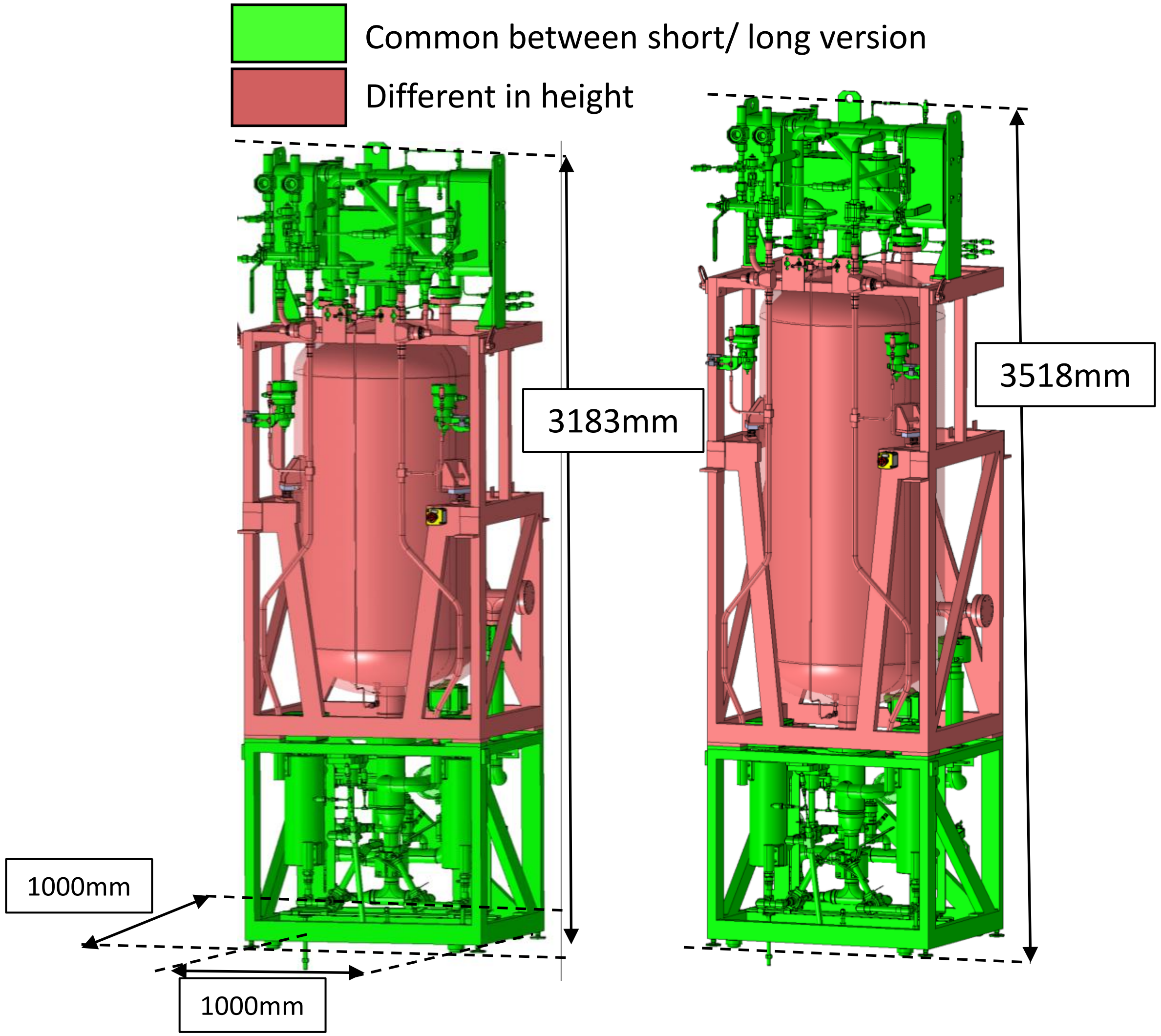
Flow through concept concluded



- Tests have shown that this concept works and that we can now meet our heat load requirements
- We still have some issues at -45°C, but we are confident that this is due to the undersized heat exchangers and oversized connection piping
- With a working Q-pipe we can increase the heat exchanger size
  - We will soon upgrade the DEMO accumulator with the final Qpipe heat exchangers
- The flow through concept is easy to control and very stable
  - The baseline operational method!
- Normal 2PACL is a back-up operational mode in case of accu capacity problems
  - 2PACL mode also used at start-up

Plant and Accumulator design

Accumulator design overview



Short version Accumulator

Long version Accumulator

- 2 Accumulator versions : short and long
  - 2 Vessel volumes
- Heat exchangers optimized for flow through mode (larger size and Q pipe)
- New heaters (Cast heaters)

DEMO – Final 2PACL differences

<u>WHY</u> we made re-design? Space, weight, cost

The DEMO plants are prototypes designed with **large flexibility for testing purposes**
- Highly modular pipe assembly
- Modular frame
- Cold box with individual compartments for each head (possibility to service one head while plant runs)

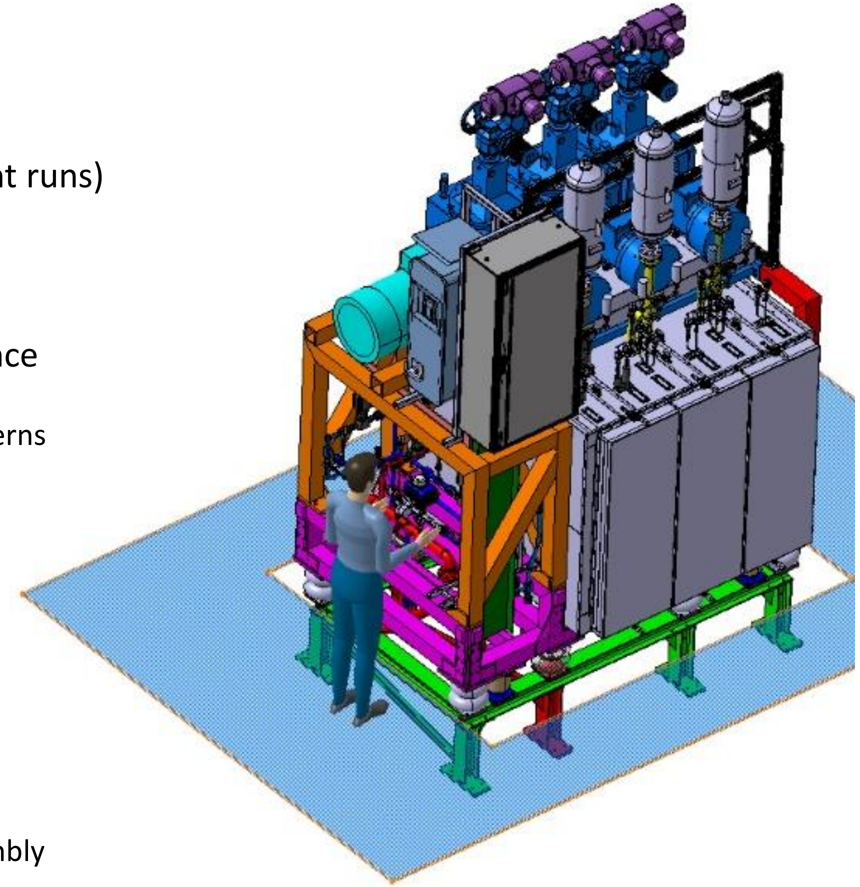
2PACL Plants for final system objectives

- Integrate the **control objects within the plant frame** volume for easier installation and maintenance
  Scheduled pump maintenance every 5 years
  To remove a pump, it must go through the narrow corridors in between the cooling plants in ATLAS and CMS caverns
  Apart from the pump drive unit, no other objects shall be installed on the frame

- **Reduce** plant **footprint** and height to comply with experiments integration requirements
  Plant depth along y: 1590mm → below 1450mm
  Plant height along z: 3332 mm → below 3000 mm

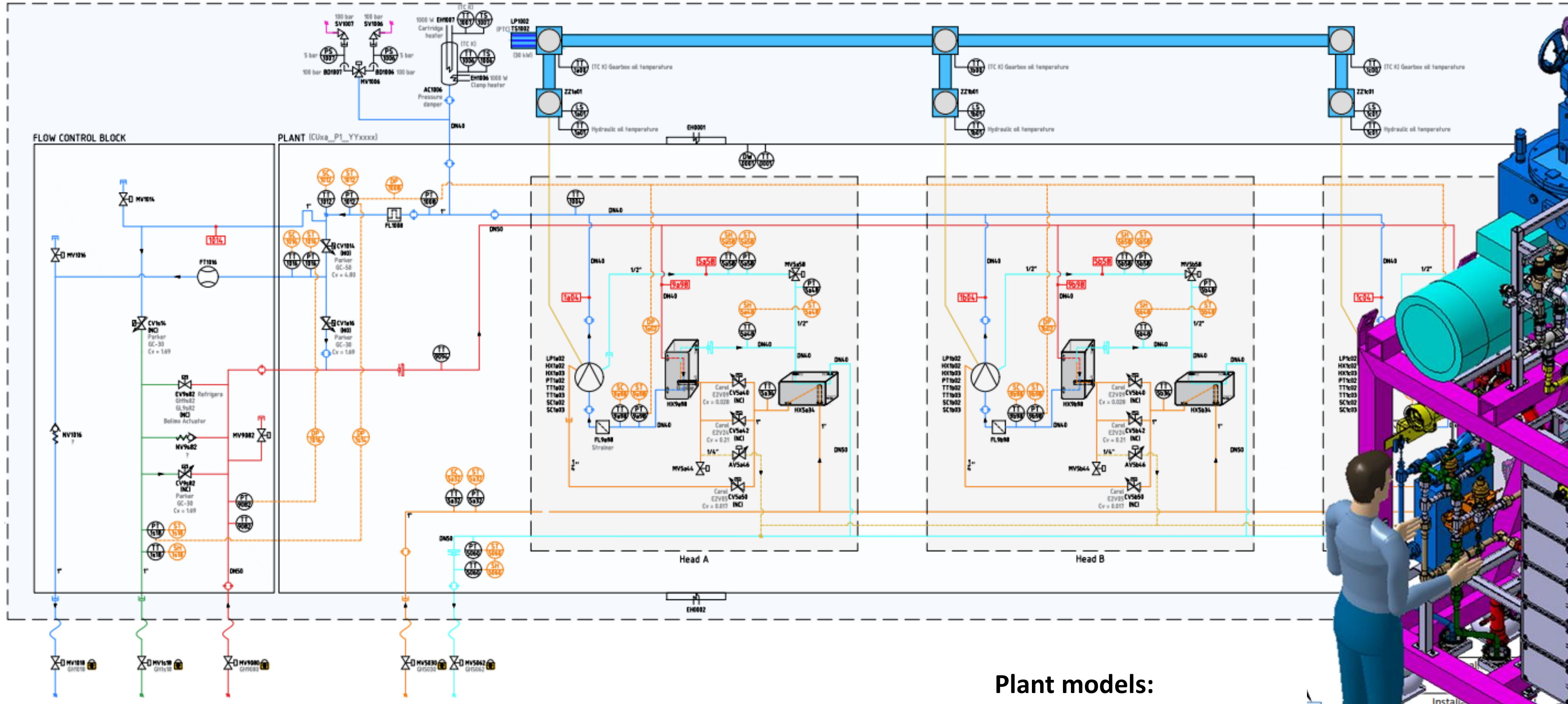
- **Reduce** the **weight** to comply with the available transportation tools
  USC-55 Crane capacity : 3,2T
  3-heads pump drive unit with the electric motor 2.3 T (this is the largest pump)
  3-heads plant weight without drive unit must stay below 3T to allow installation with the minimum on-site assembly

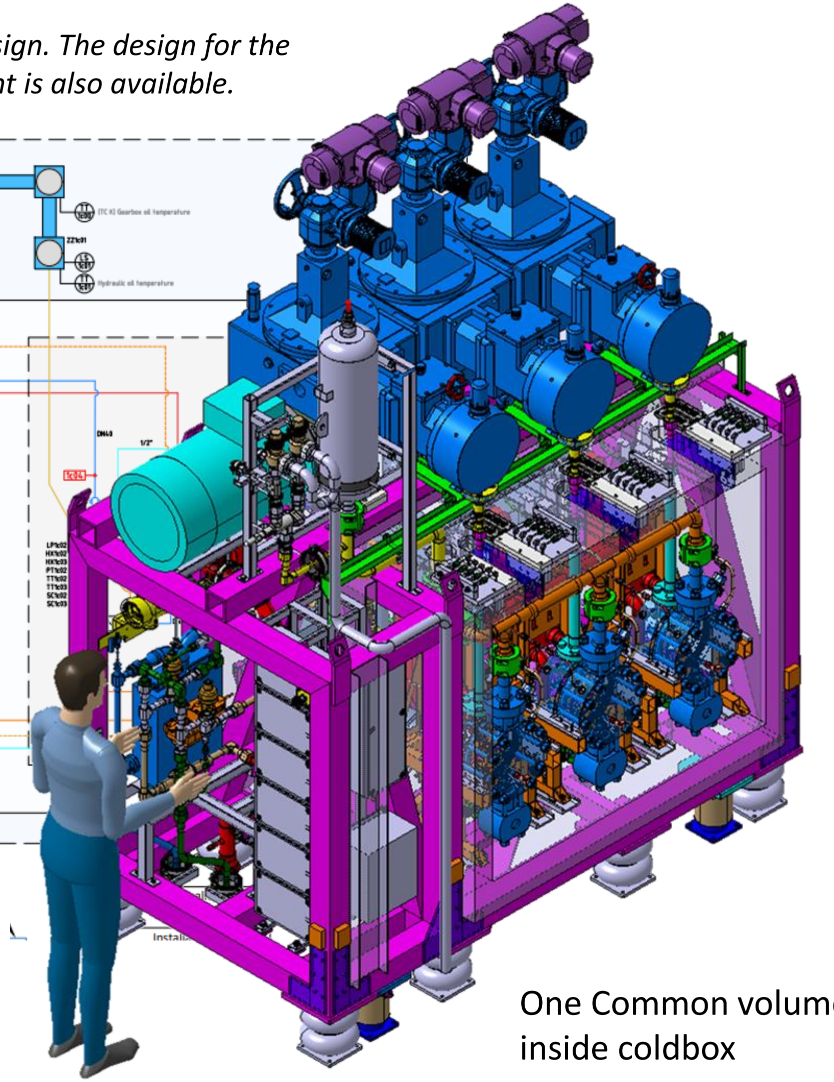
- **Reduce** the **cost**



2PACL Design – Overall view

This presentation is focused on the 3heads plant design. The design for the 2Heads and 1Head plants based on 3Head final plant is also available.



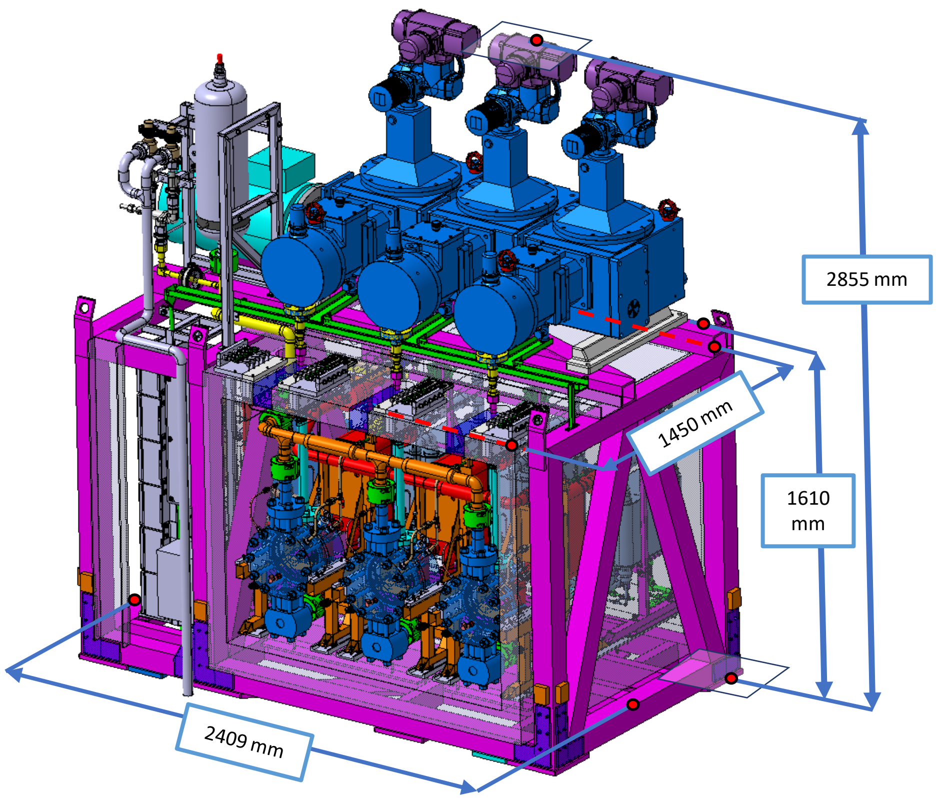


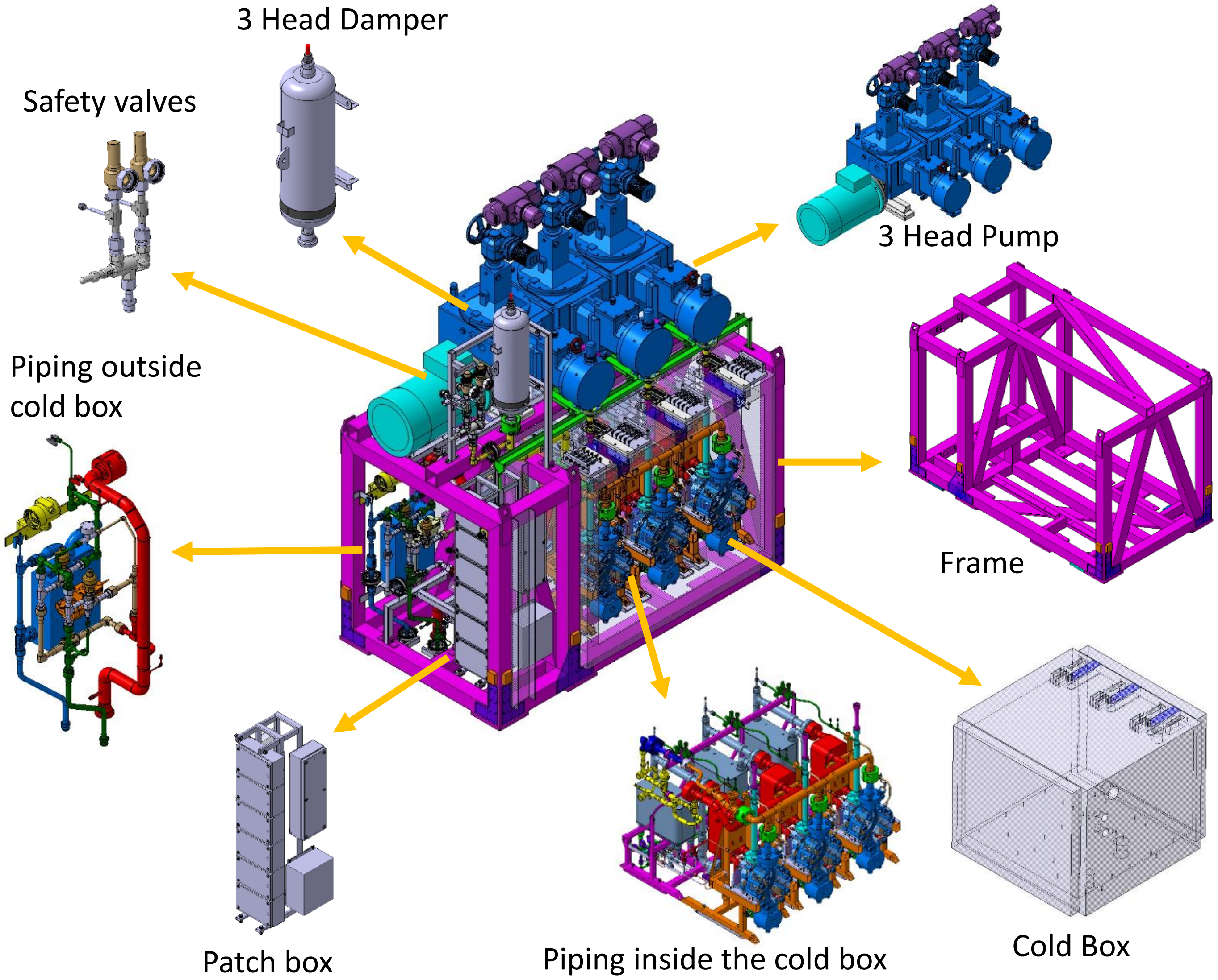
2PACL P&ID: https://edms.cern.ch/document/2603473/1.3

Plant models:
ST1442045_01 3H Plant
ST1534838_01 2H Plant
ST1534855_01 1H Plant

One Common volume inside coldbox

Overall dimensions and Components





- Height calculated with the **anti-vibration feet at their tallest configuration is 3085 mm.**
- Width including both cold box doors is **1706 mm.**

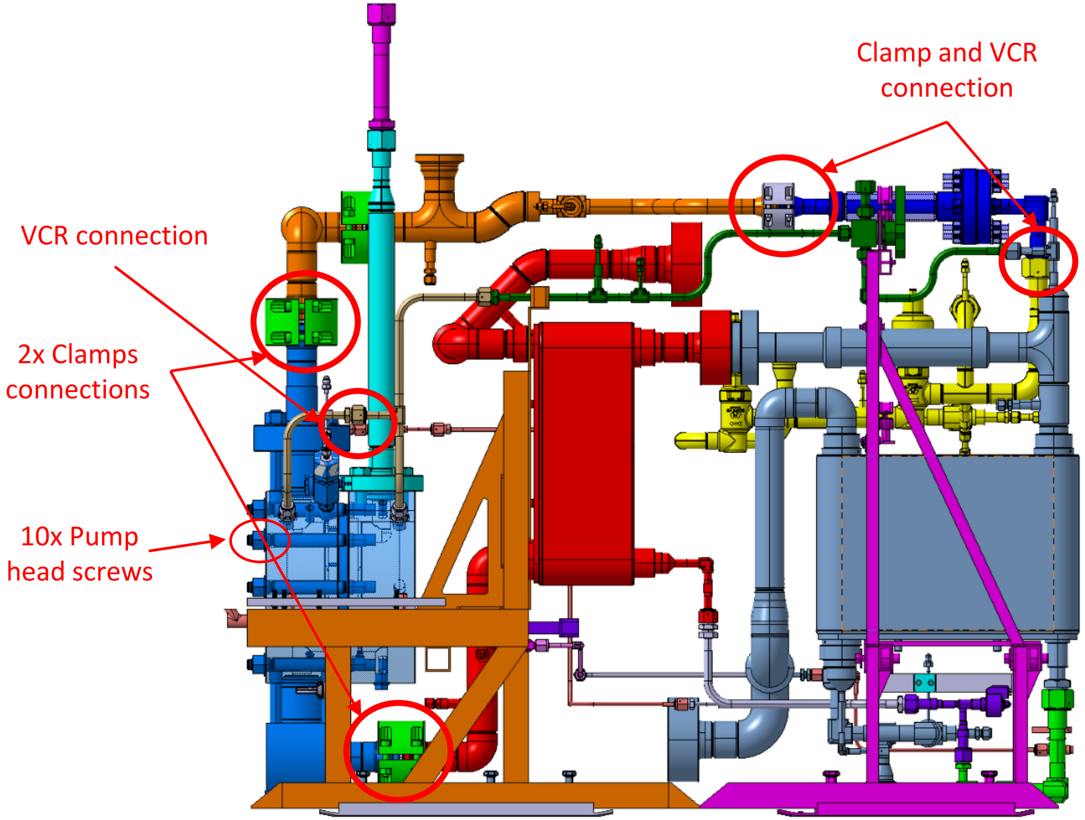
Maintenance plan

- **Every year:**
  - Pump basic maintenance
    - Replacement of membranes (plus associated gaskets and O-rings), oils (gear box and hydraulic) and pump valves
  - Filters cleaning
  - Valves piloting verification and position switches calibration (if needed)
  - Sensors inspection and calibration (if needed)
  - Verification of electrical connections
    - With thermal camera while system is running before the maintenance
    - Re-torquing of all electrical connections with dynamometric tools when system is OFF
  - Pumps and heaters current measurement (while system is running)
  - Resistance measurements for motors, coils…
  - Heaters insulating resistance measurement up to 1000VDC
  - EMS STOP testing
  - Differential circuit breakers tests

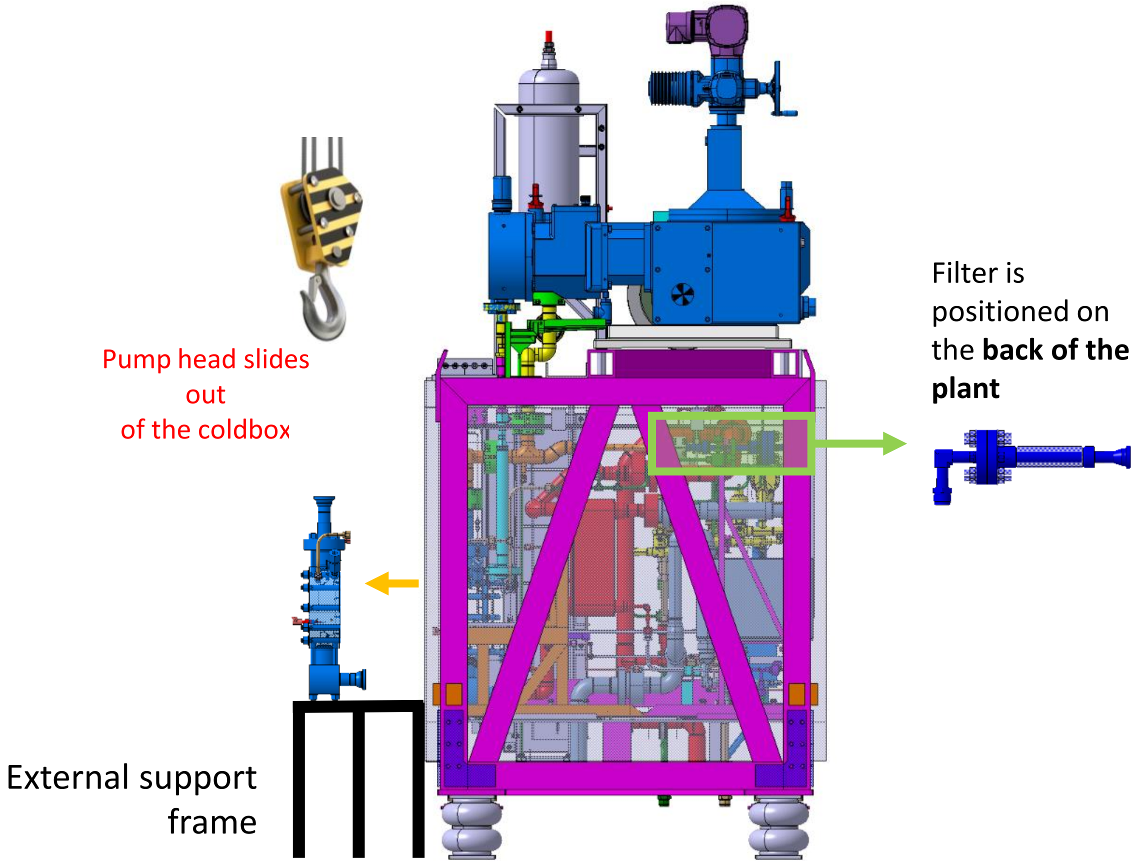
- **Every 2 years:**
  - Safety valves calibration
  - Pump internal safety valve inspection and calibration
  - Valves battery packs replacement
  - Flexible inspection (CO_2 leak test - sniffer)
- **Every 5 years:**
  - Pump in-depth maintenance (performed at the supplier's premises):
    - Membrane replacement (plus associated gaskets and O-rings) + oils replacement (gear box and hydraulic), valves replacement + gear box inspection and replacement of worn parts + piston and hydraulic head inspection and replacement of worn parts
- **Every 10 years:**
  - Burst discs replacement
- **Every 12 years:**
  - Accumulators inspections by HSE

Maintenance examples

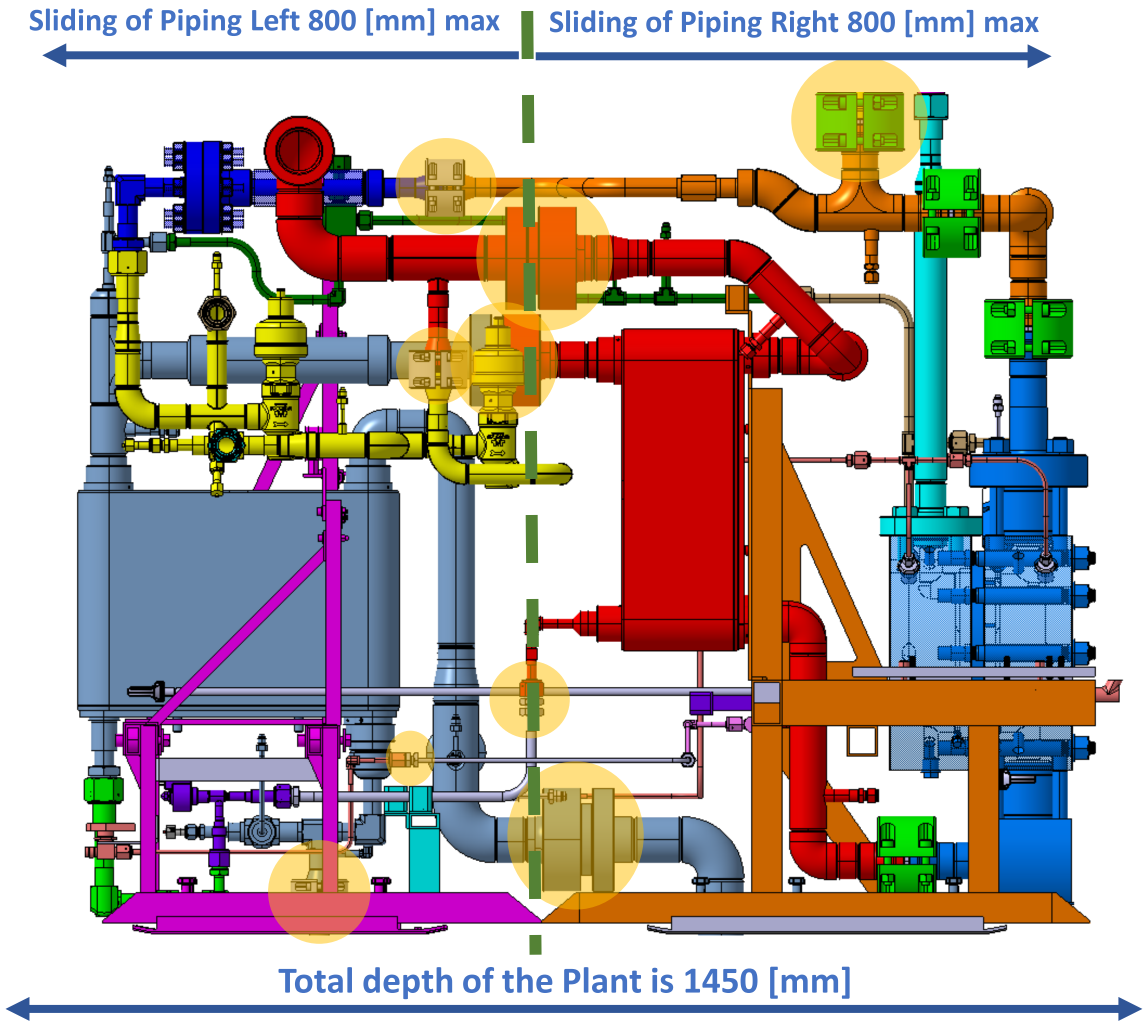
Pump head extraction:
Step 1: Disconnection of 2 flanges + 2 VCR's inside the box
Step 2: Unscrew pump head screws
Step 3: Pump head slides out on an external frame
Step 4: Pump head is taken by **<u>a crane</u>** (~100 kg)



Filter extraction:
Step 1: disconnection of 1 VCR fitting and one 1" Clamp connector
Step 2: filter is lifted and then taken out **<u>by hands</u>** (8 kg)



2PACL Plant piping - intervention

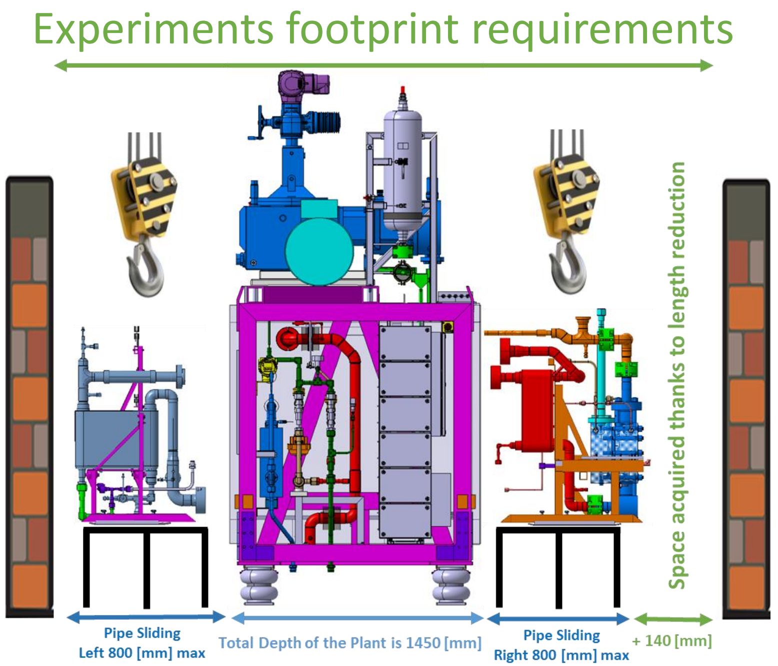


FINAL CO_2 Plant piping redesign aspects:

- Central splitting plane

  Main benefit: we no longer need to slide the entire piping assembly but half of it→ simpler operation and shorter intervention time

- Optimization of pipe routing:
  - More space for maintenance
  - less welds + less connectors
  - Less piping sub-assemblies



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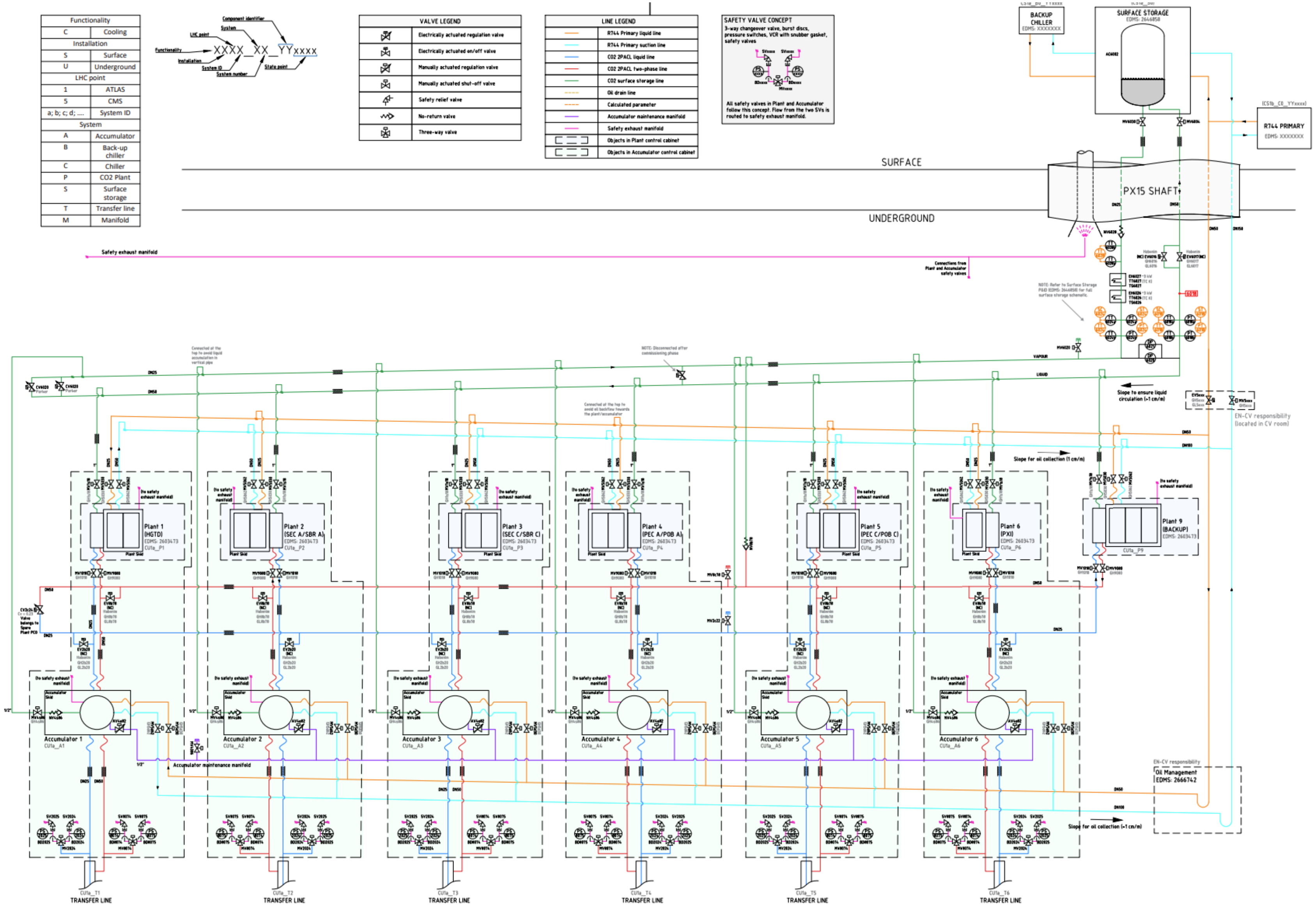
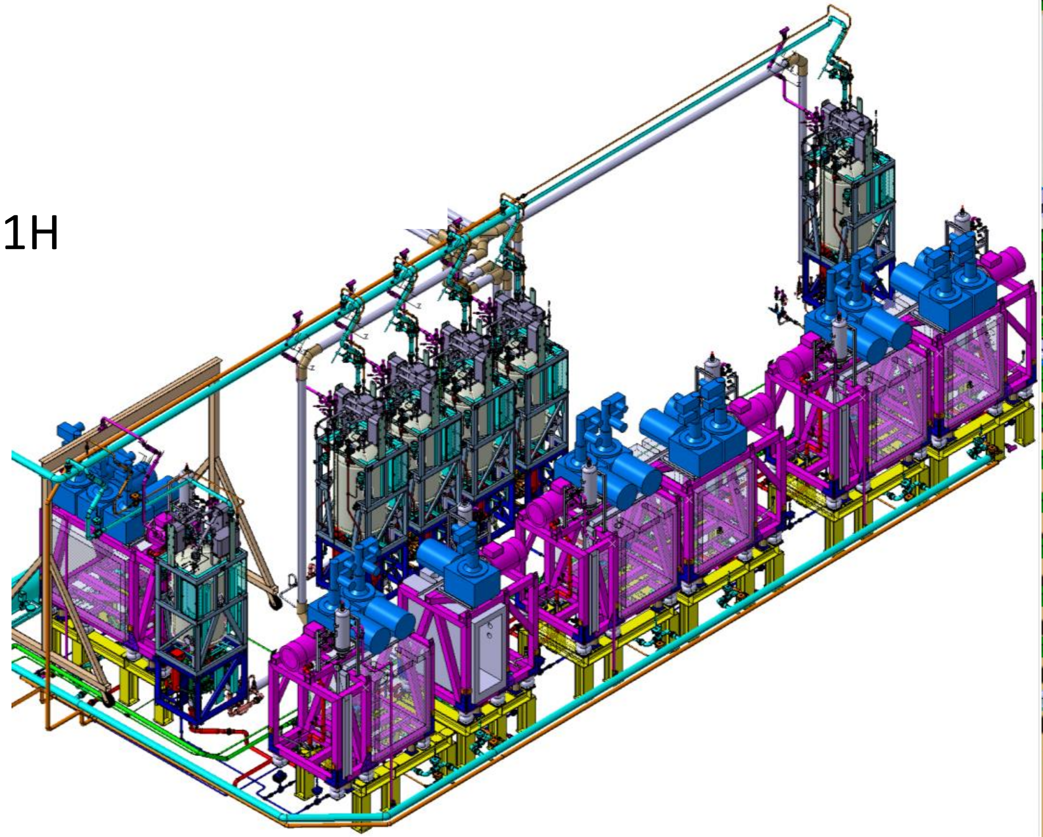
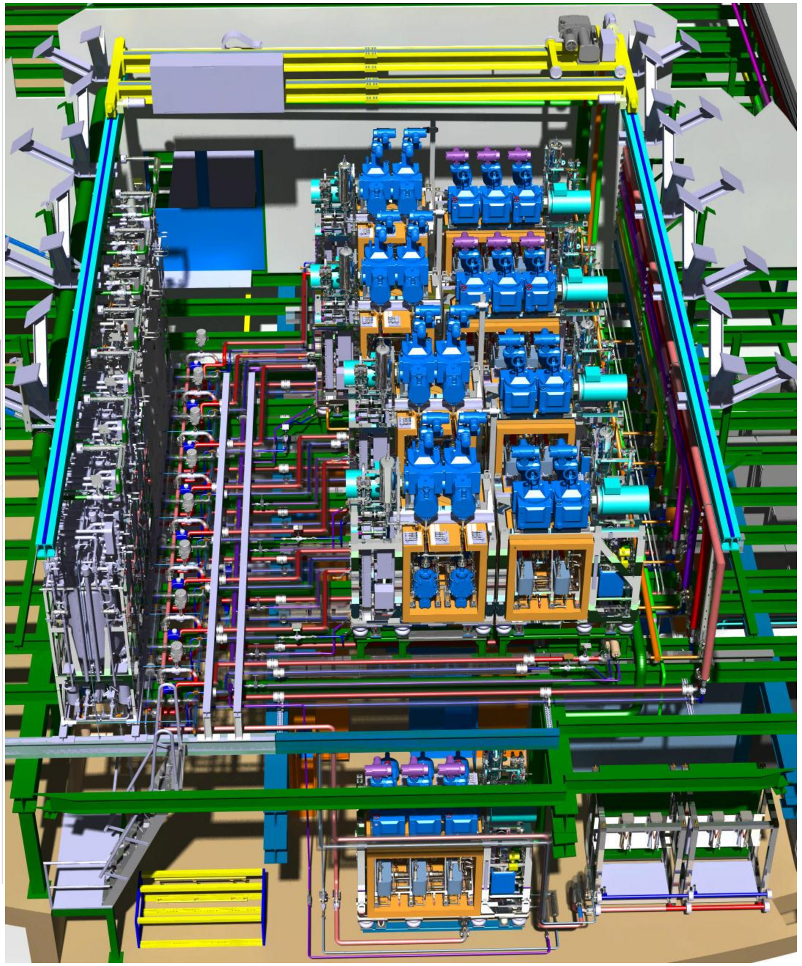
Service Cavern – P&ID



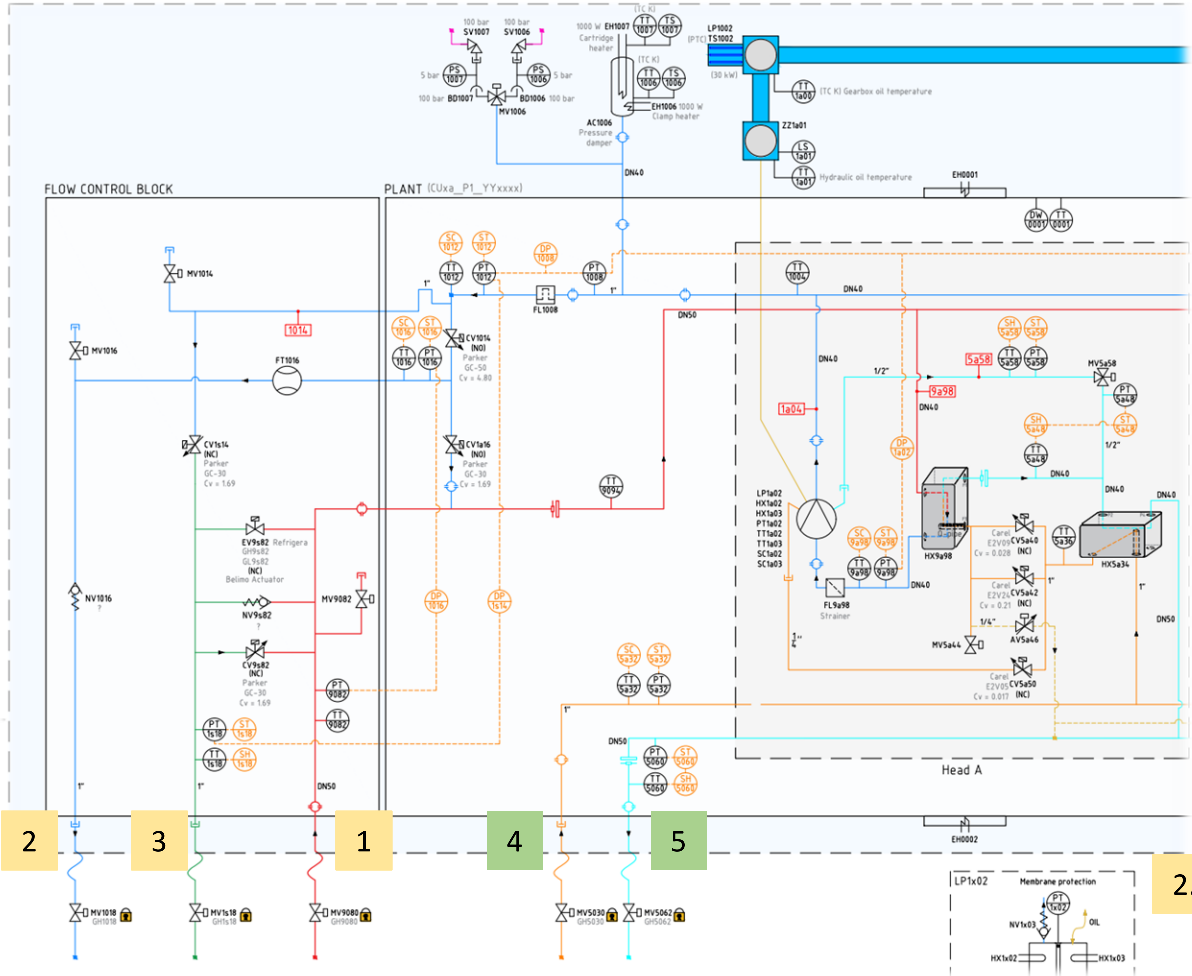
ATLAS and CMS systems

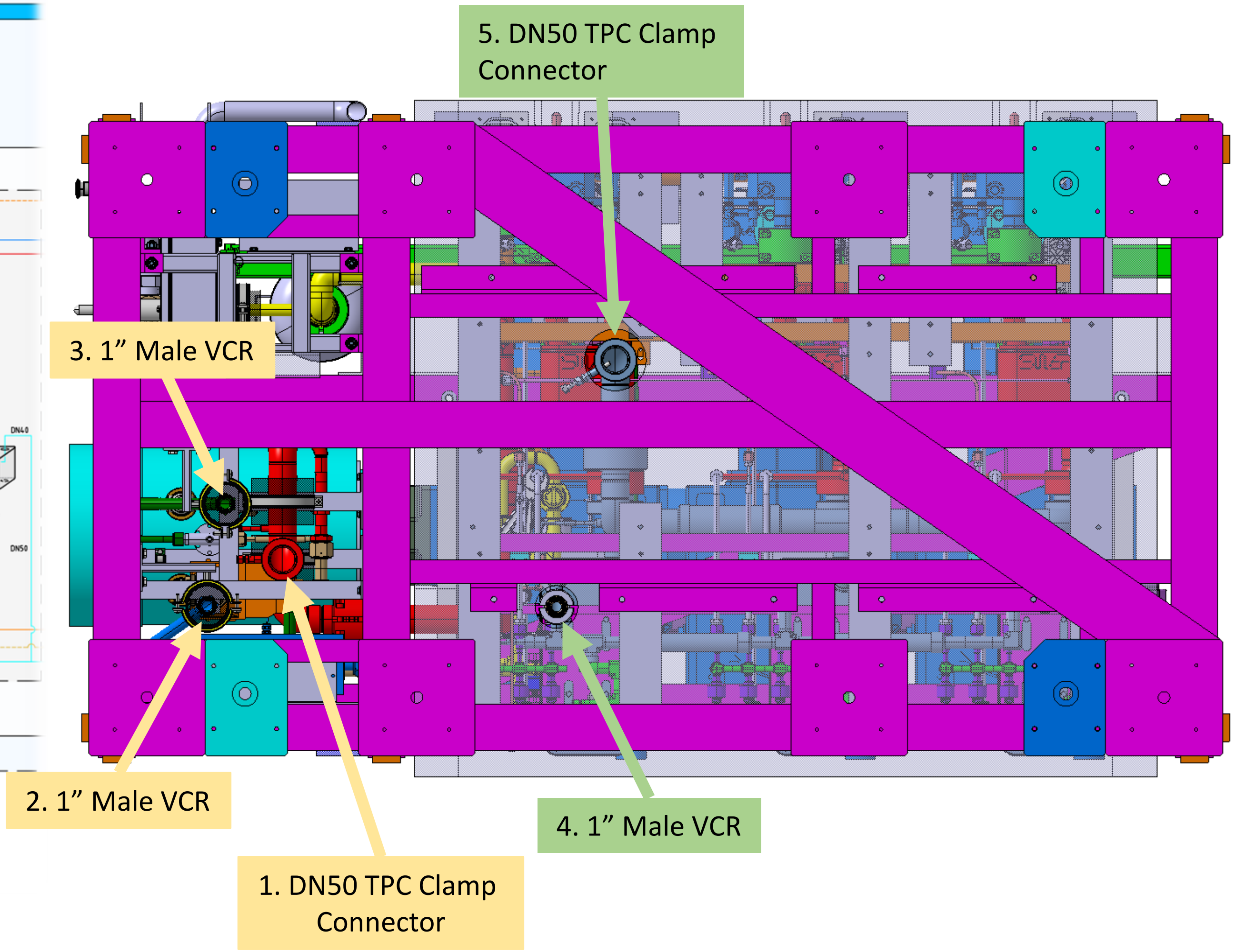
- ATLAS:
  - 7 cooling plants
    - 1x3H, 5x2H, 1x1H
  - 6 accumulators
- CMS:
  - 9 cooling plants
    - 3x3H, 6x2H
  - 8 accumulators



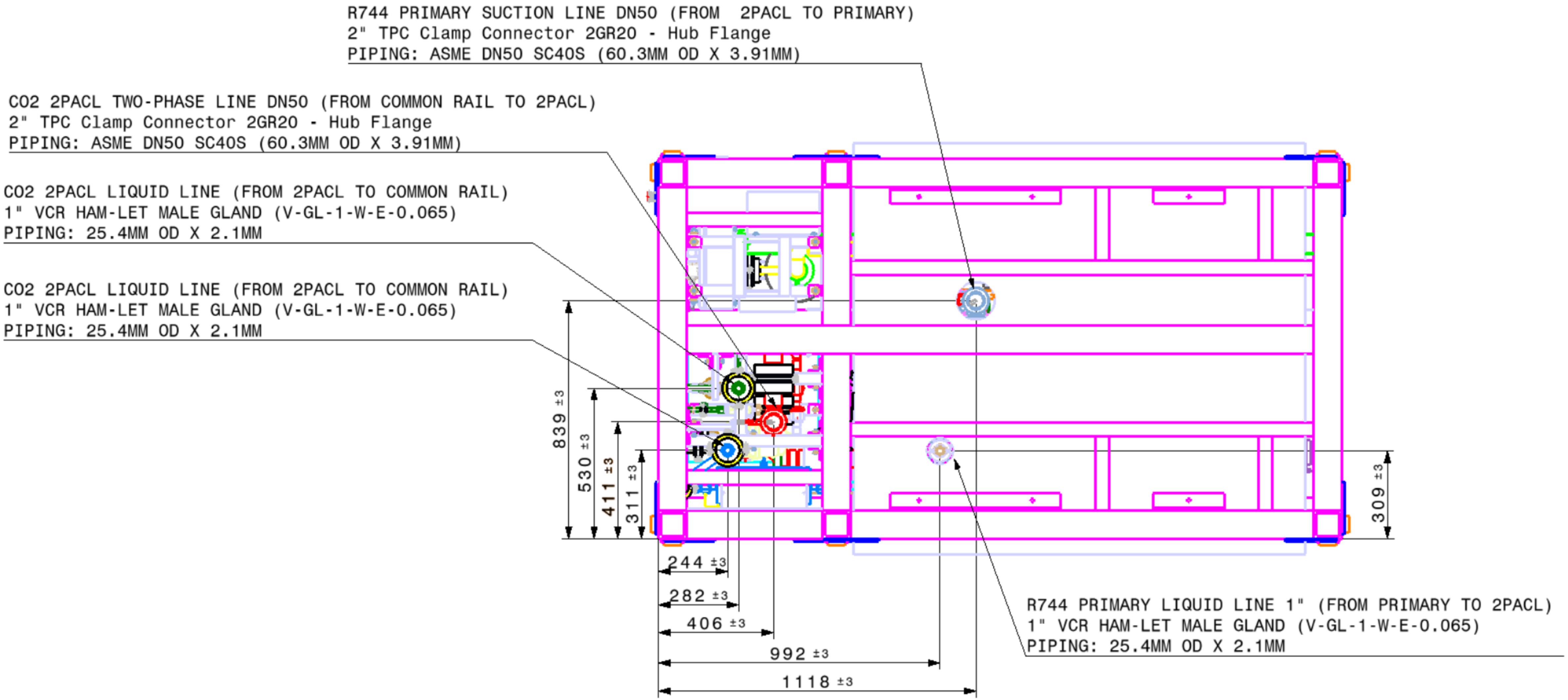


2PACL Plants Connection Interfaces





2PACL Plants Interfaces Locations



2PACL Plant connections towards underground piping

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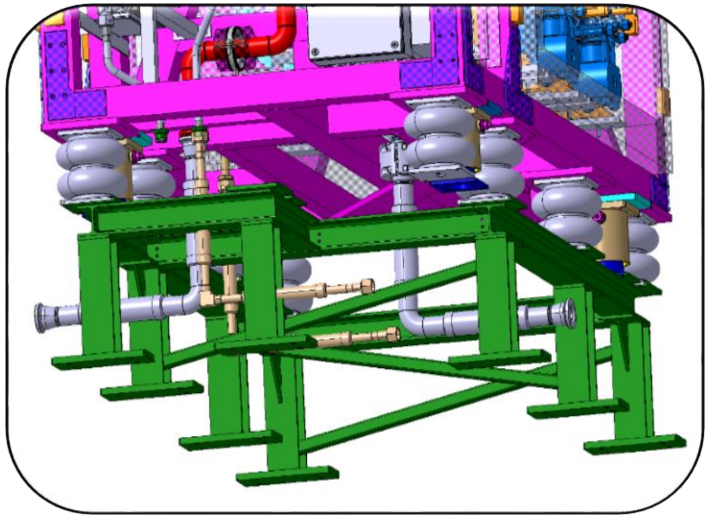
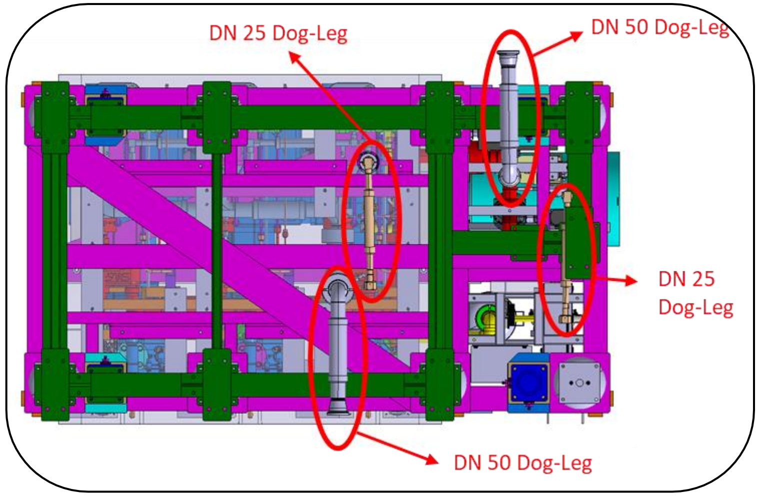


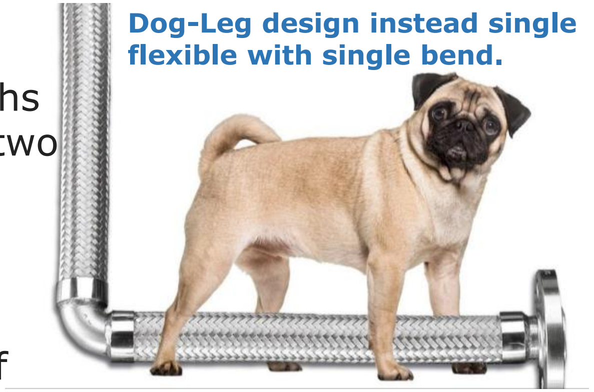


What is the Dog-Leg?

Dog leg refers to an assembly made by joining two lengths of hose to a 90º/45º elbow to allow for movement from two planes of motion in a piping system.

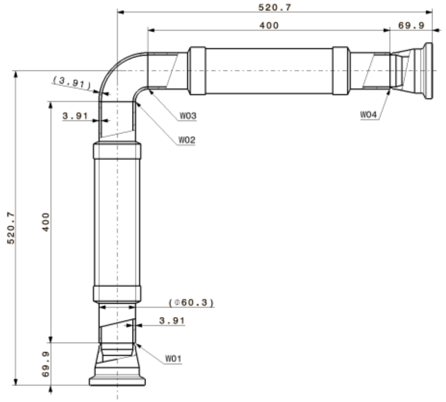
The Dog Leg can be an good solution for a piping system whenever vibration are present. The assembly combines flexibility and allows the assembly to go a combination of up, down, and side-to-side.

Dog-Leg design instead single flexible with single bend.



Dog-leg benefits:

- Bigger Flexibility in multiple directions
- Longer lasting service life especially in vibration present environment
- Less connections = More reliability



Dog-Leg drawing example.

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Number of Components

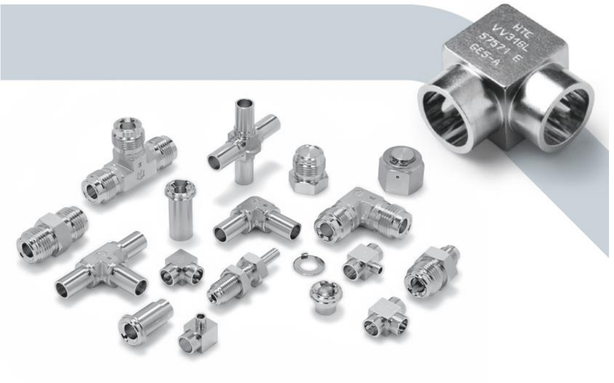
		DEMO Plant Design 3H	Final 3H System	Result
WELDS	2" tube Welds	21	34	60% Increase: +25h of Welding
	1 ½" tube Welds	187	116	40% Reduction: -90h of Welding
	1 ¼" tube Welds	30	23	23% Reduction
	≤25,4mm tube Welds	501	417	17% Reduction
	Other welds (pickage, valves welding)	62	42	33% Reduction
FLANGES	2" flanges	3	3	No change
	1 ½ " flanges	81	9	88% Reduction
	1 " flanges	0	3	Newly implemented
WEIGHT & DIMENSIONS	Total Weight	6500 kg	5870	10% Reduction
	Weight without the driveunit and pump motor	4200 kg	3571	15% Reduction
	Width	2409 mm	2409 mm	No change needed
	Depth	1590 mm	1450 mm	Target value achieved
	Height	3332 mm	3086 mm	
COMPONENTS	Manual valves	28	8	64% Reduction
	Control valves	19	13	30% Reduction
	PT	25	16	35% Reduction
	TT	28	33 (12 for pump)	10% Increase
	Dampers	3	1	33% Reduction-1 damper for any plant size

Pipe Size	Dimensions (OD x t in mm)	Piping according to standard	Connections
1/4"	6.35mm x 0.889mm	ASTM A213 / A269	Face seal fittings (VCR)
3/8"	9.65 mm x 0.889mm	ASTM A213 / A269	Face seal fittings (VCR) and tube fittings
1/2"	12.7mm x 1.24mm	ASTM A213 / A269	Face seal fittings (VCR)
3/4"	19.05mm x 1.24mm	ASTM A213 / A269	Face seal fittings (VCR)
1"	25.4mm x 2.11mm	ASTM A213 / A269	Face seal fittings (VCR)
DN20	26.7mm x 2.87mm	ASME B16.9	Face seal fittings (VCR) or DN25 Clamp Connectors TP
DN25	33.4mm x 3.38mm	ASME B16.9	Face seal fittings (VCR) or DN25 Clamp Connectors TP
DN40 Sc40S	48.3mm x 3.68mm	ASME B16.9	Clamp Connectors and Compact Flanges from TP
DN50 Sc40S	60.3mm x 3.91mm	ASME B16.9	Clamp Connectors and Compact Flanges from TP

The Pressure Equipment Directive (PED) applies to our design

Components for 2PACL plant

- Ham-Let fittings



HAM-LET Group

Swagelok equivalent
25% price difference between Swagelok
Fully compatible with Swagelok
Report available in EDMS: 2873526

- Swagelok small ball valves

Well known = Tested
Reliable

- TPC for flanges

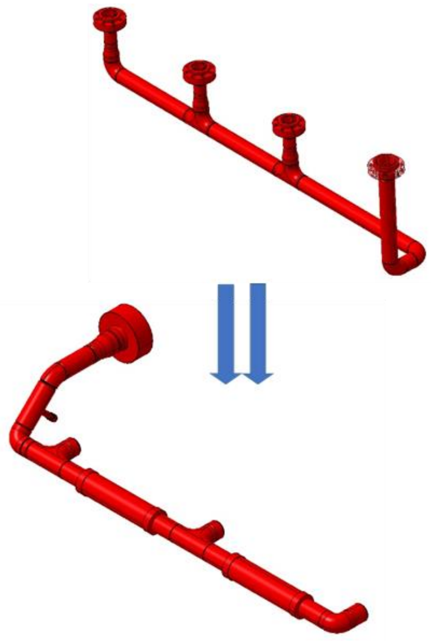
Freudenberg equivalent
40% of the price difference
Fully compatible with Freudenberg

- Habonim valves

Reliable solution
Report available in EDMS: 2874223

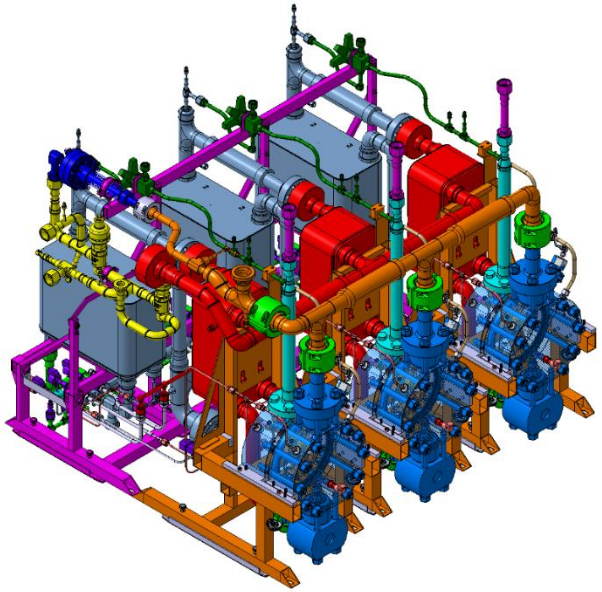
Lesson learnt from DEMO

- New manifold concept



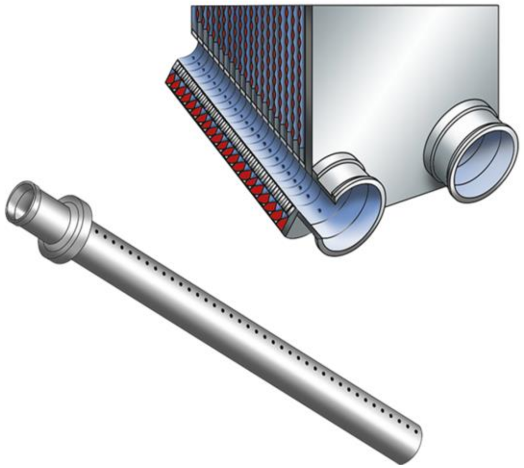
- More equal flow distribution with horizontal inlets

- Alignment + flexibility



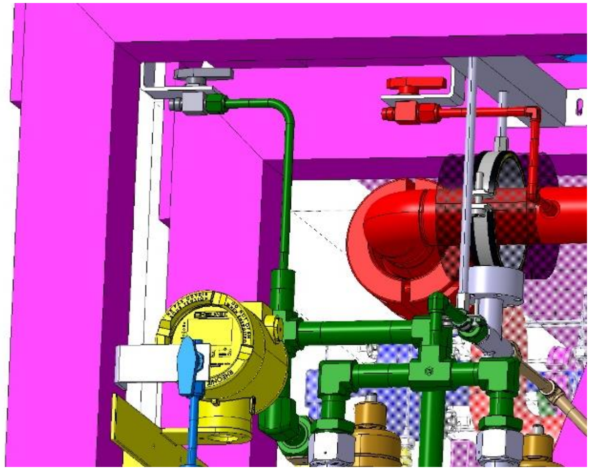
- Flexible hoses present in the manifold
- Flexible hoses present on the contact point of two halves
- Height adjustment on the Piping frames

- New HX concept Q pipe



- New HX concept with Q pipe for evaporator only

- Components supports



- Each valve/ sensors has additional support as it was after vibration measurements done by EN-MME

Thank you !

BACK-UP Slides

Accumulator design overview

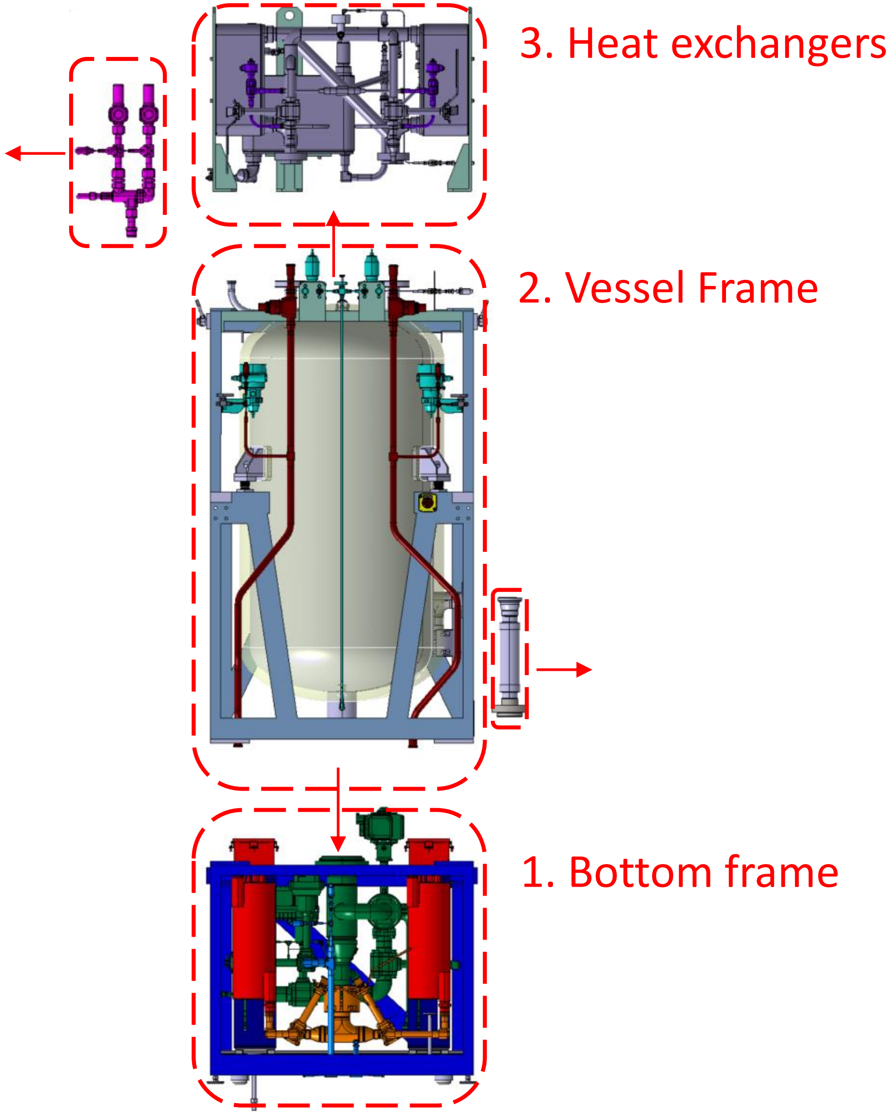
Modular design for assembly/ transport in the caverns

1. Bottom frame
2. Vessel frame
3. Heat exchangers

This modular design allows to transport either :

- 1+2+3
- 1+2
- 2+3

Depending on the transport scenario of ATLAS & CMS



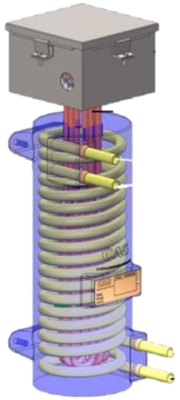
Accumulator design: Heating

Heaters, lessons learned from DEMO :

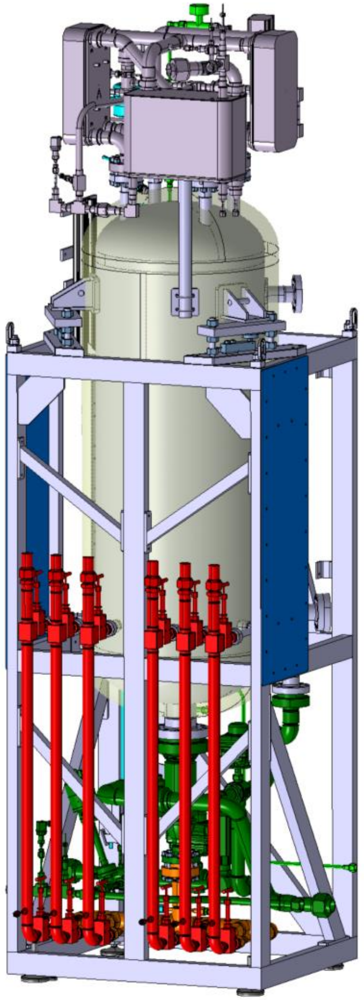
- Cartridge heaters have been discarded for safety concerns
- Cartridge heater is not efficient, heat flux density is too large : Heater dries-out

Final design:

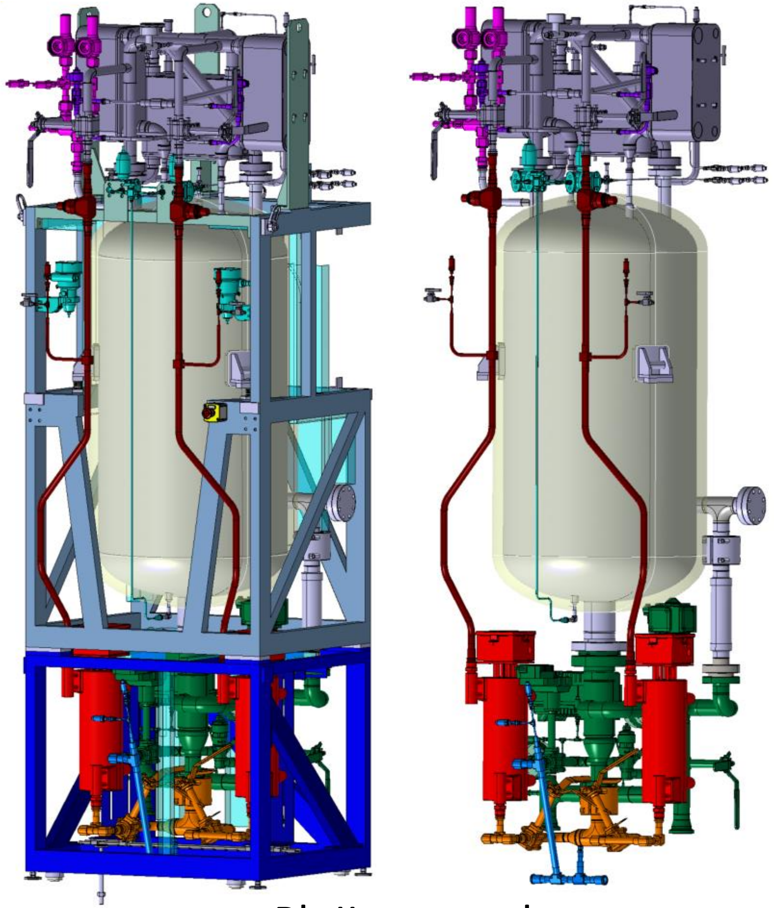
- Cast aluminium heater (x2) (25kW & 17,1kW)
- Standard component
- Can be maintained/ replaced during operation
- Redundant



Cast X heater with dual flow tubes

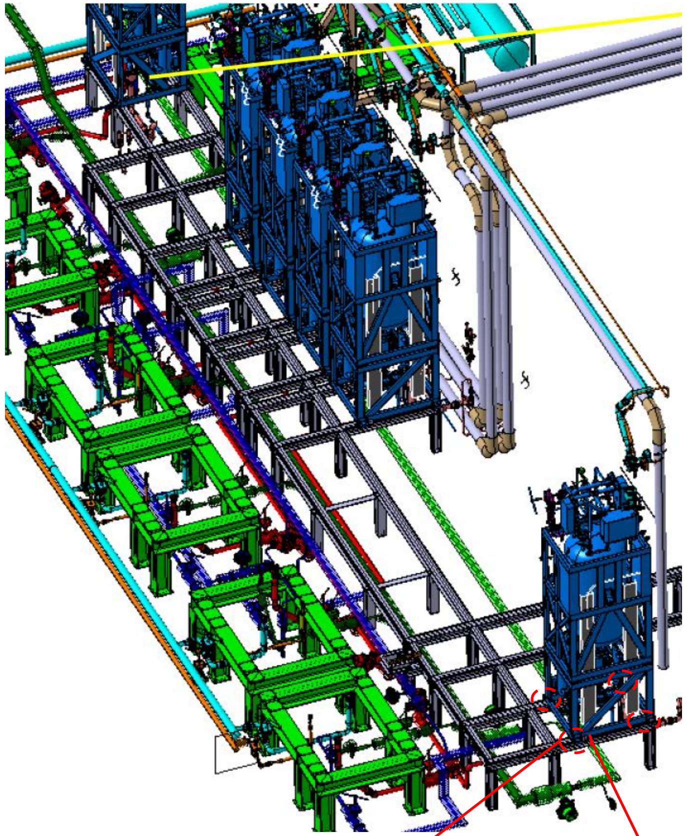


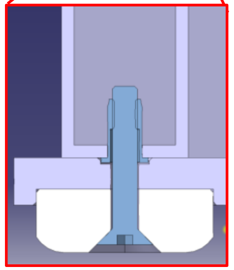
Demo accumulator
6x immersion heater



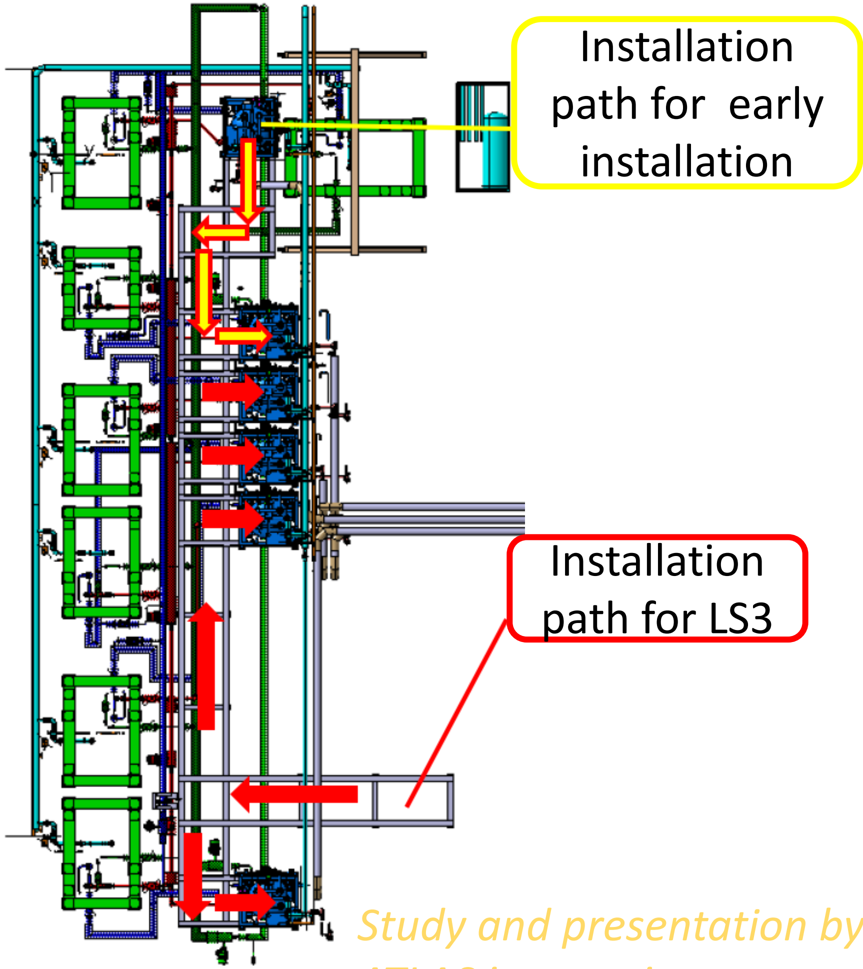
Ph II accumulator
2x Cast heaters

Accumulator design installation

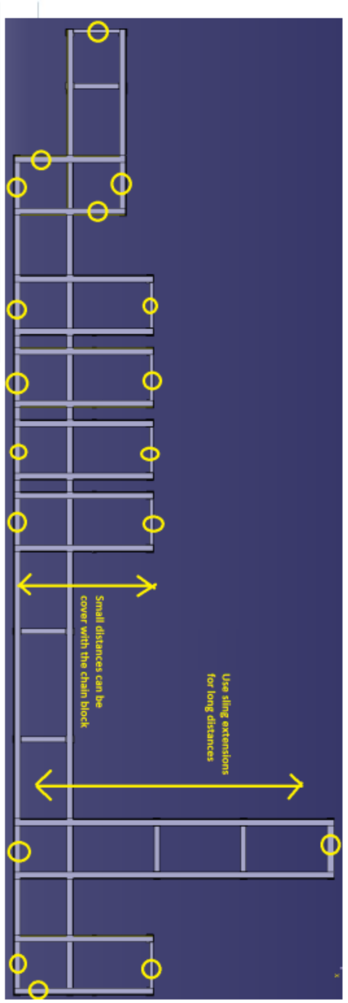




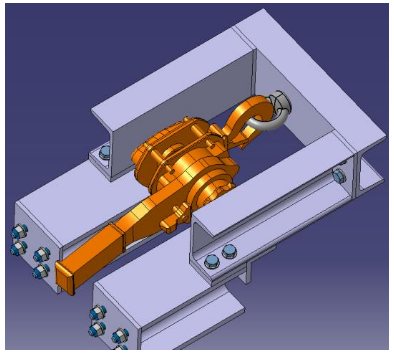
Study/ test made by ATLAS integration TEAM
EDMS : 2796144



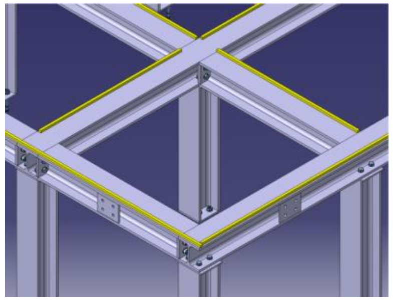
Study and presentation by ATLAS integration team



Pulling mechanism

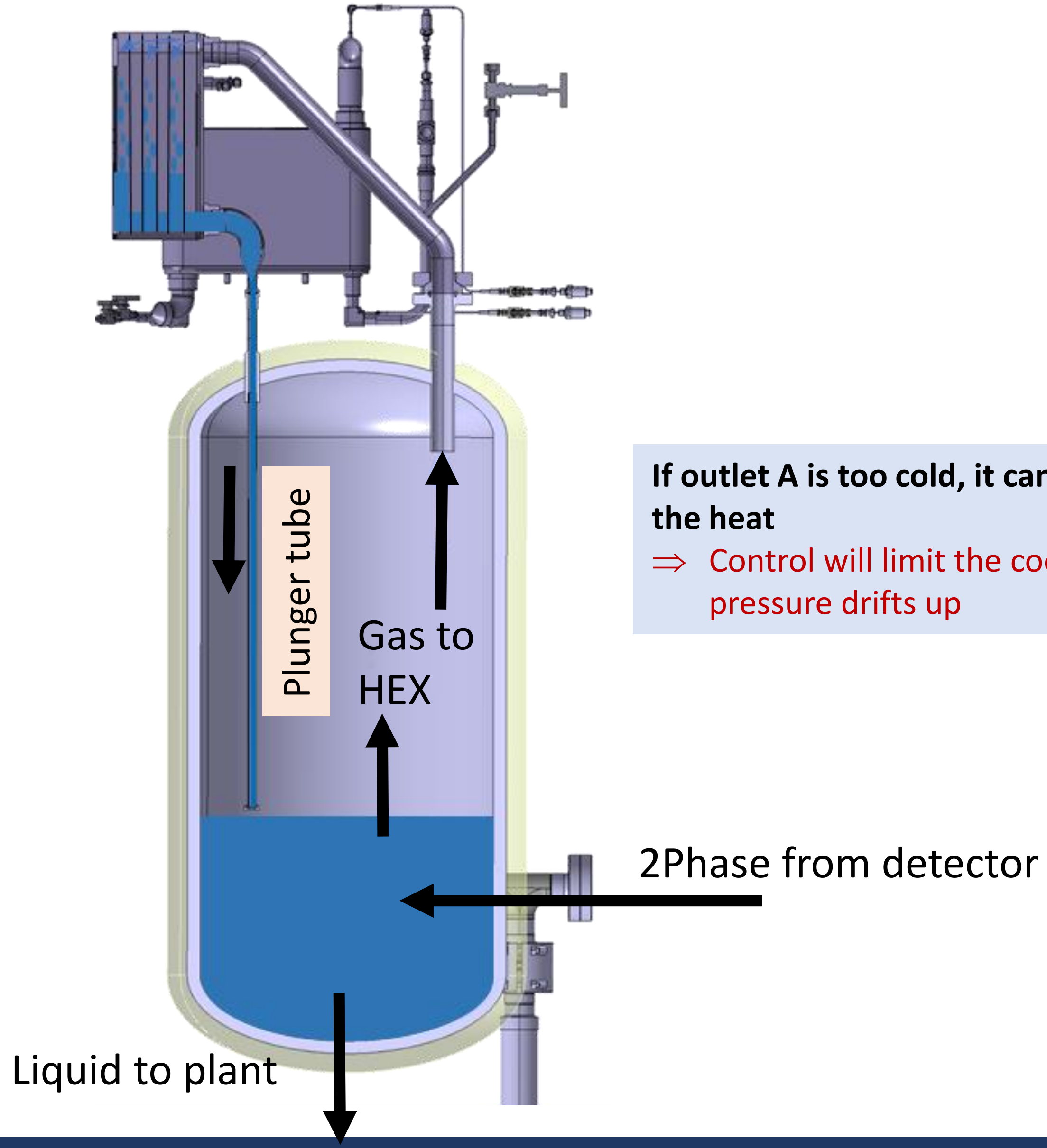


Guiding mechanism



Accumulator condenser

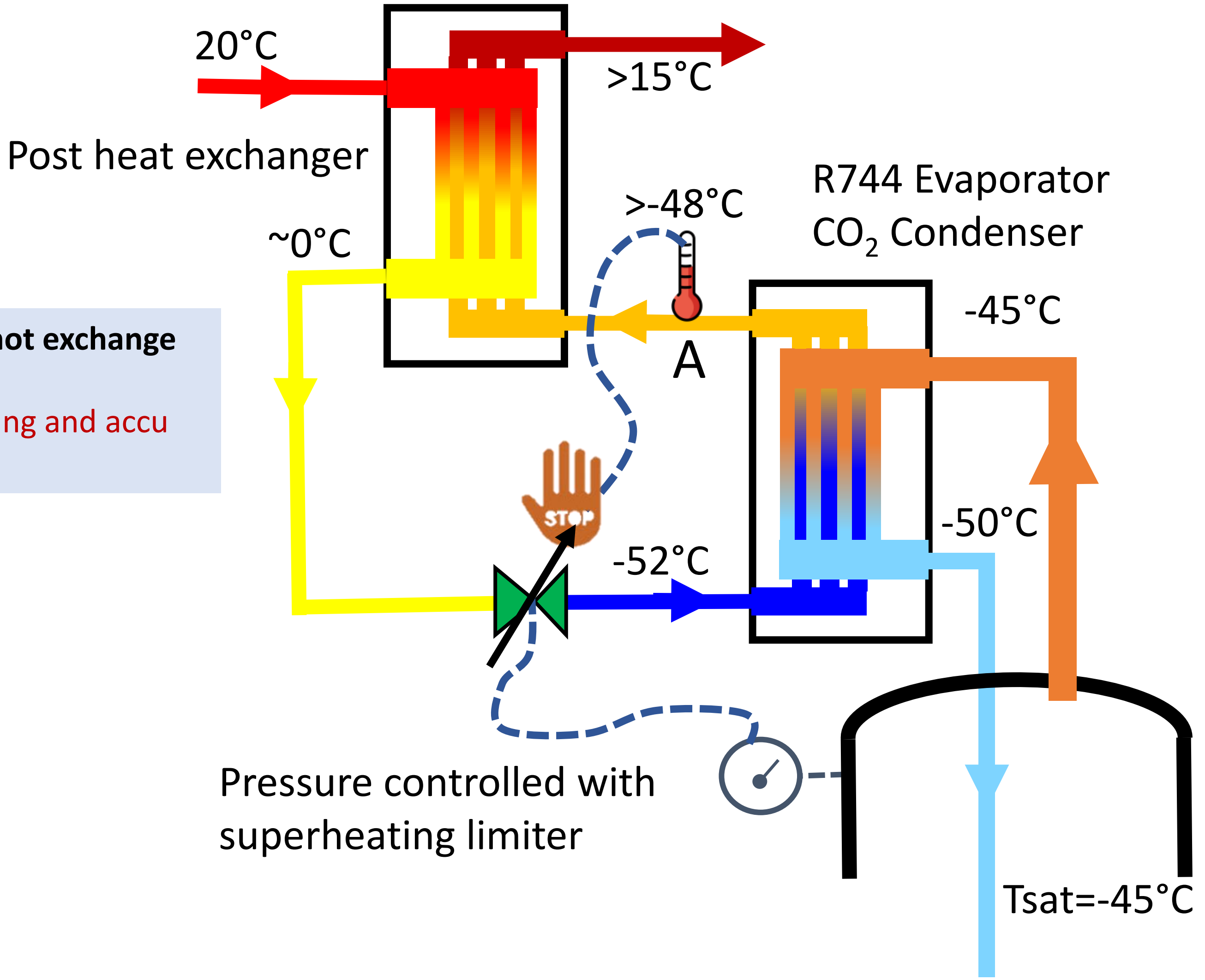
EP-DT
Detector Technologies



If outlet A is too cold, it can not exchange the heat

⇒ Control will limit the cooling and accu pressure drifts up

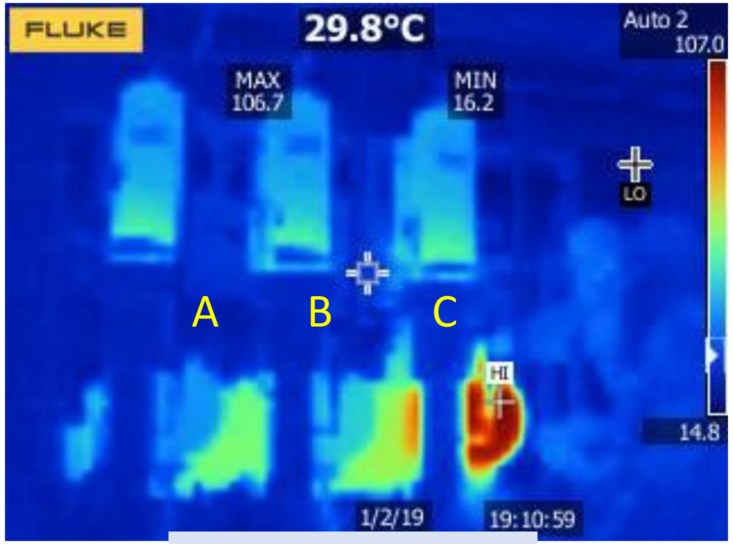
By Bart Verlaat



LEWA membrane pump development

Frequency deviation detected, now our signal of a pump head loss

- The long term running (and long term stop) has learned us important lessons for the pump.
- Some issues have come up which have led to a much better design
  - A new membrane and diffuser concept to eliminate goosebumps
  - A better hydraulic oil monitoring
    - Level switch and temperature sensor
  - Frequency deviation indicating a loss of a pump head



Over heated pump module due to a rare mechanical failure

Open goose bumps after a long standstill

Only small goose bumps after a long standstill test

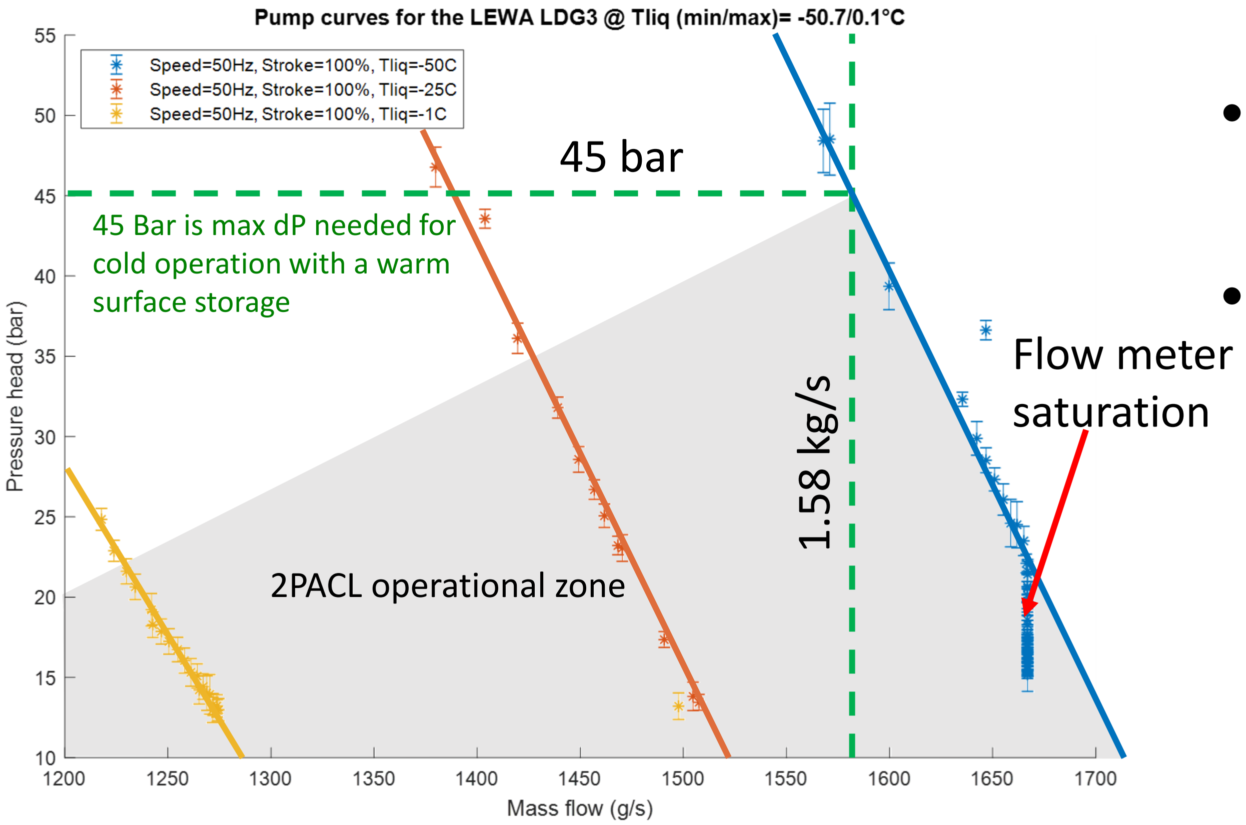
"Goose bumps holes caused big CO_2 vent in April

Pump performance tests

EP-DT
Detector Technologies

	Flow rate		By-pass flow	Available flow	Available flow	Max power	Nominal power	Max power	Nominal power
Pump configuration	100% stroke	70% stroke		100% stroke	70% stroke	-35 °C, 33 % VQ		-35 °C, 42 % VQ	
	[kg/s]		%	[kg/s]		[kW]		[kW]	
3 heads	1.58	1.11	10%	1.42	1.00	147	103	187	131
2 heads	1.05	0.74	10%	0.95	0.66	98	69	125	87
1 head	0.53	0.37	10%	0.47	0.33	49	34	62	44

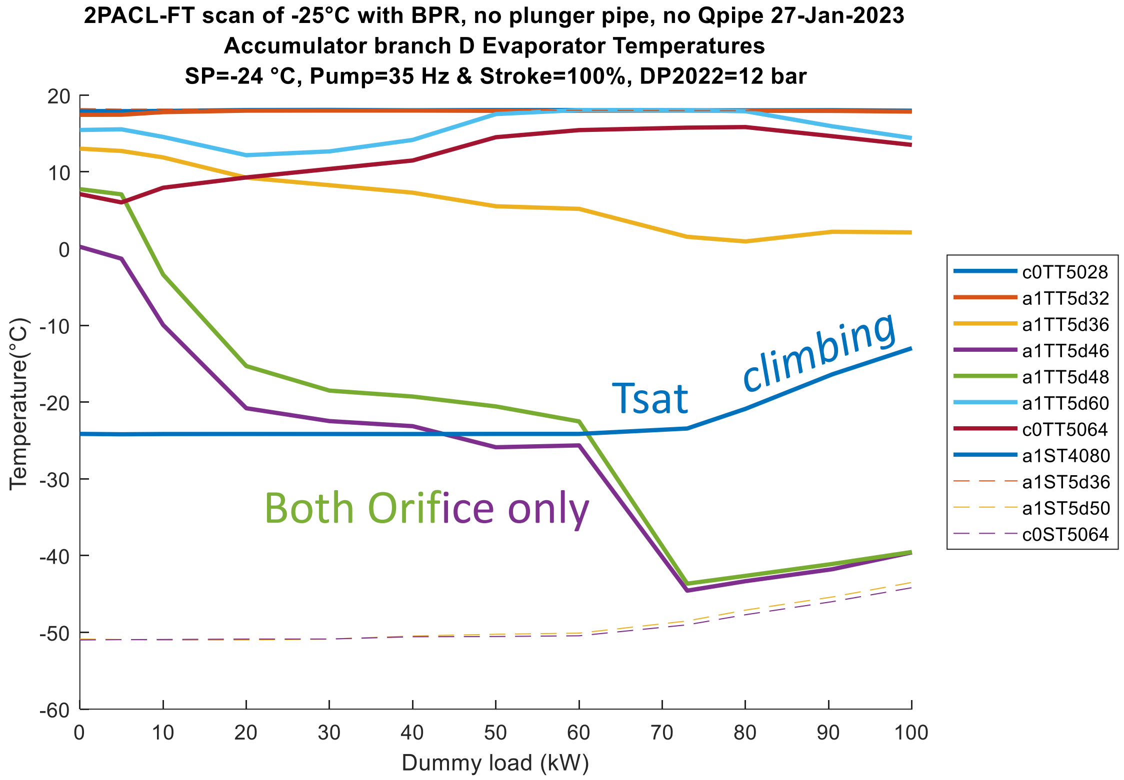
Numbers to be compared against



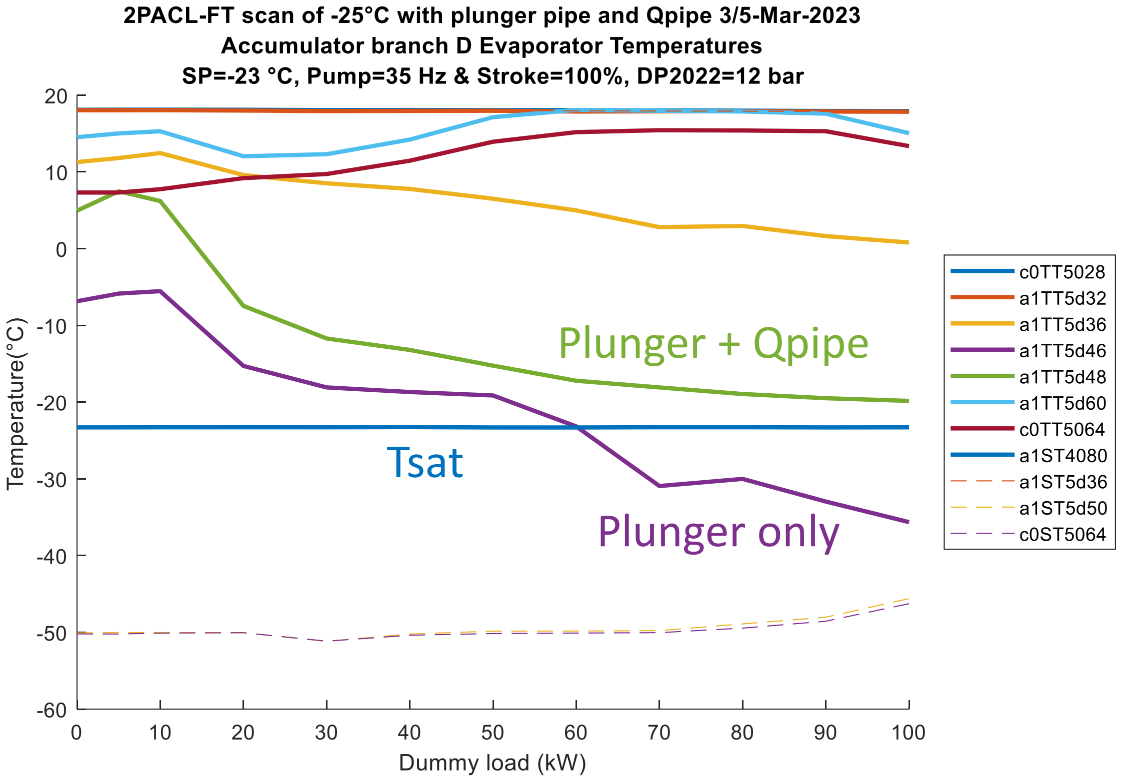
- The pump is performing well and meet the design specs
- 30% is reserved for occasional surface storage pumping, it was believed to achieve that by a reduced stroke. For better controllability, the baseline is reversed
  - We run full stroke and adjust the speed

Plunger pipe and Q-pipe improvement

Before plunger and Q-pipe installation

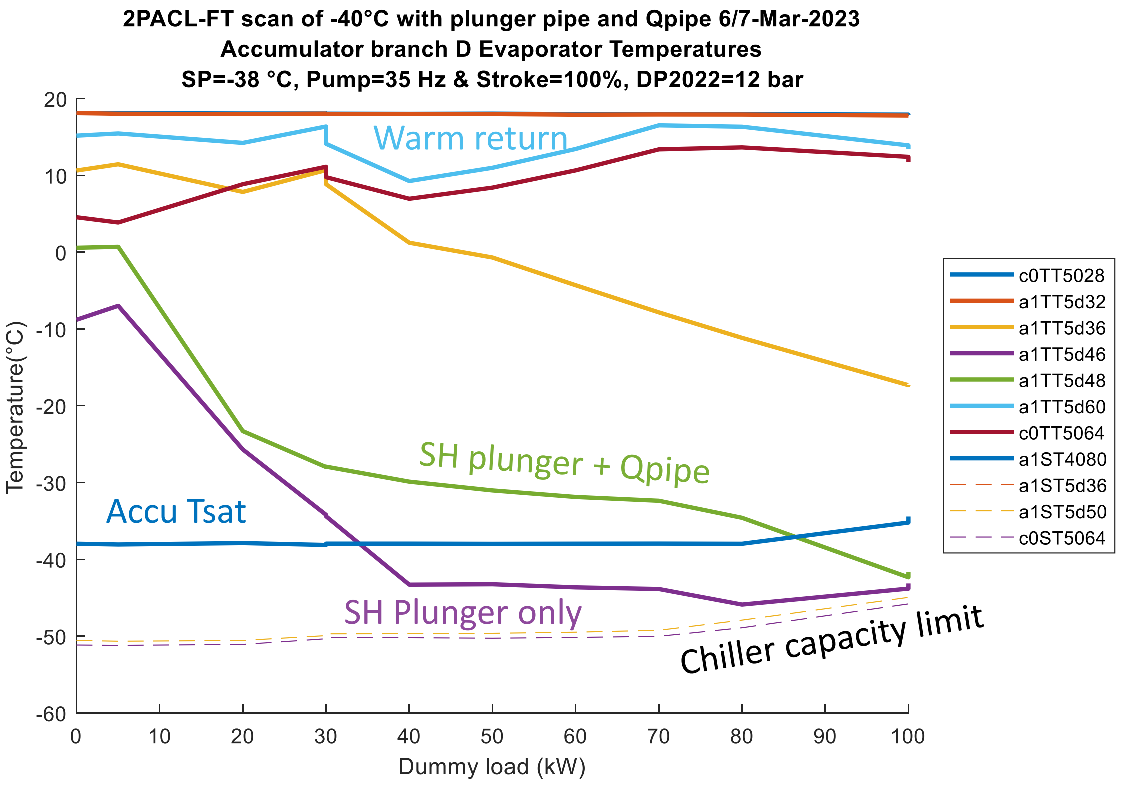


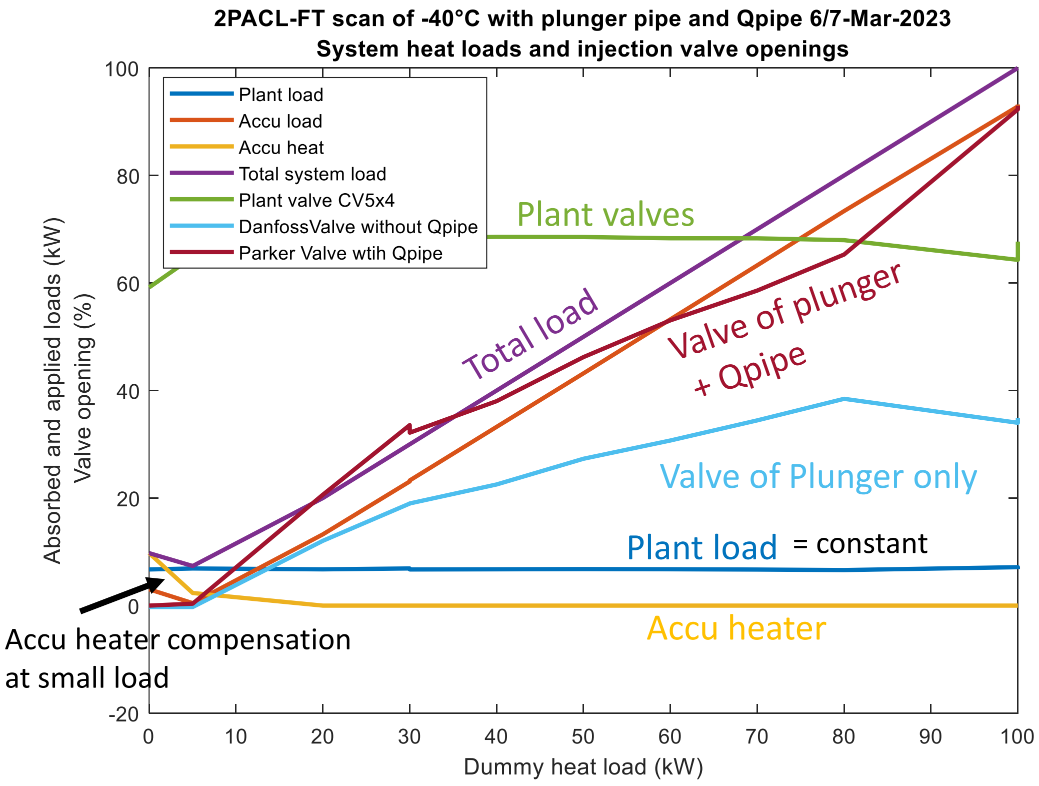
After plunger and Q-pipe installation



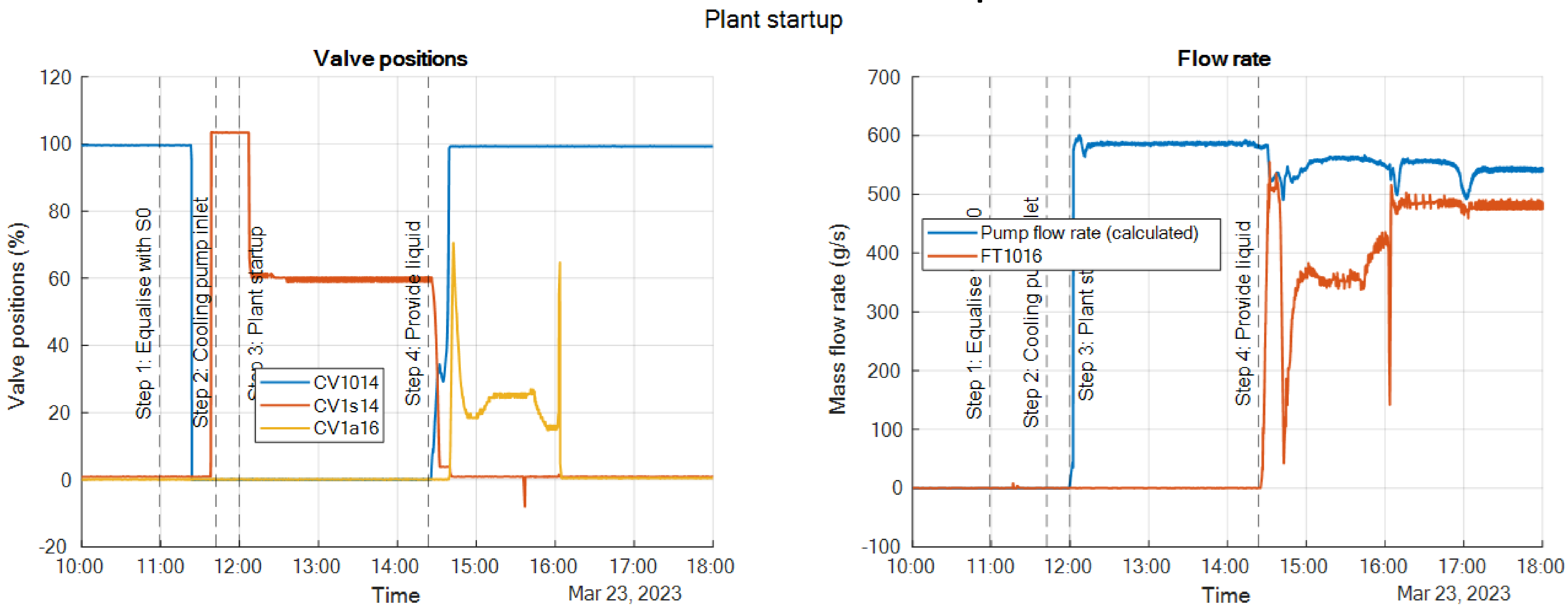
2PACL-FT @ -40°C & liquid dT=5°C

- The 2PACL Flow-Through concept is demonstrated to work down to -40°C at 50kW load on the plunger + Qpipe concept



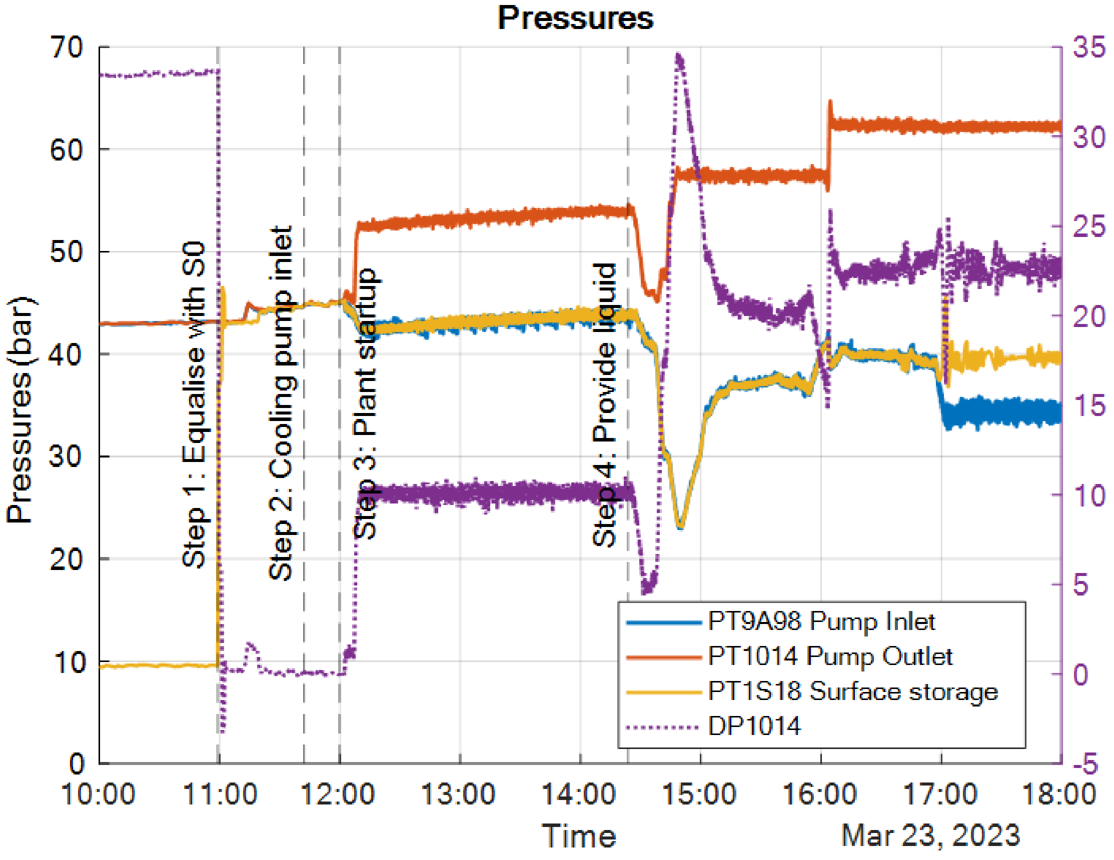


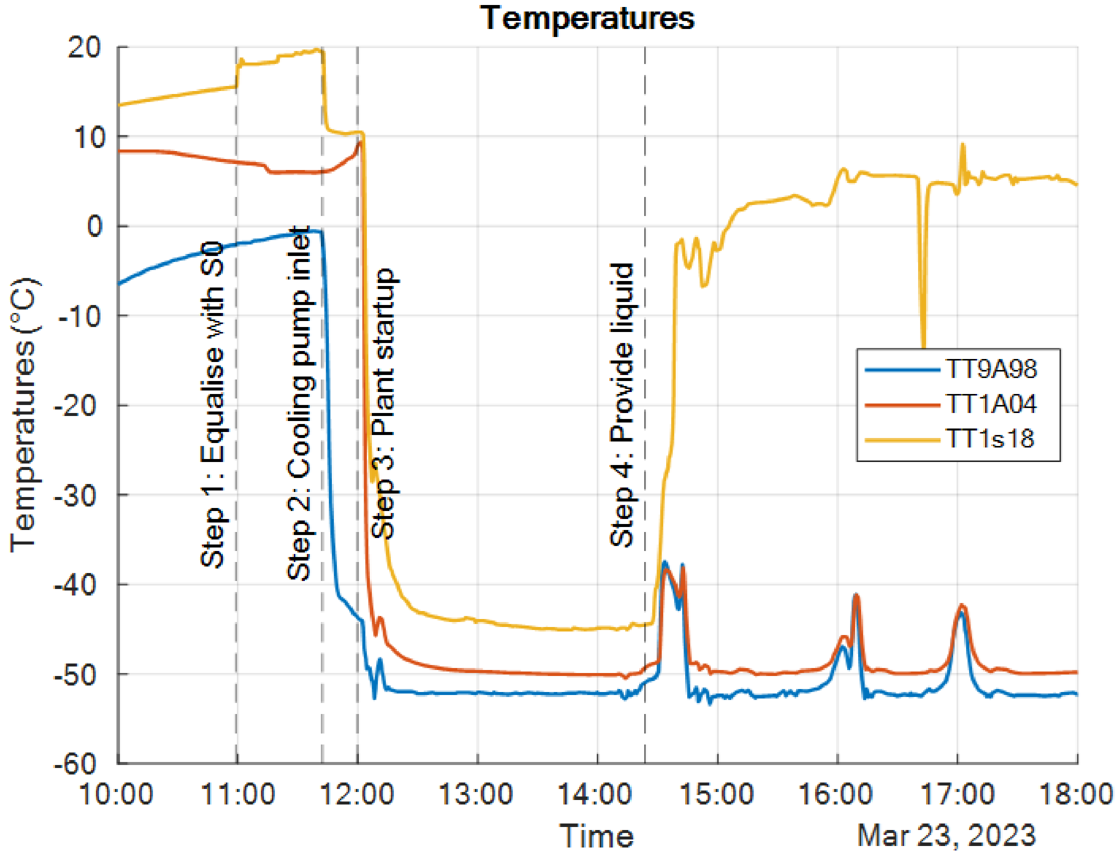
Plant start-up



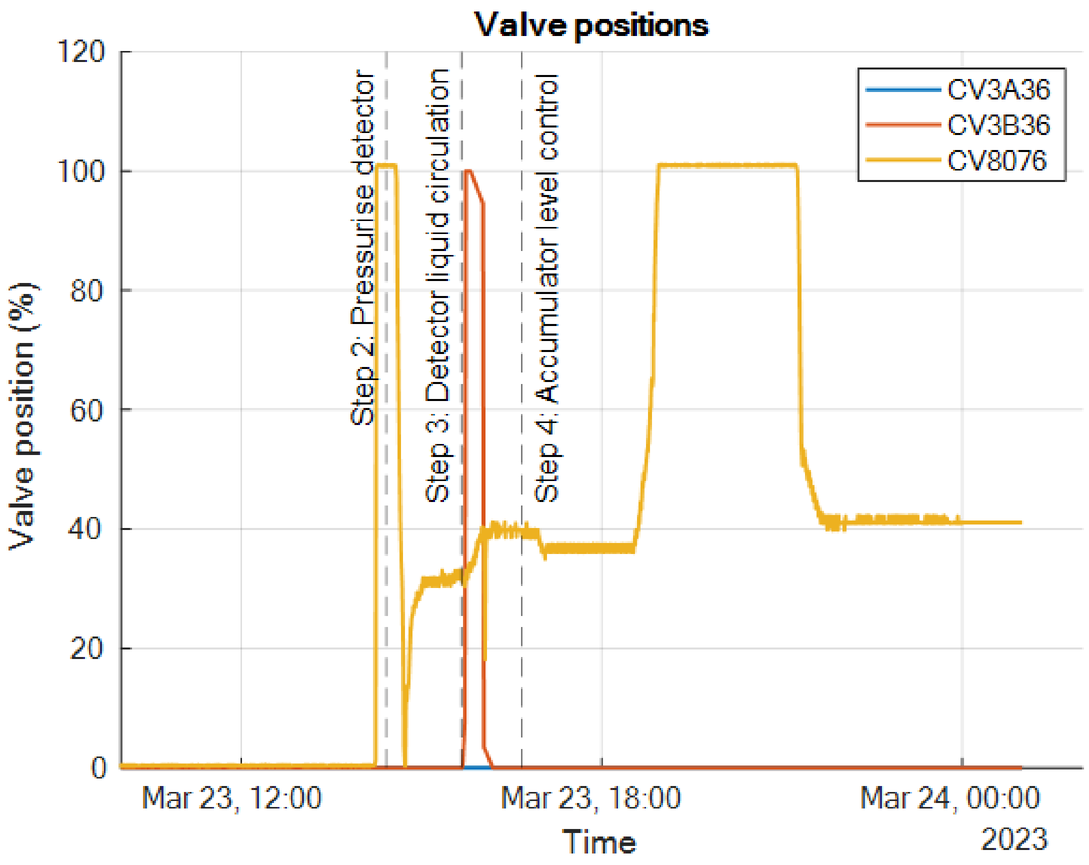
EP-DT
Detector Technologies

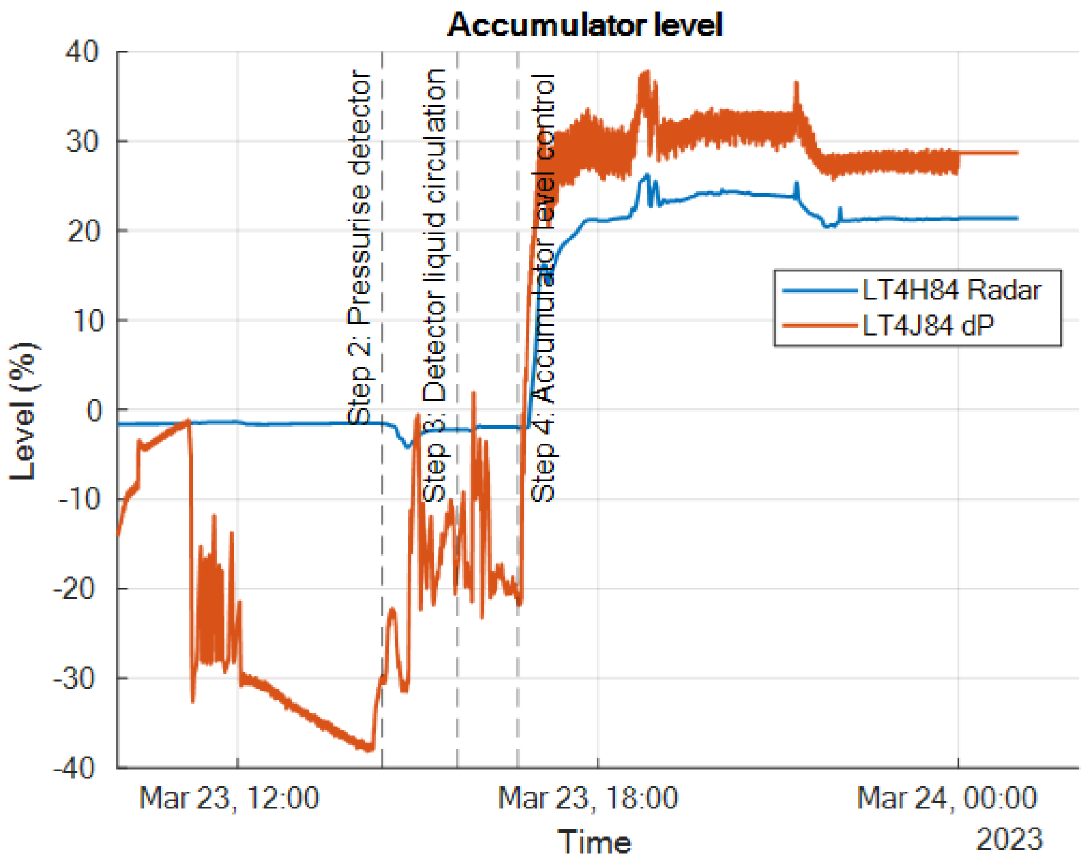
Plant start-up

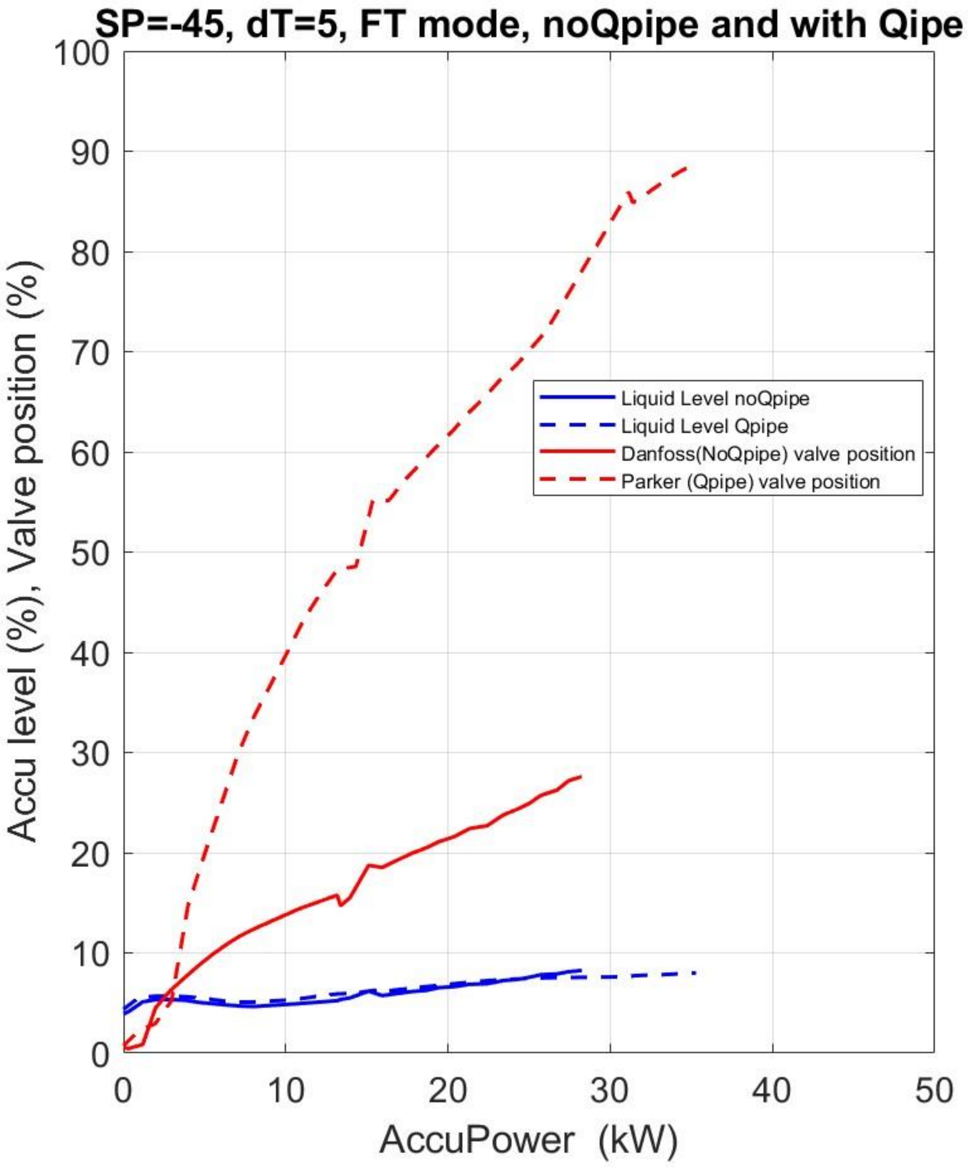


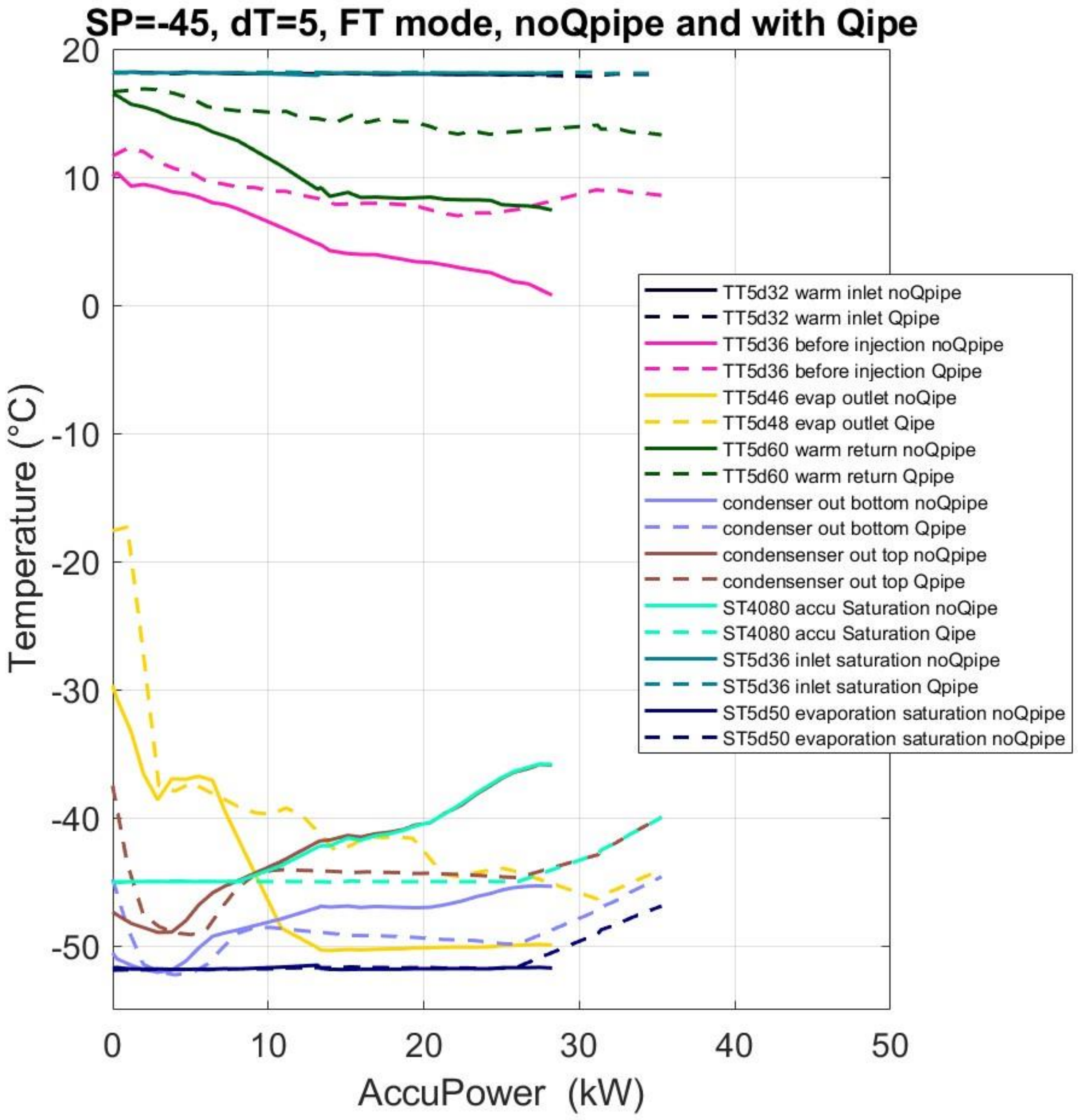


Accumulator start-up





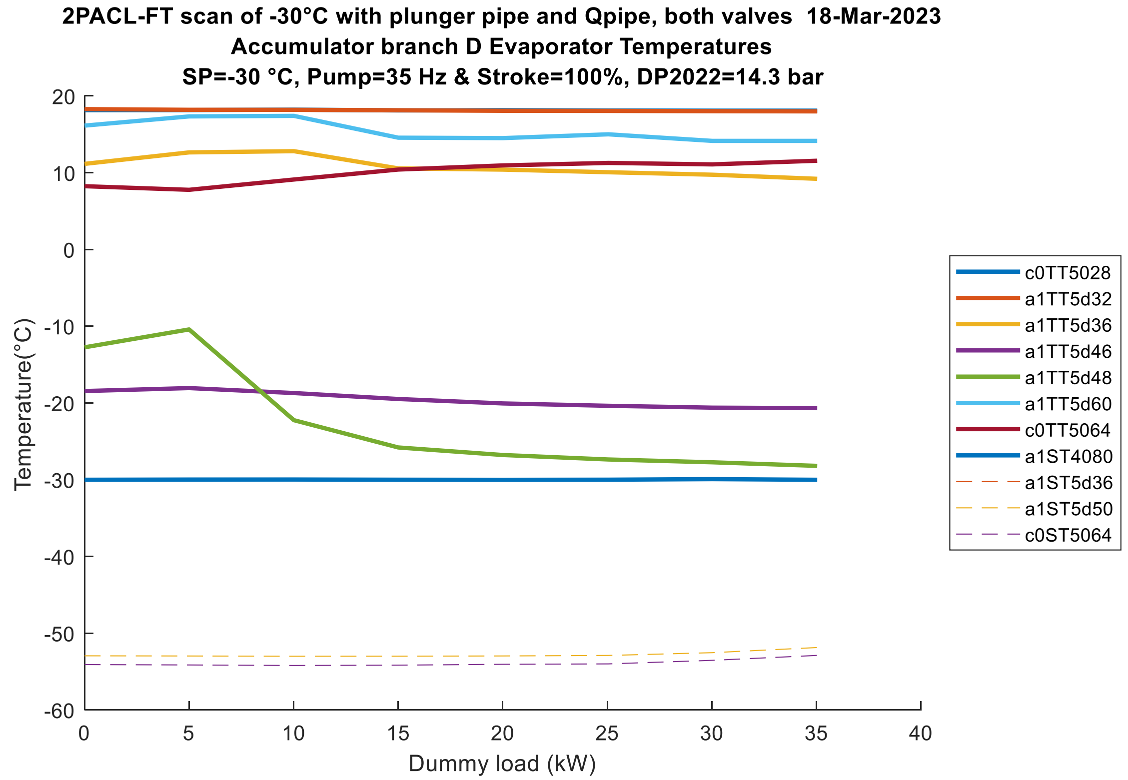

SP=-45, dT=5, FT mode, noQpipe and with Qipe
Accu level (%), Valve position (%)
AccuPower (kW)
Liquid Level noQpipe
Liquid Level Qpipe
Danfoss(NoQpipe) valve position
Parker (Qpipe) valve position
0
10
20
30
40
50
60
70
80
90
100
0
10
20
30
40
50

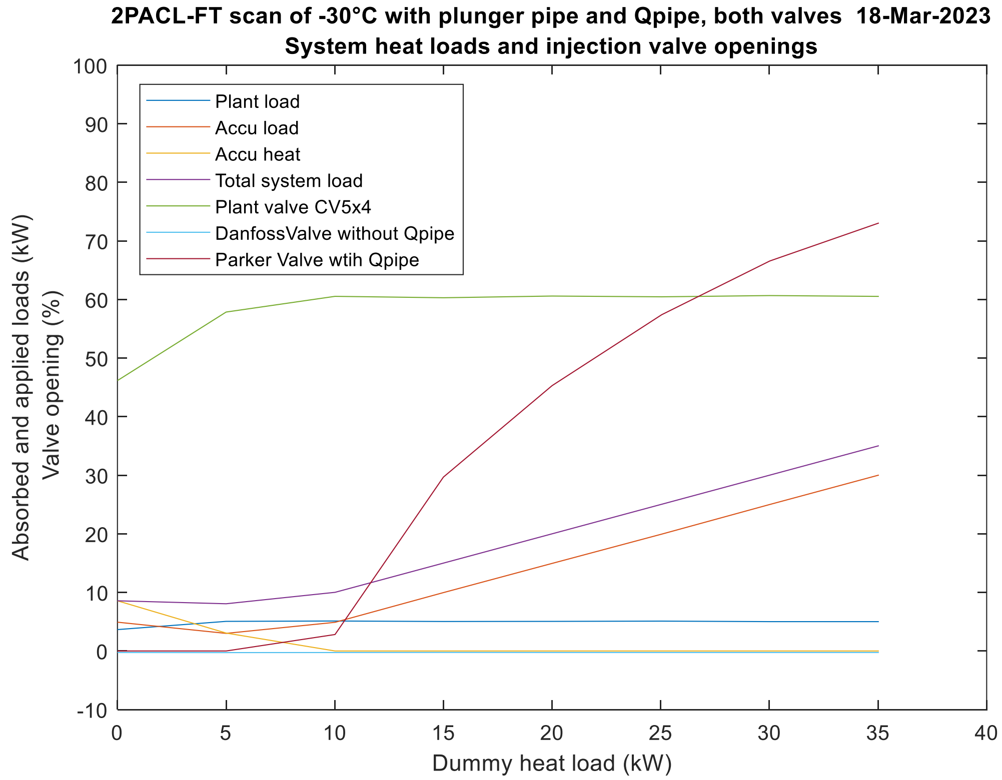

SP=-45, dT=5, FT mode, noQpipe and with Qipe
Temperature (°C)
AccuPower (kW)
TT5d32 warm inlet noQpipe
TT5d32 warm inlet Qpipe
TT5d36 before injection noQpipe
TT5d36 before injection Qpipe
TT5d46 evap outlet noQipe
TT5d48 evap outlet Qipe
TT5d60 warm return noQpipe
TT5d60 warm return Qpipe
condenser out bottom noQpipe
condenser out bottom Qpipe
condensenser out top noQpipe
condensenser out top Qpipe
ST4080 accu Saturation noQipe
ST4080 accu Saturation Qipe
ST5d36 inlet saturation noQpipe
ST5d36 inlet saturation Qpipe
ST5d50 evaporation saturation noQpipe
ST5d50 evaporation saturation noQpipe
20
10
0
-10
-20
-30
-40
-50
0
10
20
30
40
50

2PACL-FT @ -30°C & liquid dT=5°C

Accu condenser configuration:

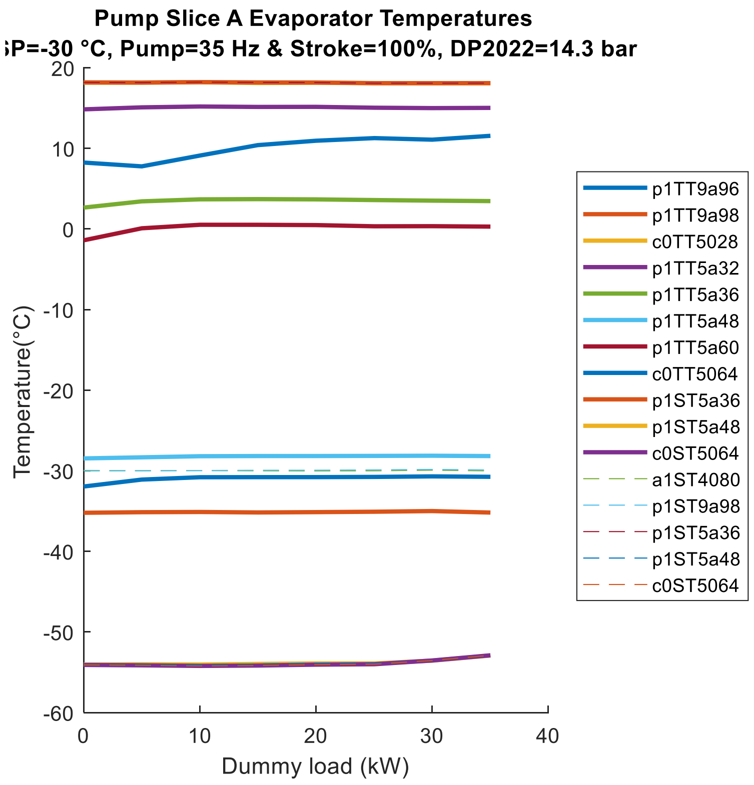
- ~~Danfoss valve CV5D40 with plunger~~ Switched off
- Parker Valve CV5D42 with Q-Pipe and plunger

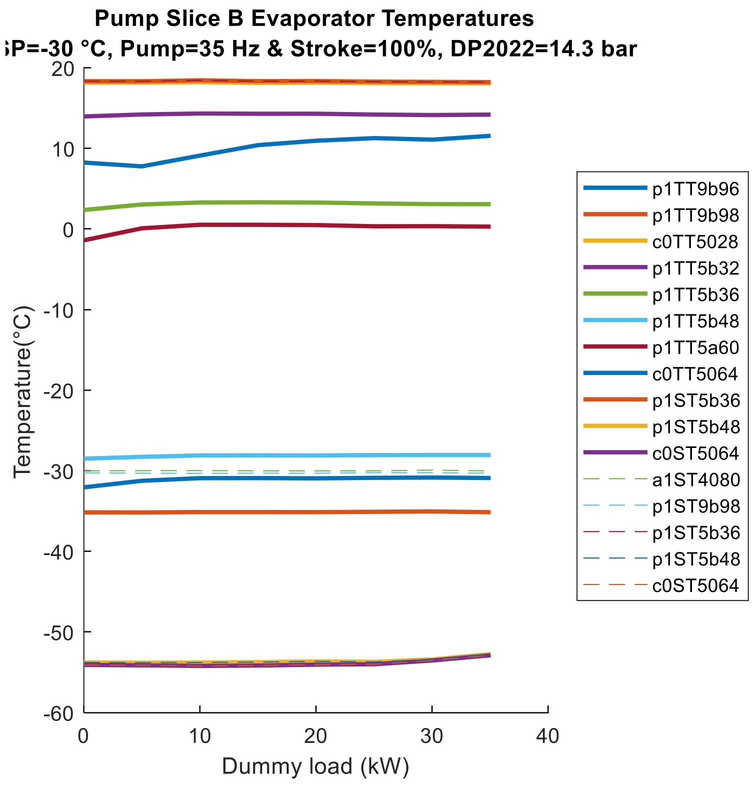


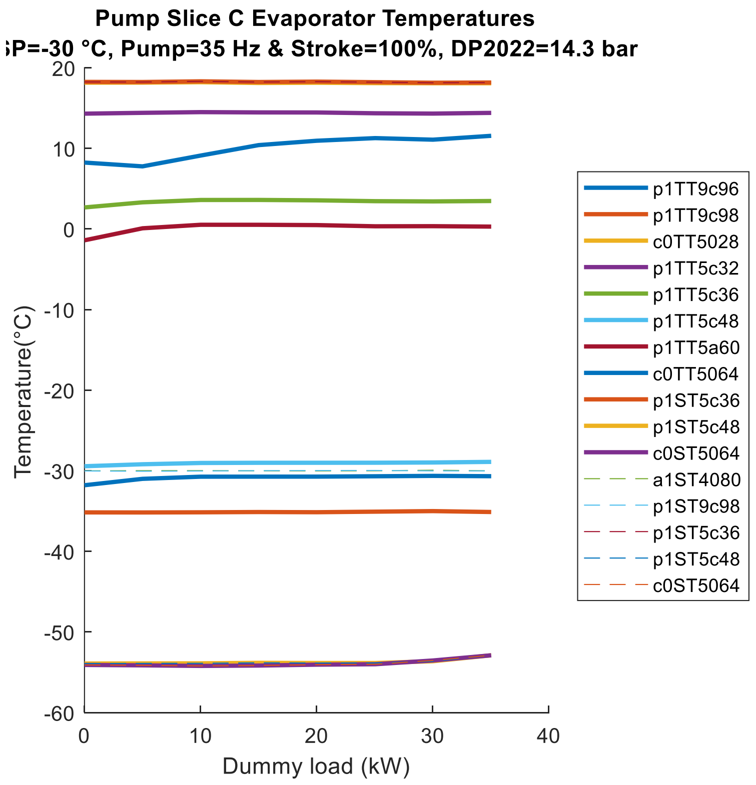


2PACL-FT @ -30°C & liquid dT=5°C

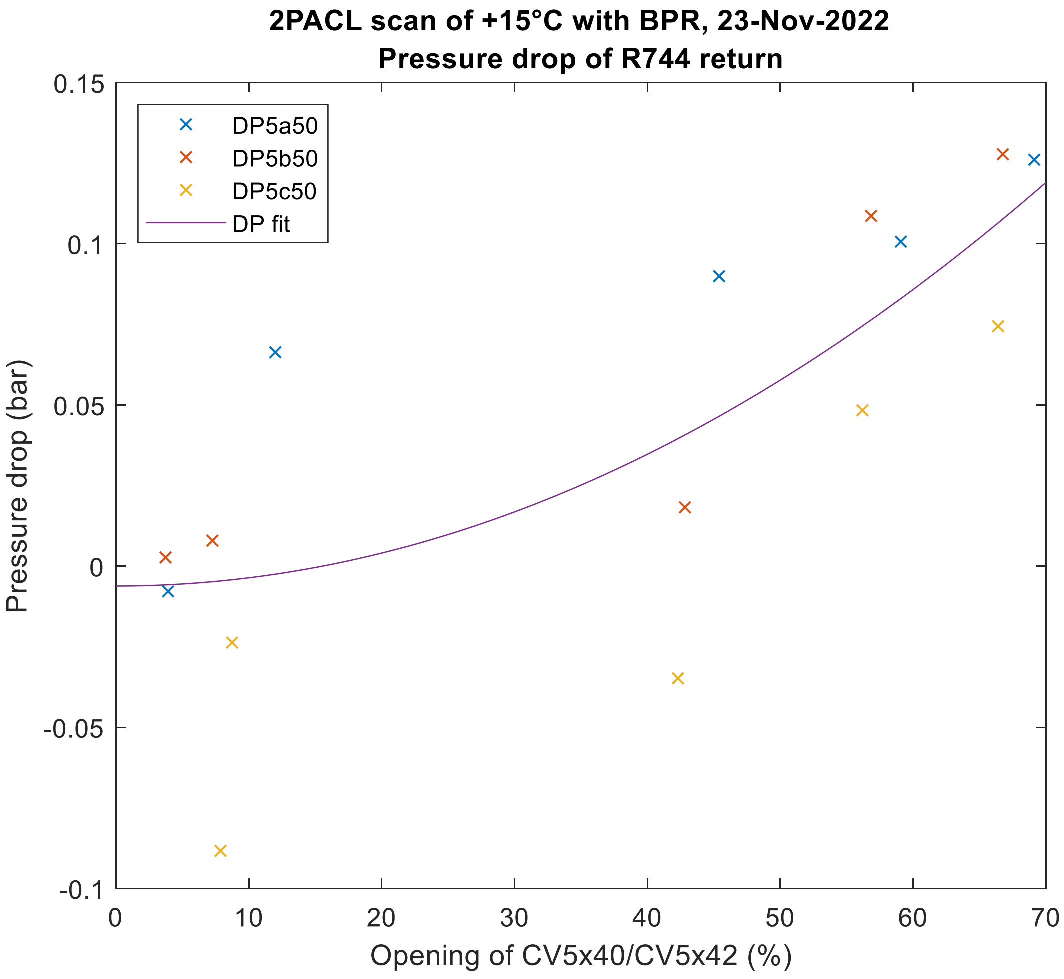
Plant pump slice performance

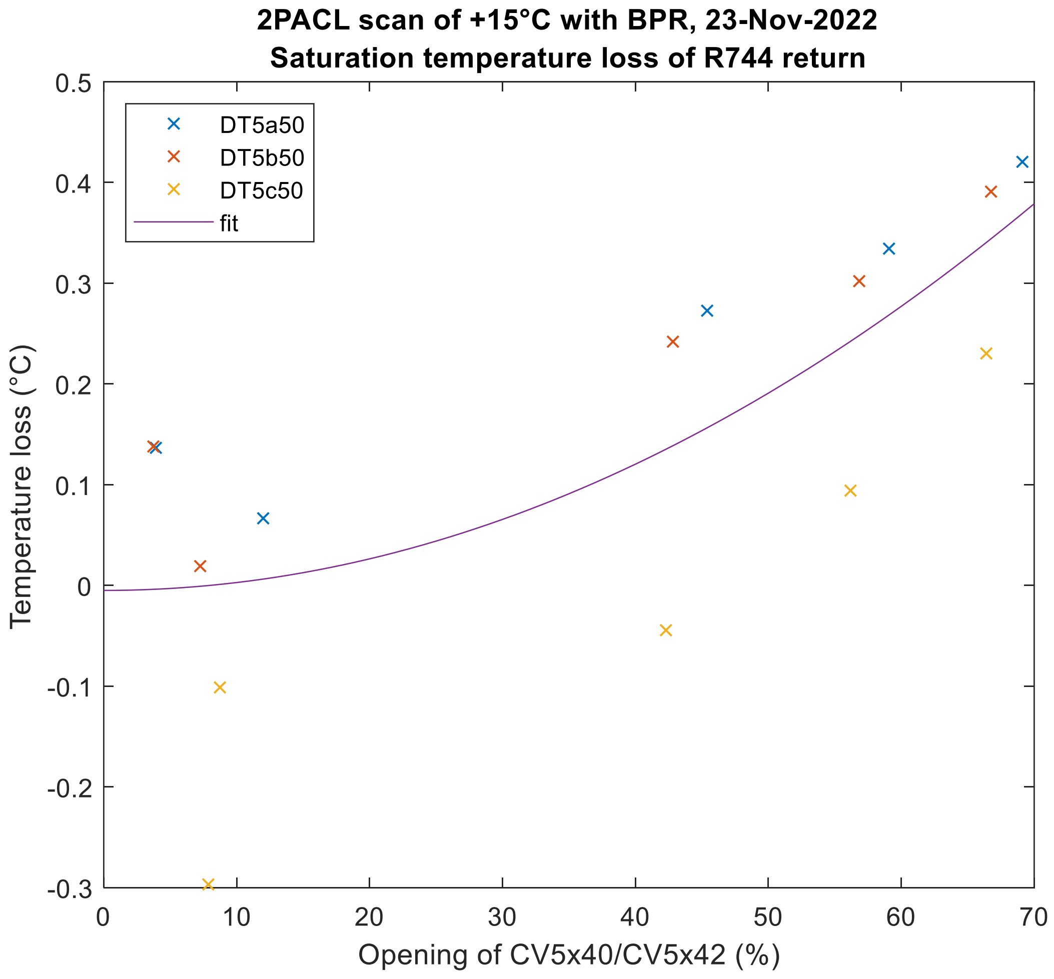






Traditional 2PACL @ 15°C

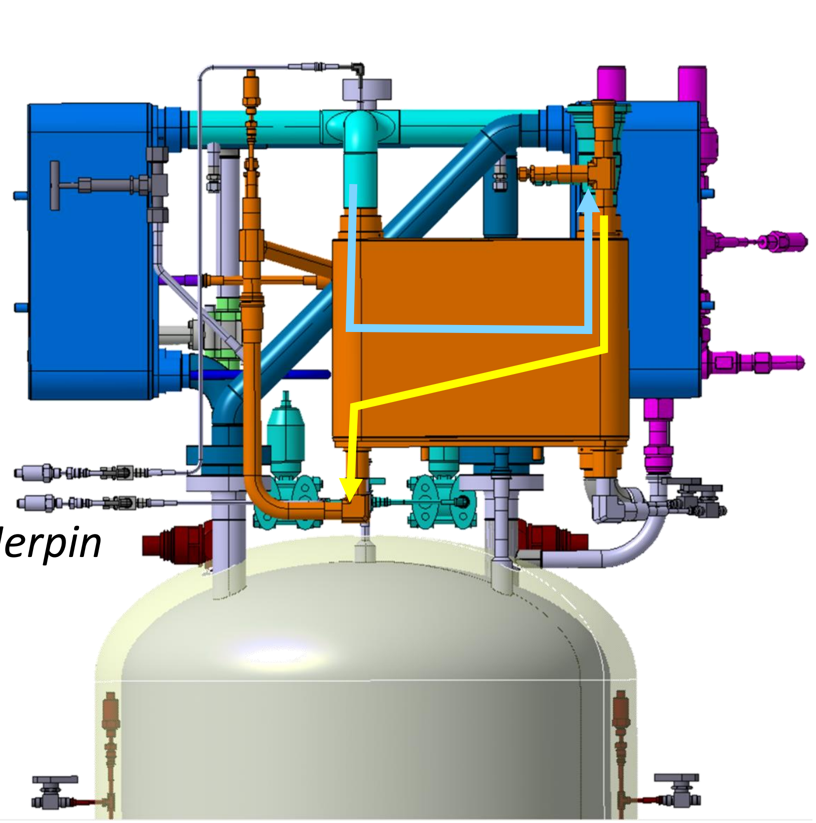




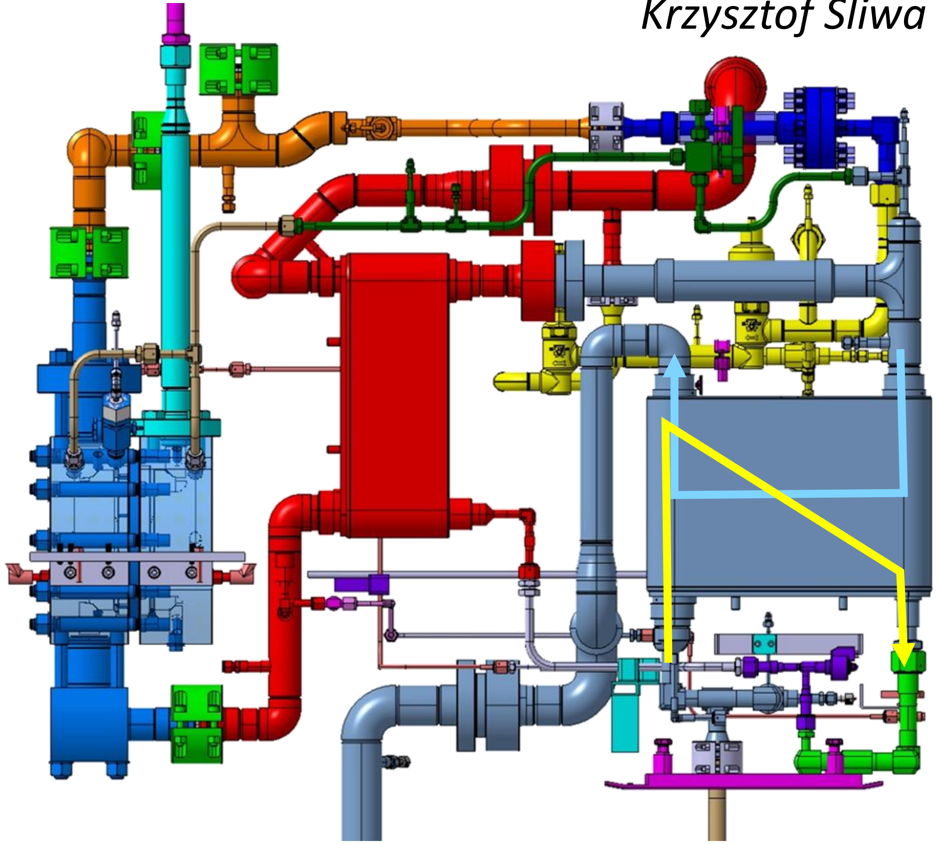
Post heat exchanger performance

We need to send back warm gas to the surface R744 chillers (Not insulated)

Krzysztof Sliwa



Yann Herpin

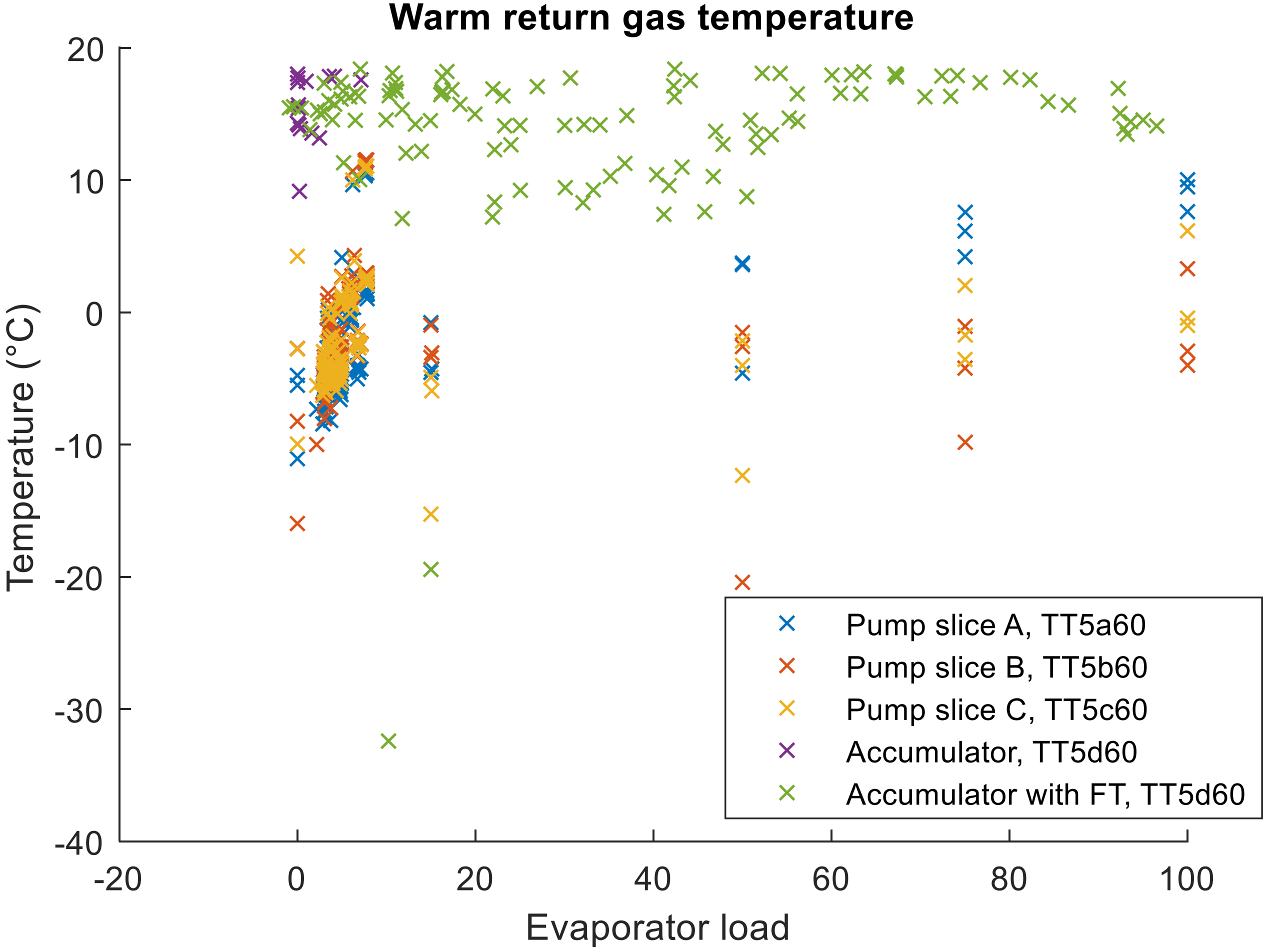


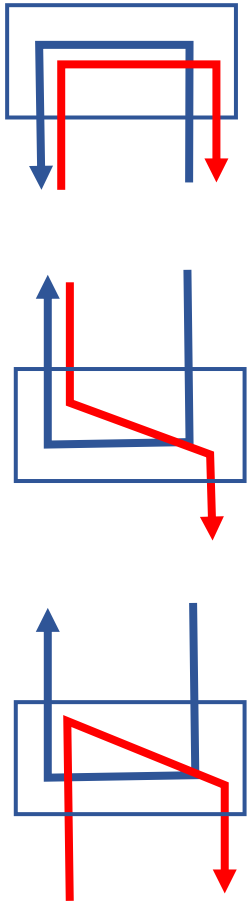
Proven and tested post heat exchanger in the DEMO accumulator

Adapted post heat exchanger in the final plant

EP-DT
Detector Technologies

Post heat exchanger performance





DEMO post hex orientation

Bad exchange due to gravity effects

Accu post hex orientation

Good exchange due to gravity effects

(And works a phase separator incase of liquid)

Final plant post hex orientation

Accu flow concept simulated with internal riser

This graph shows all tests we have done including different tunings. The lowest temperatures shown are from tests with non optimal tuning parameters

Piping and fittings standards

The cooling system piping and hydraulic components shall be selected for an operational pressure of 100 bar.
Depending on the type of components, different standards and pressure classifications are applied

Component type	Pressure rating	Standard
Piping	Varies with pipe schedule	ASME 36.19
Flanges	Class 150, 300, 400, 600, 900, 1500, 2500	ASME B16.5
Socket weld fittings	Class 3000, 6000, 9000	ASME B16.11
Threaded fittings	Class 2000, 3000, 6000	ASME B16.11

Pipe pressure ratings according to ASME 36.19:

Nominal pipe size		**Sch. No**	**Nom. Wall thickness (mm)**	**SS 304L**		**SS 316L**	
				Max P (bar)		Max P (bar)	
DN	NPS			Piping	Elbow	Piping	Tee (EN 1.4547)
32	1 ¼”	10S	2.77	140	98	168	85
		40S	3.56	183	127	220	119
40	1 ½”	10S	2.77	122	86	146	69
		40S	3.68	164	116	197	102
		80S	5.08	233	152*	280	182*
50	2”	40S	3.91	138	101	166	81
		80S	5.54	201	140*	241	156*

Piping 1 ¼ “: Schedule 40S ; **Piping 1 ½”:** Schedule 40S ; **Piping 2”:** Schedule 40S

Additional requirements for piping:

- Compatibility with VCR connectors technology
- Material: 304L/316L
- Seamless piping
- Free of scratches, suitable for bending and flaring
- All butt-welded fittings must have the same thickness with the piping

More on information EDMS:2044083

Piping and fittings standards

FLANGES:

Pressure rating of flanges is given by ASME B16.5. Depending on the maximum pressure flanges can withstand under a certain temperature they are categorized in the pressure classes 150, 300, 400, 600, 900, 1500 and 2500. The pressure rating depends on the material used. Considering that 304L/316L is preferred, the pressure class of flanged is 900.

ASME B16.5-2003 PIPE FLANGES AND FLANGED FITTINGS

Table 2-2.3 Pressure–Temperature Ratings for Group 2.3 Materials

Nominal Designation	Forgings	Castings	Plates
16Cr–12Ni–2Mo	A 182 Gr. F316L		A 240 Gr. 316L
18Cr–8Ni	A 182 Gr. F304L (1)		A 240 Gr. 304L (1)

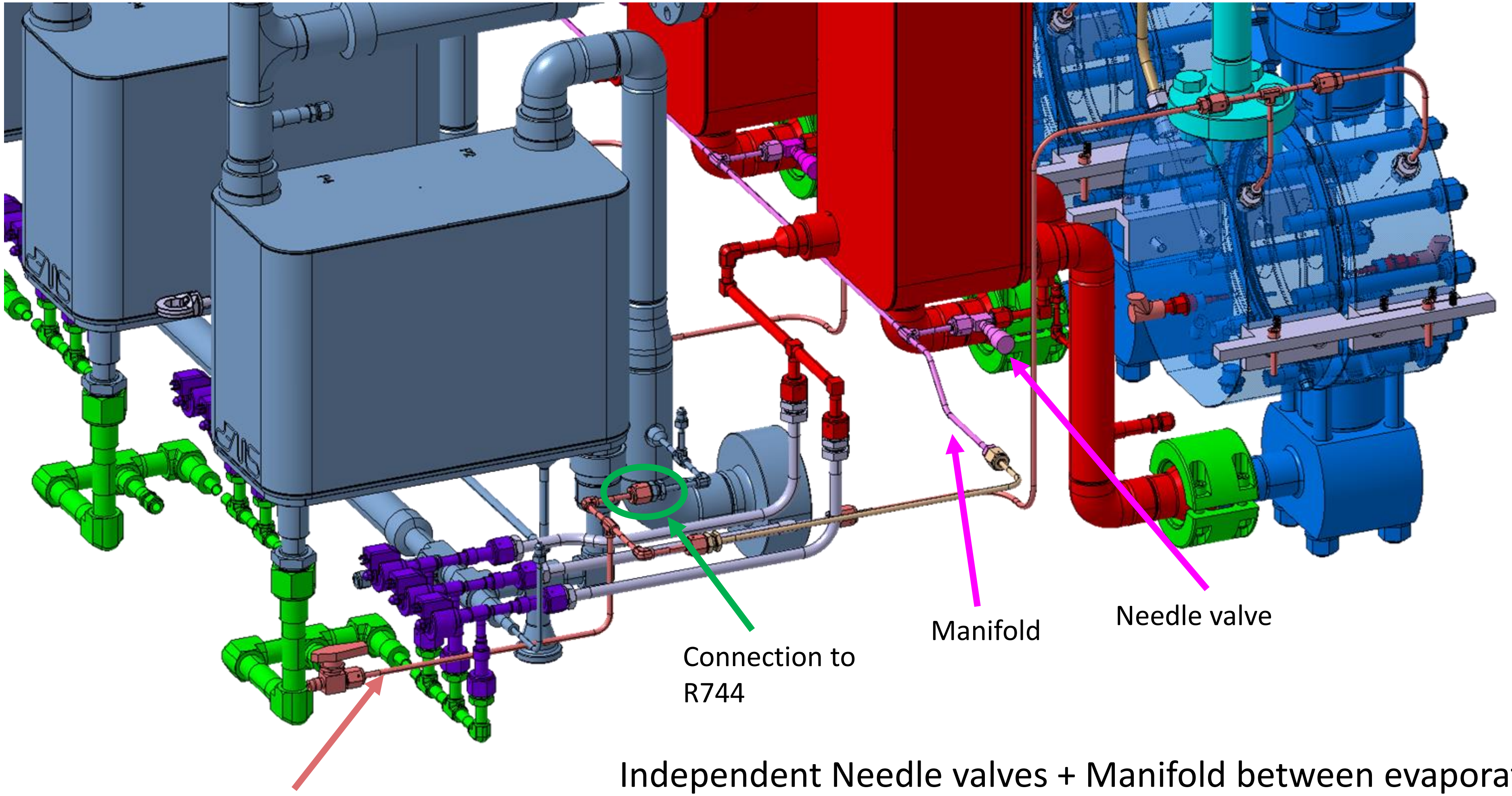
Working Pressures by Classes, bar

Class Temp., °C	150	300	400	600	900	1500	2500
−29 to 38	15.9	41.4	55.2	82.7	124.1	206.8	344.7
50	15.3	40.0	53.4	80.0	120.1	200.1	333.5
100	13.3	34.8	46.4	69.6	104.4	173.9	289.9
150	12.0	31.4	41.9	62.8	94.2	157.0	261.6
200	11.2	29.2	38.9	58.3	87.5	145.8	243.0
250	10.5	27.5	36.6	54.9	82.4	137.3	228.9
300	10.0	26.1	34.8	52.1	78.2	130.3	217.2
325	9.3	25.5	34.0	51.0	76.4	127.4	212.3
350	8.4	25.1	33.4	50.1	75.2	125.4	208.9
375	7.4	24.8	33.0	49.5	74.3	123.8	206.3
400	6.5	24.3	32.4	48.6	72.9	121.5	202.5
425	5.5	23.9	31.8	47.7	71.6	119.3	198.8
450	4.6	23.4	31.2	46.8	70.2	117.1	195.1

NOTE:
(1) Not to be used over 425°C.

More on information EDMS:2044083

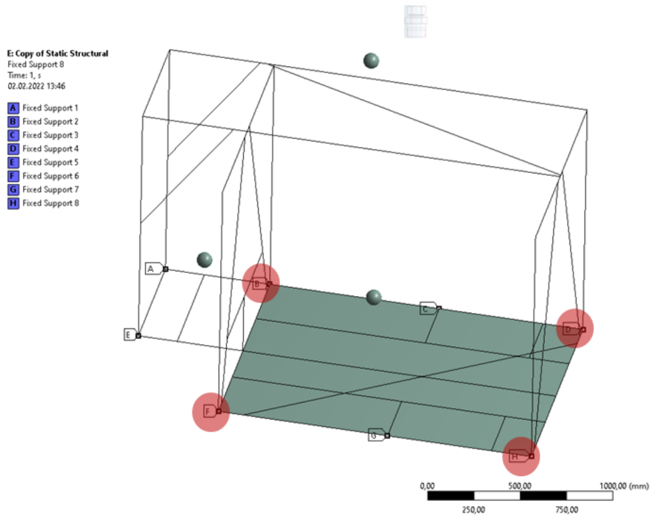
Retention for oil

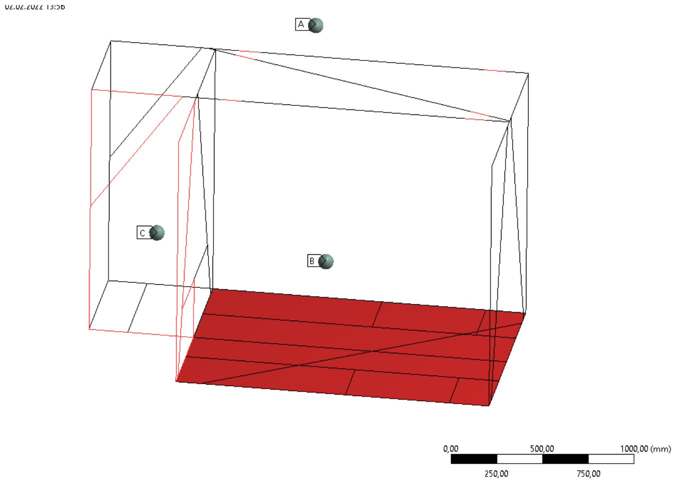


Independent Needle valves + Manifold between evaporators + oil drain line + connection of the manifold to R744 = Oil retention system

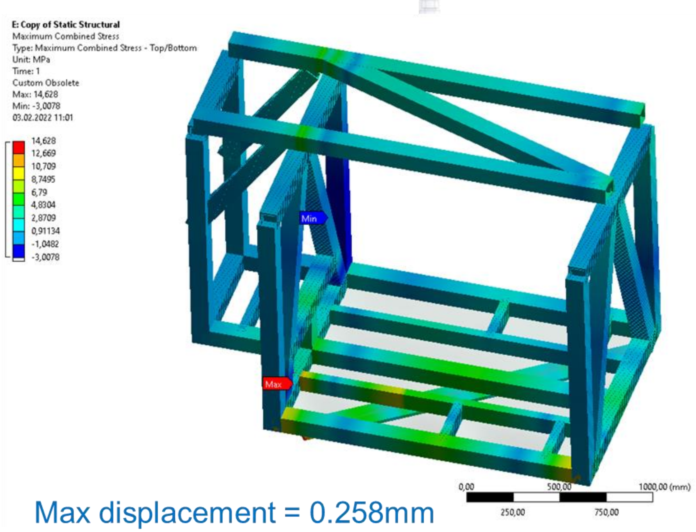
2PACL Frame FEA

Fixed support on 4 feet (B, D, F, H)

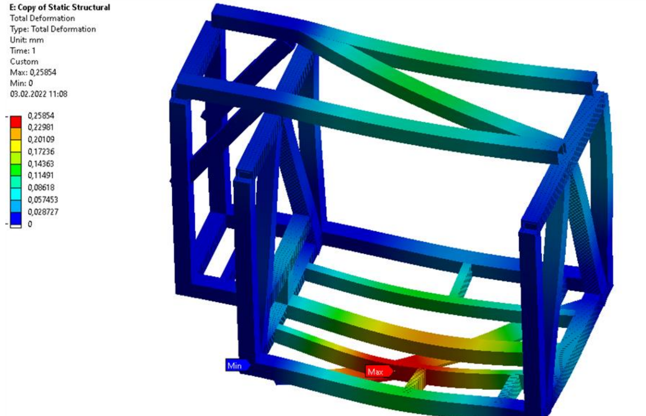




Max stress = 14,6 MPa



Max displacement = 0.258mm

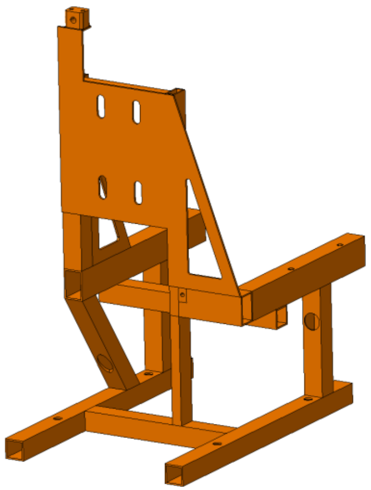


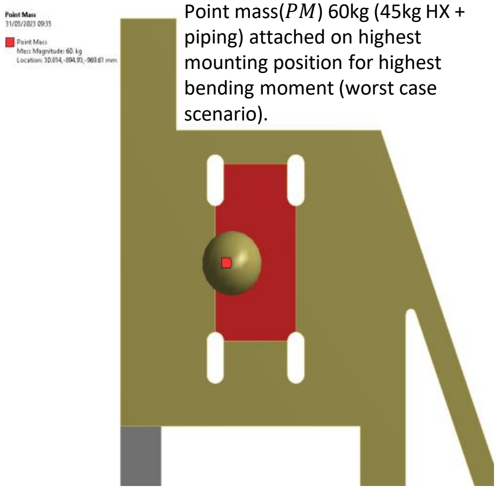
Deformation shape scale:
620x true deformation

Frame was studied under 3 different fixed supports scenarios. More results are available on request

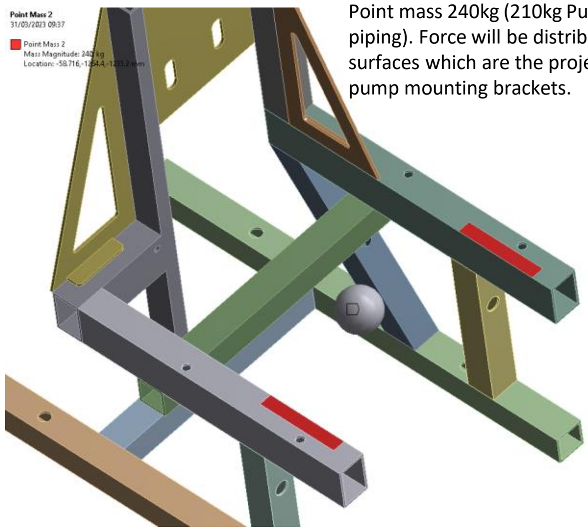
Piping and fittings standards

1 Head Frame



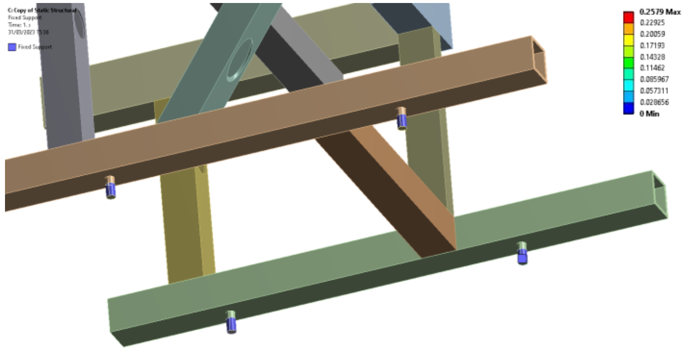


Point mass(PM) 60kg (45kg HX + piping) attached on highest mounting position for highest bending moment (worst case scenario).

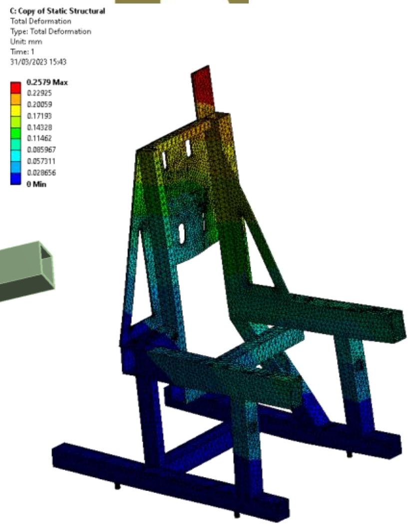


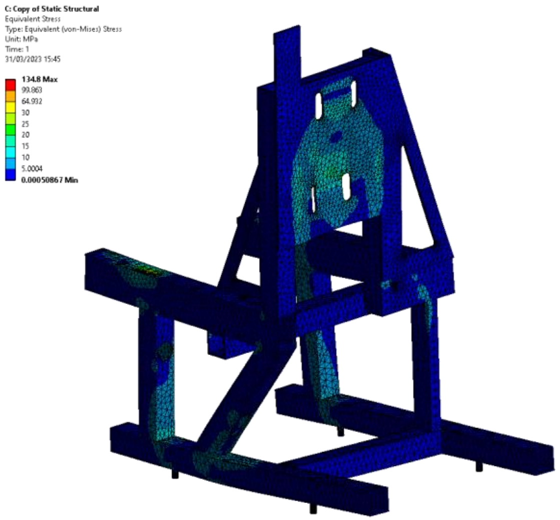
Point mass 240kg (210kg Pump + piping). Force will be distributed along 2 surfaces which are the projections of pump mounting brackets.

	Time [s]	Minimum [mm]	Maximum [mm]	Average [mm]
1	1.	0.	0.2579	5.0491e-002



Fixed support on bolts :
ux=0, uy=0, uz=0
wx=0, wy=0, wz=0





	Time [s]	Minimum [MPa]	Maximum [MPa]	Average [MPa]
1	1.	5.0867e-004	134.8	4.962

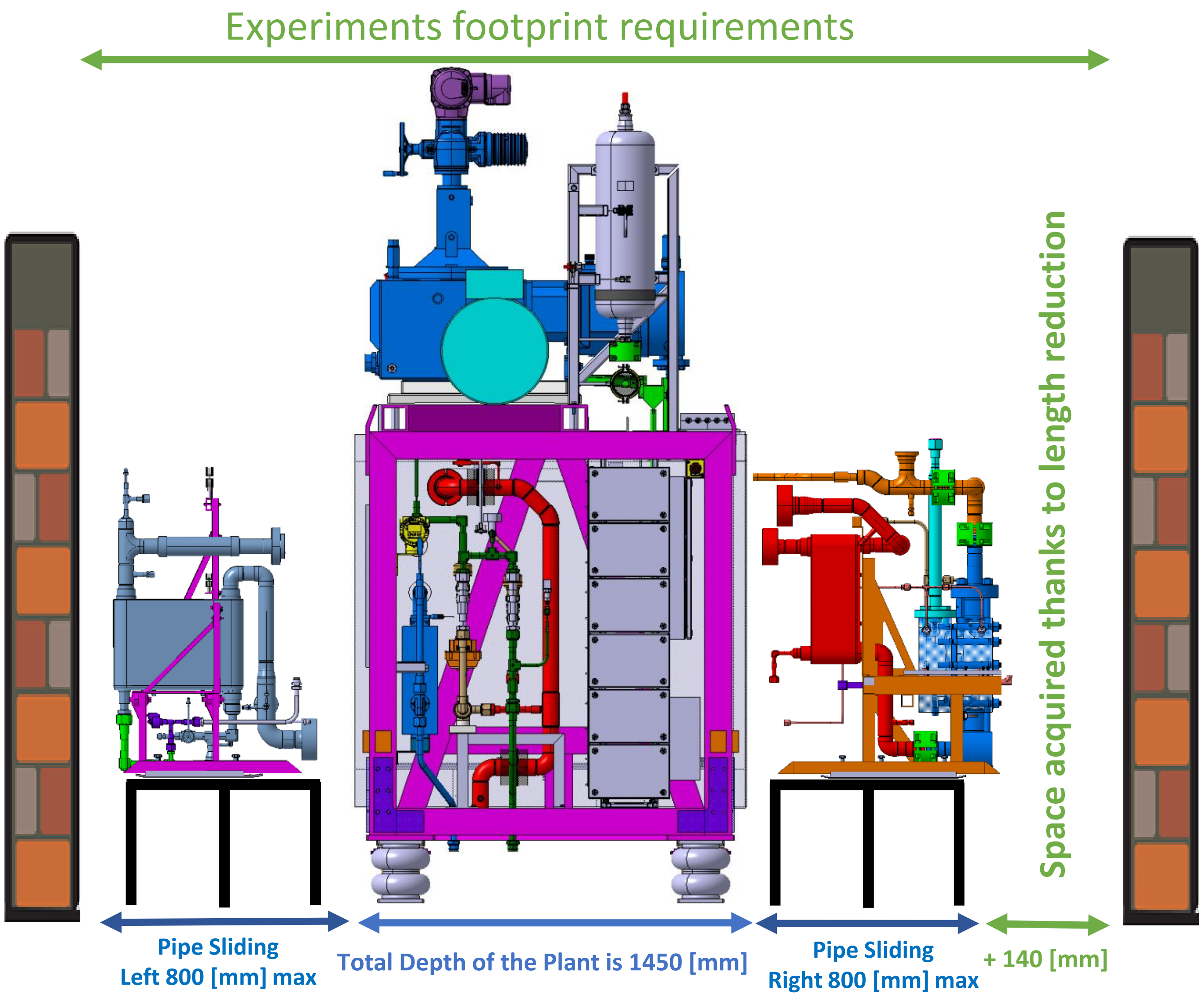
Minimum Yield point for DIN EN 24018 - M12 x 60 bolts, Grade 10.9

$$R_e = 940\ MPa$$

Factor of safety (FoS) > 6.97

$$FoS = \frac{R_e}{\sigma_{max}}$$

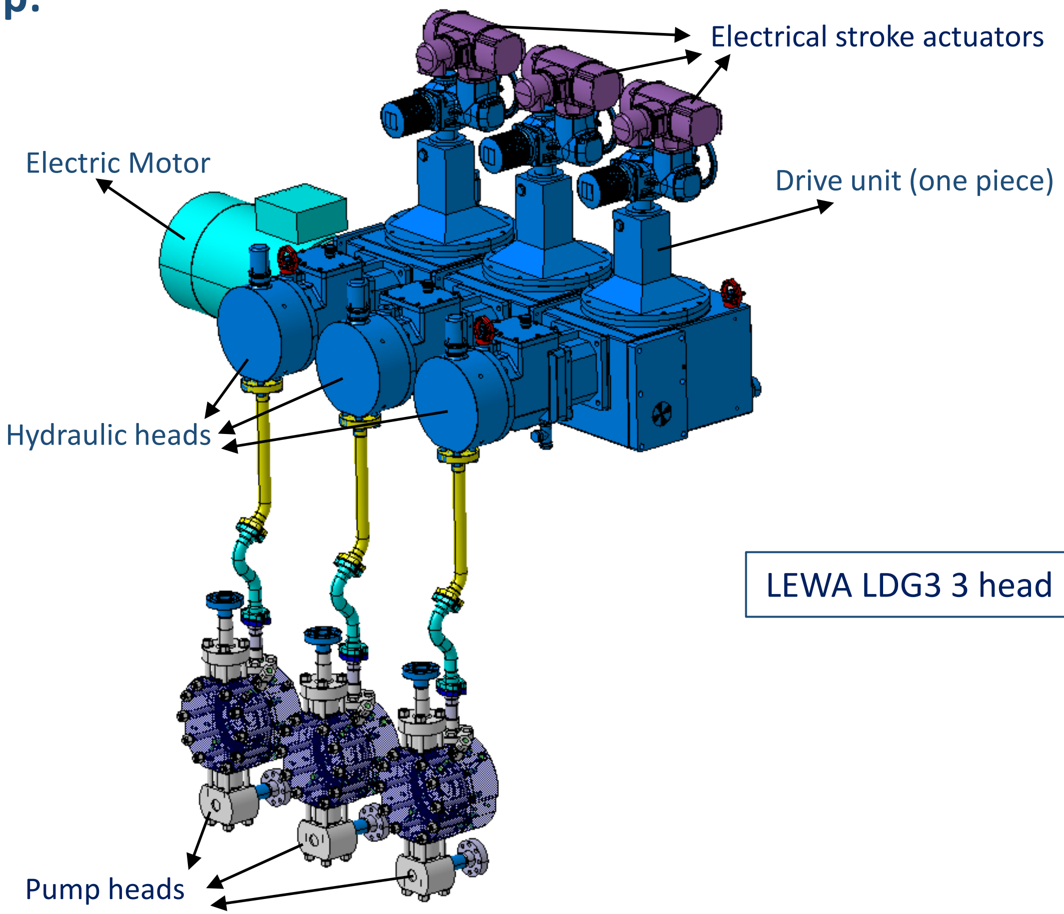
2PACL Plant piping - intervention



- No need to slide the entire hydraulic assembly
- Sliding half of the piping assemblies are fully independent
- Maintenance work can be done just on the one piping side while the second stays in cold box
- Plant depth reduction allows to have more space for piping

2PACL plant CO2 Pump

The pump:



LEWA LDG3 3 head pump

Maintenance procedures – Pump drive unit and motor

Drive unit + motor extraction

There is **free access on the back, right and top** of the plant.

For the **left and the front** of the plant we have **reduced moving capacity** due to the damper and the safety valve.

Extraction:

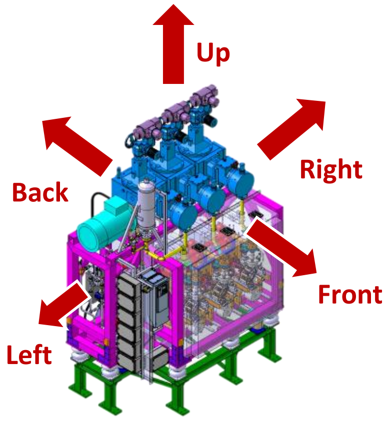
Step 1 (for left and front movement only): Disconnection of the damper piping Techlok clamp and the damper support structure. Removal of the damper and its frame as well as the safety valve. Removal of the oil gutter.

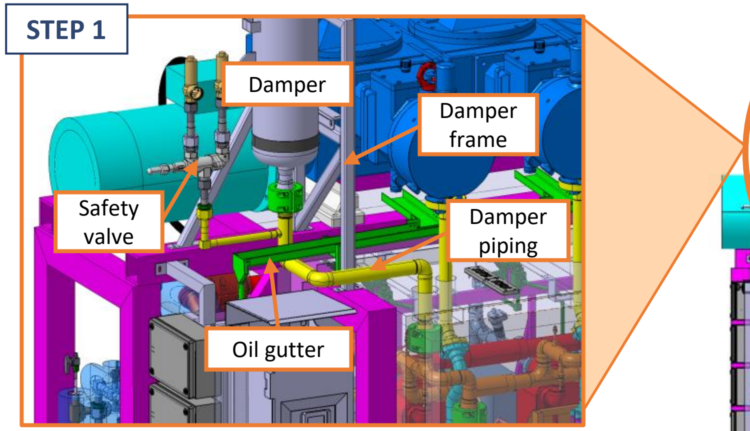
Step 2: Disconnection of the pump unit flanges**.**

Step 3: Vertical lifting (lifting rings) of drive unit (about 2cm) before any horizontal movement with an overhead crane (weight 2100kg). The drive unit is provided with 4 lifting points (for lifting of the drive unit with motor).

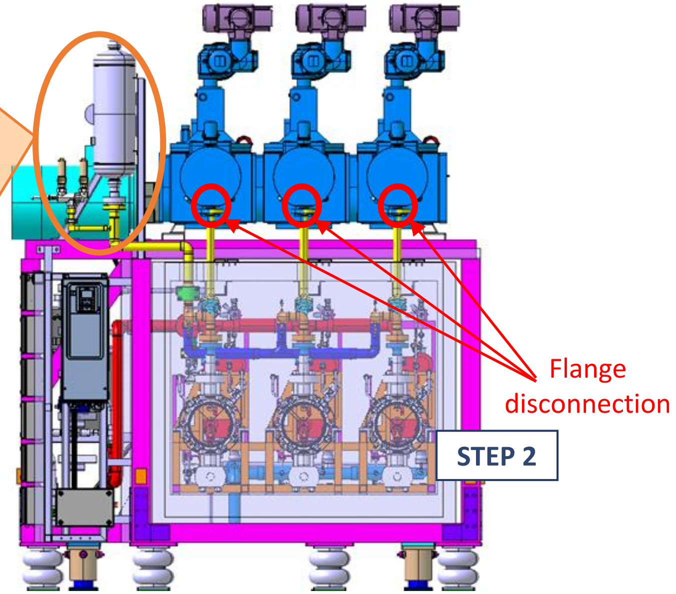
Step 4: Use of the overhead crane to translate the unit horizontal onto a "loading area" (onto pallets with space for forklift)

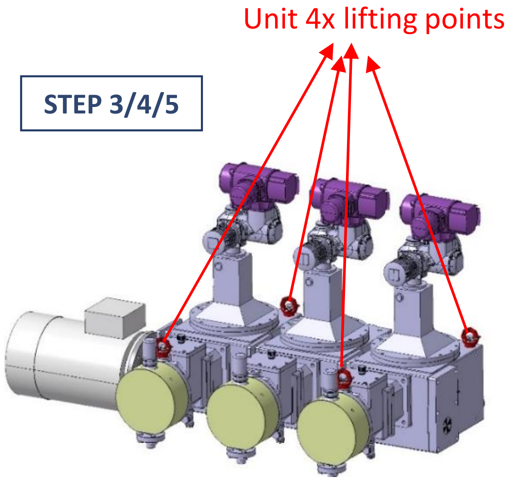
Step 5: Use of mobileve or other moving device to take drive unit outside the plant area

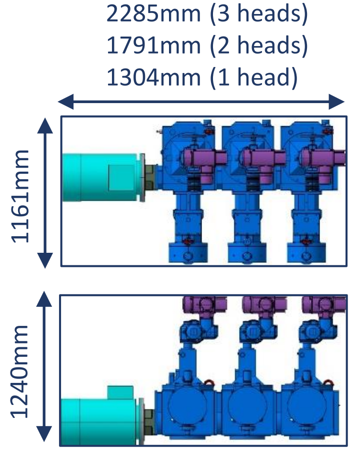




Damper, safety valve and oil gutter removal







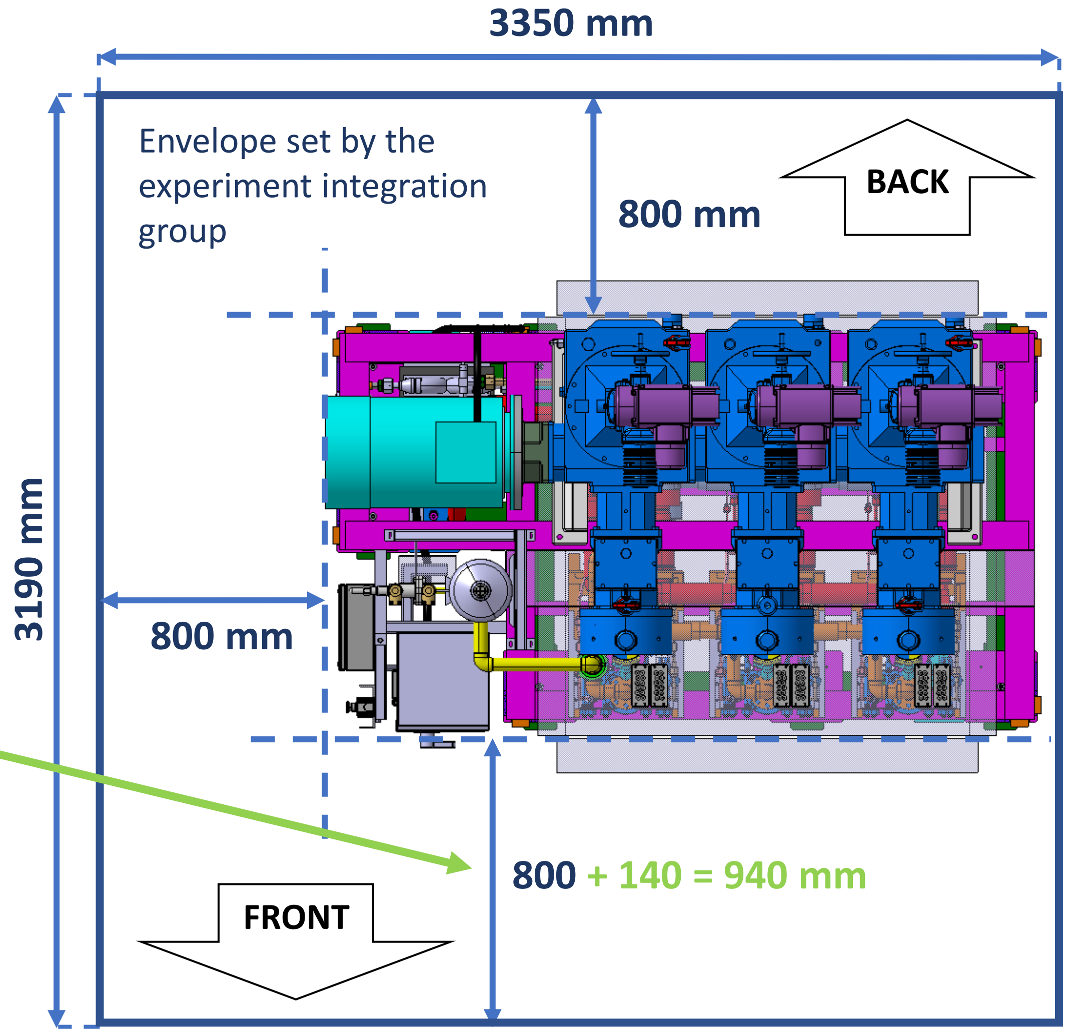
Unforeseen interventions – Access needs

Unforeseen interventions:

Three sides of the plant need to be accessible for interventions on the hydraulic components inside the coldbox. **800mm on each side is sufficient to slide out the piping assemblies.**

The **same access is needed** for the 3 heads, 2 heads and 1 head plants

The plant redesign allowed to add an extra +140mm to the original 800mm envelope. This **+140mm can be allocated to the front and/or the back of the plant depending on integration needs**.



To scale 1 ppt cm = 26.7 cm

Access needs and maintenance

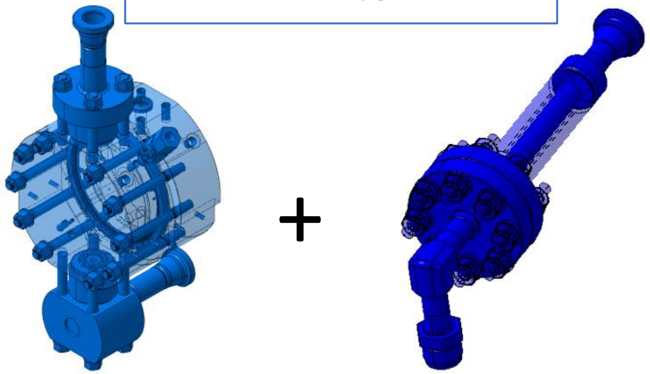
SCHEDULED MAINTENANCE:

1. **Pump head:** every year
2. **Filter:** every year
3. **Pump drive unit:** every 5 years while the neighboring plants are running!

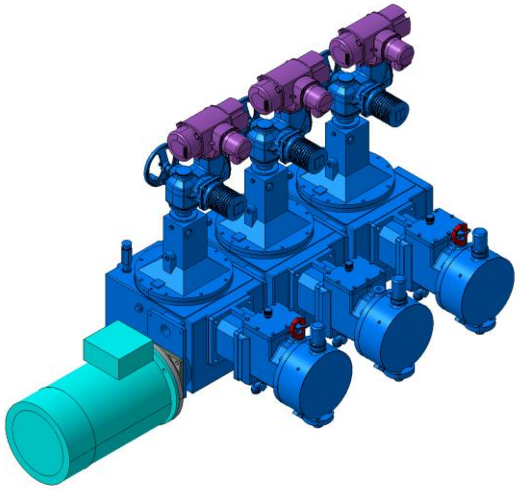
- These maintenance procedures respect the envelope set by the integration team, requiring **800mm space on the front, back and left side of the plant**.

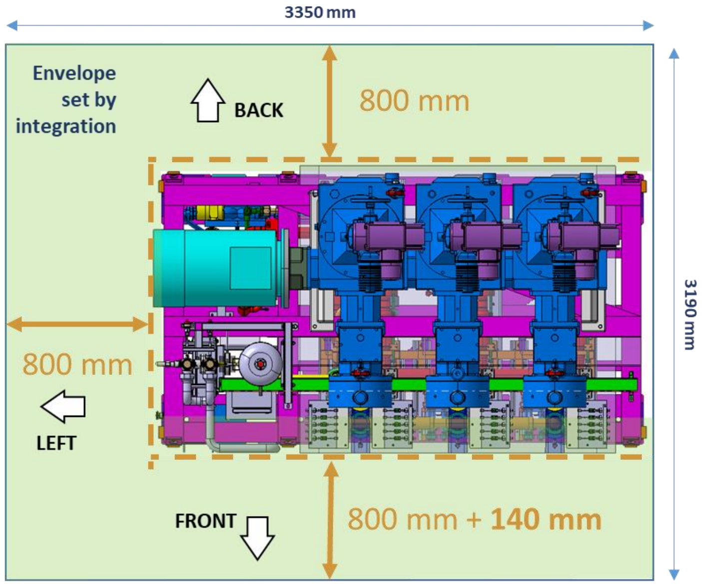
- The **same access is needed** for the 3 heads, 2 heads and 1 head plants

Yearly: Pump Head + Filter



Every 5 years: Pump Drive Unit





Safety valves

1 Use of a Refrigera 3-way Manual Valve:
Supplier reference: P/N: DX1100N0000 (In 1”NPT / Out 1“ NPT)
ST number: ST1484027 (assembly: ST1484128)

2 Use of a Nuova General Instruments Safety valve:
Supplier reference: Nuova E14/LS (In 1”NPT / Out 1 ¼“G)
ST number: ST1484408 (assembly: ST1484128)