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EDMS No.

ST/CV - Cooling of Electronics & Detectors

File name:
LCSv.2calculations.doc

GUIDE

LEAKLESS COOLING SYSTEM V.2

PRESSURE DROP CALCULATIONS AND ASSUMPTIONS

Objectives
Guide to Leakless Cooling System v.2 in LHC experiments.

Abstract
This note gives the formula used to calculate the flow rate, pipe section and pressure drop in a monophase cooling system. It also presents the main assumptions used to design a circuit working according to the LCS v.2 principle.

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Date:	2001/02/22	***Date:***	200Y/MM/DD	***Date:***	200Y/MM/DD

Distribution
List

History of Changes

Rev. No.	***Date***	***Pages***	***Description of Changes***
1	2003/03/03		Update document following Full Scale Test Results.

TABLE OF CONTENTS

1. LCS V.2 OPERATING PRINCIPLE

The liquid is held in a storage tank (3) maintained below atmospheric pressure by a vacuum pump (2). A check valve (5) discharges any excess air in the event of drainage and prevents the pressure in the storage tank from rising above atmospheric pressure. The liquid is moved into the exchangers (1) incorporated through the electronic system by a circulator (4). The pressure at the various points of the circuit depends on the head losses and hydrostatic pressures.

At start-up, if the pressure in the storage tank is not low enough the vacuum pump is activated. While the later is in operation, in the event of an air intake for instance, the circulator cannot run. The pressure throughout the circuit still equal to the pressure in the storage tank.

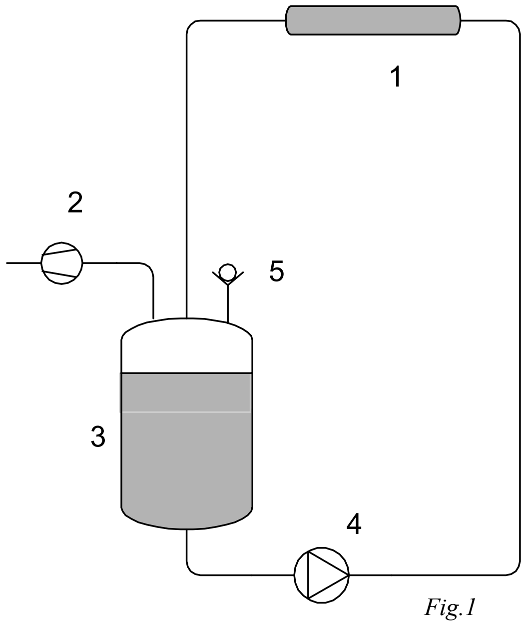


Fig.1

2. PRESSURE DROP CALCULATIONS

2.1 Mass flow:

$$\dot{M}\,[kg/s] = \frac{\dot{Q}}{C * \Delta T}$$

with $\dot{Q}[W]$ dissipated power
C[J/kg.K] specific heat
ΔT[K] temperature difference

(temperature difference of the fluid between the inlet and the outlet of the heat exchanger)

2.2 Volumetric flow:

$$\dot{V}\,[m^3/s] = \frac{\dot{M}}{\rho}$$

with $\rho[kg/m^3]$ density

$$\dot{V} = A*c$$

with $A[m^2]$ tube cross-sectional area
c[m/s] fluid velocity

2.3 Reynolds number:

$$Re[-] = \frac{\bar{c} * D_h}{\gamma}$$

with $\bar{c}[m/s]$ average velocity of the fluid
$D_h[m]$ hydraulic diameter of the tube
$\gamma[m^2/s]$ kinematic viscosity of the fluid

$$D_h = \frac{4*A}{Pm}$$

with Pm[m] inner perimeter of the tube

2.4 Linear pressure drop:

$$\Delta P[N/m^2] = \rho * \lambda * \frac{L}{D_h} * \frac{\overline{c^2}}{2}$$

with λ[-] friction factor

L[m] length of the tube

2.4.1 Laminar flow:

If $Re \leq 2300 \Rightarrow \lambda = \frac{64}{Re}$ (laminar flow)

For a rectangular cross-sectional area this formula becomes: $\lambda = \frac{K}{Re}$ and value for K depends of the ratio width / height (a/b)

a/b	K	a/b	K
0	96.00	1/4	72.93
1/20	89.91	2/5	65.47
1/10	84.68	1/2	62.19
1/8	82.34	3/4	57.89
1/6	78.81	1	56.91

2.4.2 Turbulent flow:

If $2300 \leq Re \leq 10000 \Rightarrow \lambda = 0.3164 * Re^{-0.25}$ (turbulent flow in smooth pipe).

2.5 Local pressure drop:

- Bend: if $\frac{bending \cdot radius}{D_h} \geq 3 \Rightarrow$ we use λ

- Entry: loss coefficient $\xi = 0.9$
- Exit: loss coefficient $\xi = 0.3$

$\}\ \xi^{tot} = 1.2$

Equivalent pipe straight length $L_{eq}[m] = \frac{\xi^{tot} * D_h}{\lambda}$

3. NOTE ON THE CIRCULATOR

To make the fluid circulating we use centrifugal pump that gives kinetic energy in the liquid.
The Head H of the pump is used to measure this energy (height of a liquid column which the pump could create) and this Head is constant with all the newtonian fluids. A specific Flow at a specific Head gives a duty point which one find on the performance curve of the pumps.

3.1 Head requirement:

Typically we have:

- Local pressure drop (primary heat exchanger, control valve, manifold, etc…): 500 [mbar]

- Pressure losses in inlet line: 0.5 to 1.5 [bar] depending of the standard diameter of the inlet pipe.
- Pressure drop due to height difference (between cooling station and electronic's heat exchanger): 1 [m] = [100 mbar], 20 [m] = 2 [bar]
- Pressure drop in electronic's heat exchanger (sub-atmospheric region): 900 [mbar]
- Add 20% as safety margin.

For example for a heat exchanger located at 20 [m] height we will have a pump head of 53 [m]

3.2 Output pressure:

$$P[bar] = \frac{\rho[m^3/kg]*9.81*H[m]}{100000}$$

For a specific fluid: $P_{fluid} = P_{water}$*specific gravity

3.3 Change of Head due to viscosity:

$$\frac{H_{fluid}}{H_{water}} = 1.4 - 0.4\left(\frac{\gamma_{fluid}}{\gamma_{water}}\right)^{0.1}$$

4. FLUID CHARACTERISTICS

	water @ 20°C	C6F14 @ 20°C	C6F14 @ -20°C	C8F18 @ 20°C	C8F18 @ -20°C
Density ρ [kg/m^3]	1000	1688	1792	1789	1887
Specific heat C [J/kg.K]	4187	1045	983	1045	983
Kinematic viscosity γ [m^2/s]	$1*10^{-6}$	$0.4*10^{-6}$	$0.8*10^{-6}$	$0.8*10^{-6}$	$2*10^{-6}$

5. LCS V.2 FULL SCALE TEST RESULTS AND PRESSURE DROP BALANCING

A cooling system prototype is currently under test in B.185 – See Figure 2 and 3. From the first measurement we have now a better knowledge of the different running parameters in a Leakless system.

Figure 1 shows the different pressures at different point of a LCS v.2 circuit.

- **Pt**: Pressure in storage tank; fixed value by vacuum pump and pressure switch; can varies from 0 to –500 [mbar] without affecting the Leakless mode.
- **Pc:** Pump outlet pressure; depending of the pressure drops in the circuit; See paragraph 3.1
- **Ps:** Inlet pressure in detector's heat exchanger; start of the Leakless mode (sub-atmospheric pressure) so nominal value should be 0; fixed value by the control valve at –100 [mbar] for safety reason.
- **Po:** Pressure at the higher point in electronic's heat exchanger; the theoritical minimum is –1 bar; in practical around –930 [mbar]; assume -900 [mbar] in the design.
- **V':** Flow rate in the detector's heat exchanger **Le**.
- **He:** Height difference in the sub-atmospheric sector.
- **Hi:** Height difference between cooling station and start point of the sub-atmospheric sector.
- **L1:** Inlet line

- **Lo:** Return line
- ΔP_{Le}**:** Pressure loss due to flow **V'** inside **Le** (including local pressure drops due to bend, valve, fittings, etc...).
- ΔP_{He}**:** Pressure drop due to height difference in the sub-atmospheric sector.
- $\Delta P_{v:}$ Pressure drop in the control valve.

5.1 Leakless sector:

Main point is: $\Delta P_{Le} + \Delta P_{He} =< 800$ **[mbar].**
That means that **He** has to be limited to keep comfortable pressure drop in the detector's electronic (1m = 100 [mbar].
Typical height of the sectors is 3[m] that let 500 [mbar] for the electronic's heat exchanger.
Sector of 6 [m] limits the pressure drop inside the electronic's heat exchanger at 200 [mbar]. That means that the diameter of the pipe / tube / hose has to be carefully designed if we want sufficient flow to keep a given Delta T.

5.2 Overpressure sector:

There is no limitation to **Hi** assuming that the pump is correctly dimensioned (see 3.1). We've tested up to 15m without significant change. We have the following
$\mathbf{Pc} = \mathbf{Pt} + \Delta P_v + \Delta P_{Li} + \Delta P_{Hi} + \mathbf{Ps}$

5.3 Return

Without trying to explain the phenomena we have a non-stationary flow in the return pipe **Lo** with no direct correlation between pressure in the sub-atmospheric sector **Po** and pressure in the storage tank **Pt**.
Even with atmospheric pressure in the storage tank the detector's sector stays in Leakless mode.

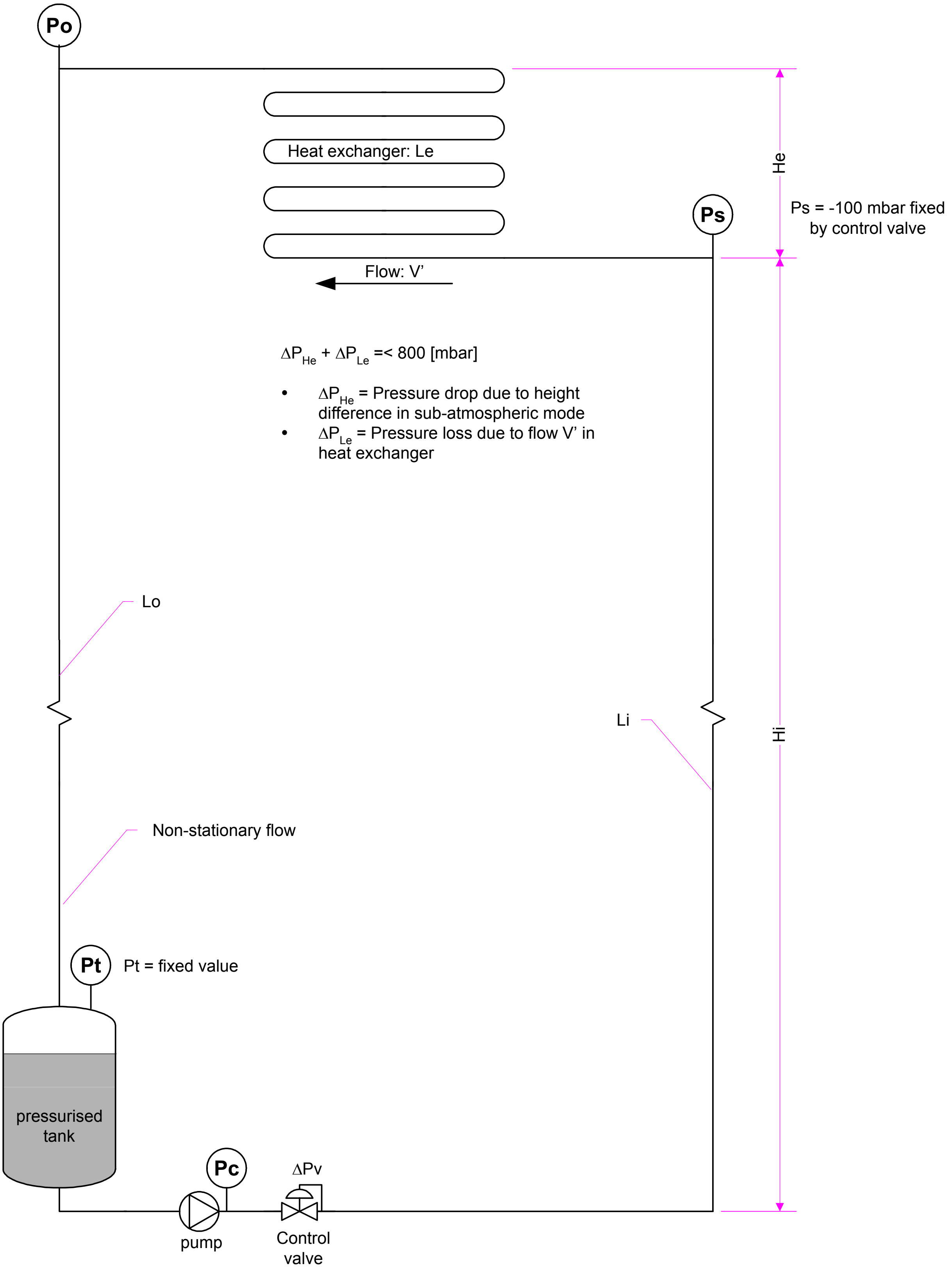
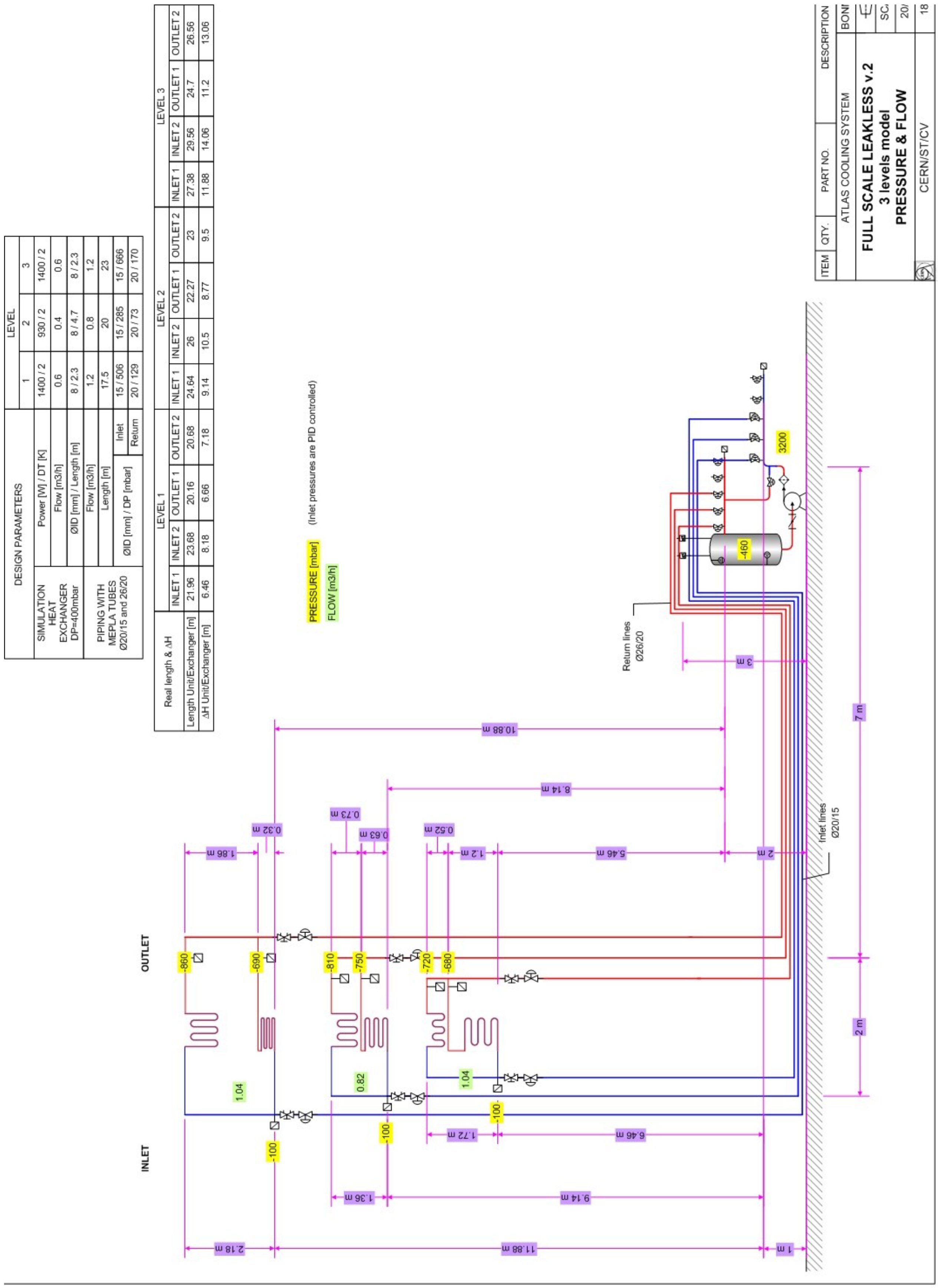

Po
Heat exchanger: Le
He
Ps
Ps = -100 mbar fixed
by control valve
Flow: V'
ΔP_He + ΔP_Le =< 800 [mbar]
• ΔP_He = Pressure drop due to height difference in sub-atmospheric mode
• ΔP_Le = Pressure loss due to flow V' in heat exchanger
Lo
Li
Hi
Non-stationary flow
Pt
Pt = fixed value
pressurised tank
Pc
ΔPv
pump
Control valve

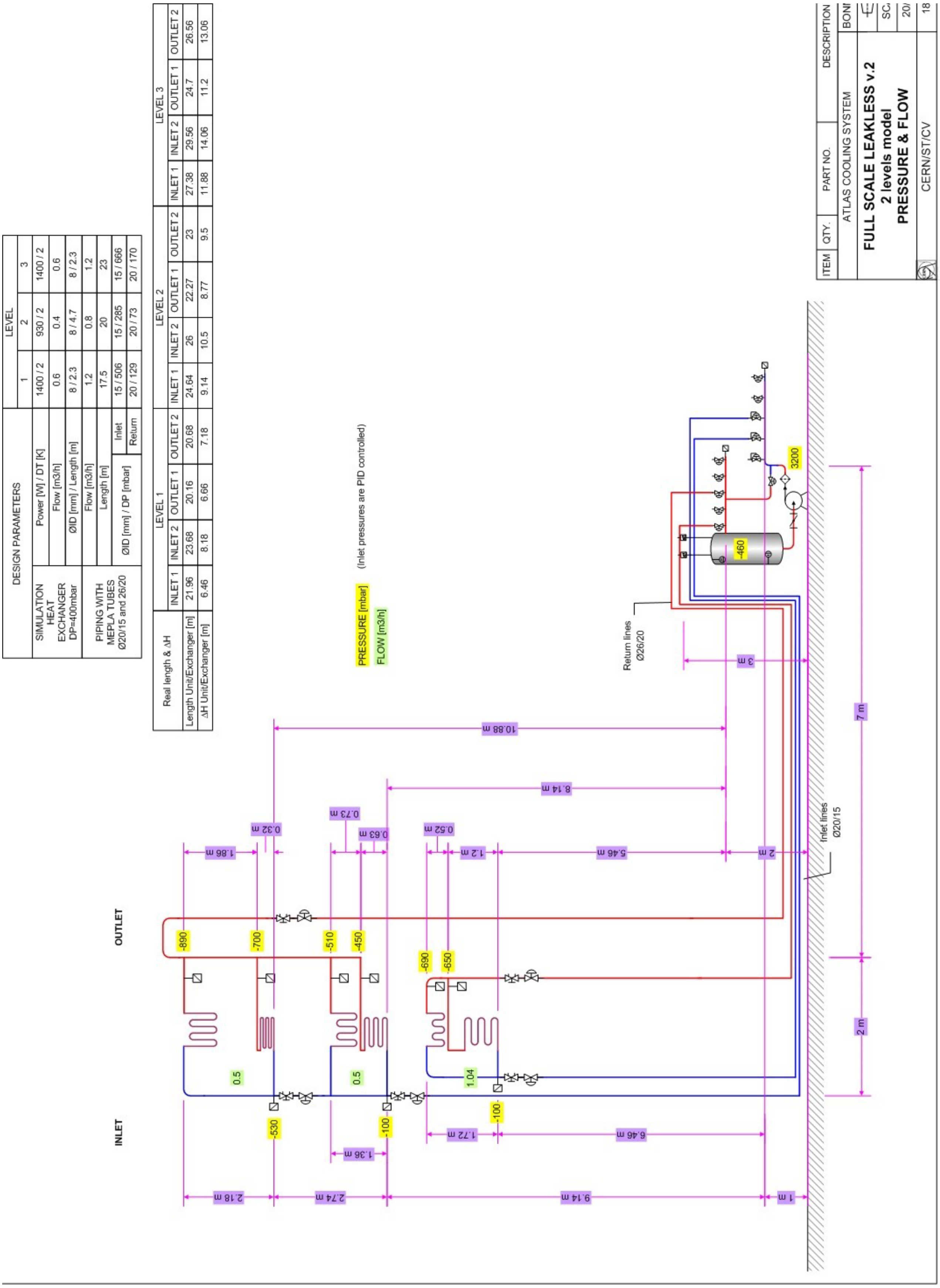
Figure 1



DESIGN PARAMETERS			LEVEL 1	LEVEL 2	LEVEL 3
SIMULATION HEAT EXCHANGER DP=400mbar	Power [W] / DT [K]		1400 / 2	930 / 2	1400 / 2
	Flow [m3/h]		0.6	0.4	0.6
	ØID [mm] / Length [m]		8 / 2.3	8 / 4.7	8 / 2.3
PIPING WITH MEPLA TUBES Ø20/15 and 26/20	Flow [m3/h]		1.2	0.8	1.2
	Length [m]		17.5	20	23
	ØID [mm] / DP [mbar]	Inlet	15 / 506	15 / 285	15 / 666
		Return	20 / 129	20 / 73	20 / 170

Real length & ΔH	LEVEL 1				LEVEL 2				LEVEL 3			
	INLET 1	INLET 2	OUTLET 1	OUTLET 2	INLET 1	INLET 2	OUTLET 1	OUTLET 2	INLET 1	INLET 2	OUTLET 1	OUTLET 2
Length Unit/Exchanger [m]	21.96	23.68	20.16	20.68	24.64	26	22.27	23	27.38	29.56	24.7	26.56
ΔH Unit/Exchanger [m]	6.46	8.18	6.66	7.18	9.14	10.5	8.77	9.5	11.88	14.06	11.2	13.06

Figure 2



DESIGN PARAMETERS
LEVEL
1 2 3
SIMULATION HEAT EXCHANGER DP=400mbar
Power [W] / DT [K] 1400 / 2 930 / 2 1400 / 2
Flow [m3/h] 0.6 0.4 0.6
ØID [mm] / Length [m] 8 / 2.3 8 / 4.7 8 / 2.3
PIPING WITH MEPLA TUBES Ø20/15 and 26/20
Flow [m3/h] 1.2 0.8 1.2
Length [m] 17.5 20 23
ØID [mm] / DP [mbar] Inlet 15 / 506 15 / 285 15 / 666
Return 20 / 129 20 / 73 20 / 170
Real length & ΔH
LEVEL 1 LEVEL 2 LEVEL 3
INLET 1 INLET 2 OUTLET 1 OUTLET 2
Length Unit/Exchanger [m] 21.96 23.68 20.16 20.68 24.64 26 22.27 23 27.38 29.56 24.7 26.56
ΔH Unit/Exchanger [m] 6.46 8.18 6.66 7.18 9.14 10.5 8.77 9.5 11.88 14.06 11.2 13.06
PRESSURE [mbar]
FLOW [m3/h]
(Inlet pressures are PID controlled)
OUTLET
INLET
Return lines Ø26/20
Inlet lines Ø20/15
10.88 m
8.14 m
0.32 m
0.73 m
0.63 m
0.52 m
1.86 m
1.2 m
5.48 m
2 m
3 m
7 m
2 m
-890
-700
-510
-450
-690
-650
-460
3200
0.5
0.5
1.04
-530
-100
-100
1.72 m
6.48 m
1.36 m
2.18 m
2.74 m
9.14 m
1 m
ITEM QTY. PART NO. DESCRIPTION
ATLAS COOLING SYSTEM
FULL SCALE LEAKLESS v.2
2 levels model
PRESSURE & FLOW
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Figure 3