Humidity measurements at LNE-CETIAT

low humidity level

Eric GEORGIN – eric.georgin@cetiat.fr

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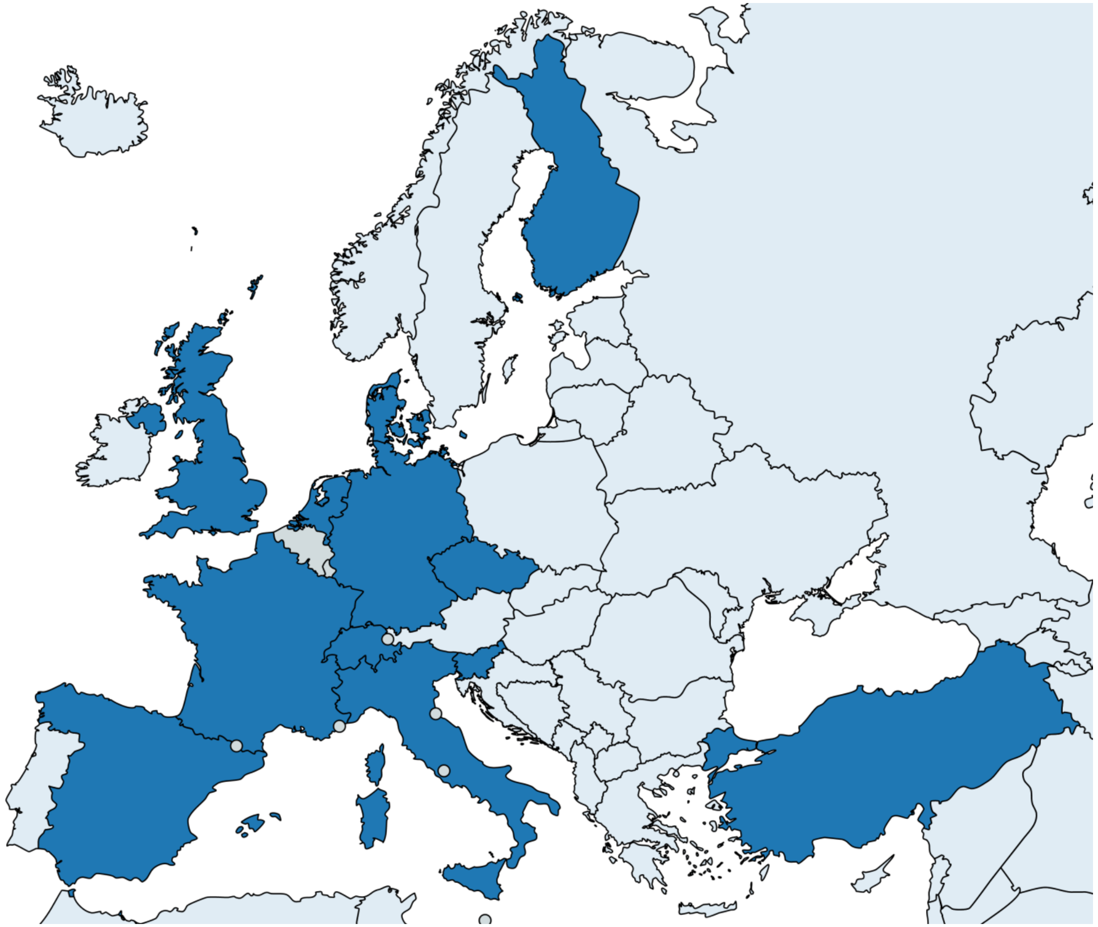
Outline

1. JRP PROMETH$_2$O
2. Humidity at LNE-CETIAT
3. Humid Air Generator – HAG / dilution
4. Results
5. Conclusion

JRP PROMETH2O – the consortium



INRiM ISTITUTO NAZIONALE DI RICERCA METROLOGICA
CETIAT ensemble, innover et valider
CEM CENTRO ESPAÑOL DE METROLOGÍA
ČESKÝ METROLOGICKÝ INSTITUT
le cnam
INTA INSTITUTO NACIONAL DE TÉCNICA AEROESPACIAL
PTB Physikalisch-Technische Bundesanstalt Braunschweig und Berlin
TÜBİTAK
Univerza v Ljubljani
VSL
VTT MIKES METROLOGIA
DTU
NIPPON GASES | RIVOIRA
Qrometric Industrial and scientific metrology
Università degli Studi della Campania Luigi Vanvitelli
UNIVERSITÀ DEGLI STUDI DI CASSINO E DEL LAZIO MERIDIONALE
MBW calibration
UVa
VAISALA

19 partners from 12 countries – 242 person-months

PROMETH2O is supported by world leading manufacturers, international organisations and metrology leaders

PRO MET H_2O

JRP PROMETH2O - Objectives

cetiat

- New primary standard… Ar and H2 down to 5… temperature) at press…
- New/improved measu… fraction range betwee… (rel. uncert. 3 % to 8 …
- New data and correla… enhancement in N2, … range from -30 °C to -…
- Demonstration at sele… real-time measureme…
- Provision of a toolkit… robust measurement… UHP process gases, b… standards and measu…

More information

Session 16 Thermometry, Hygrometry

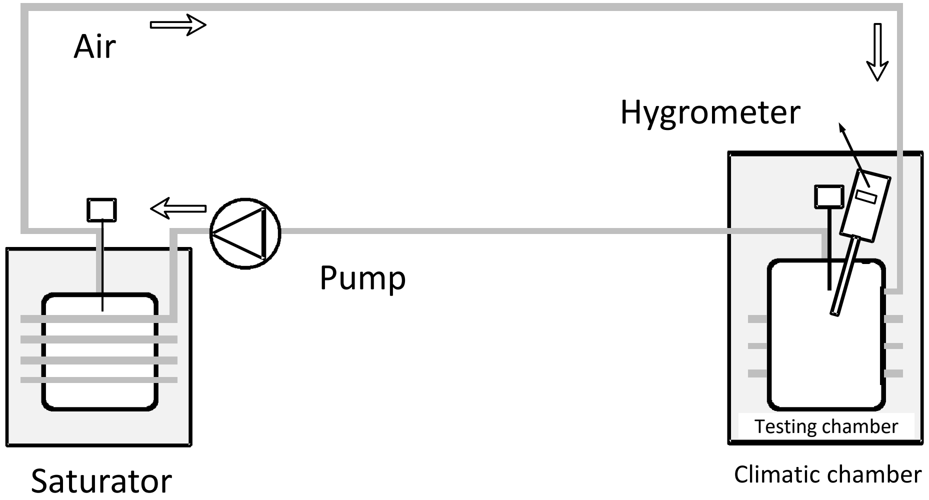
V. FERNICOLA

Website

https://www.prometh2o.eu/

Humidity at LNE-CETIAT (1/2)

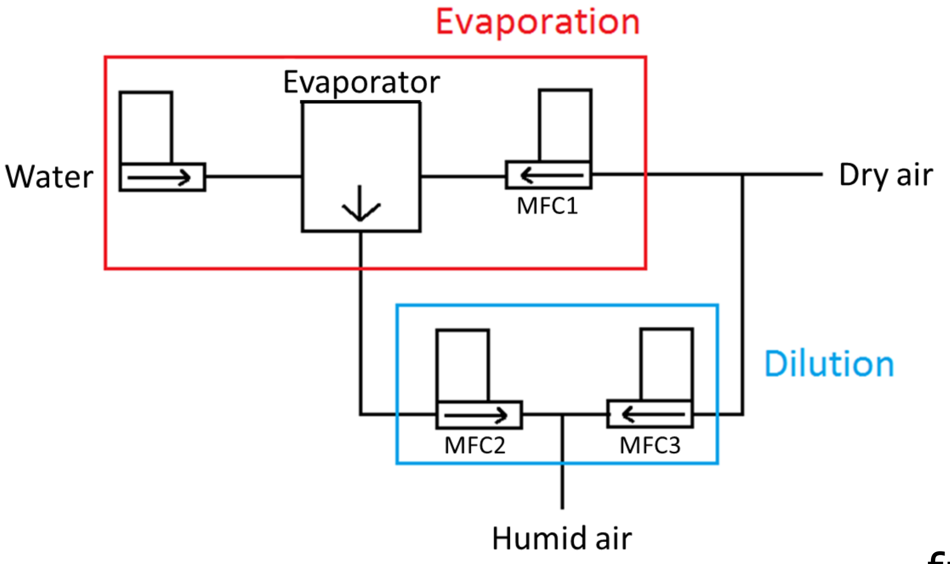
- Designated institute for the French national reference in humidity.
- Ensures SI traceability for end users
  - ≈ 600 COFRAC's calibrations per year
- Primary realization: Humid Air Generator (HAG)
  - 1T1P / closed loop
  - Dew/frost point
  - Relative humidity



$U_k=2(U_{w,i})$	U_w (%rh)										
θ_{dry} (°C)	5	10	20	30	40	50	60	70	80	90	95
-30					0,6	0,8	0,9	1,0	1,2	1,3	1,4
-20		0,3	0,4	0,5	0,6	0,7	0,8	1,0	1,1	1,2	1,3
-10	0,3	0,3	0,4	0,5	0,6	0,7	0,8	0,9	1,0	1,1	1,2
0	0,3	0,3	0,3	0,4	0,5	0,6	0,7	0,8	0,9	1,0	1,0
10	0,3	0,3	0,3	0,4	0,5	0,5	0,6	0,6	0,7	0,8	0,8
20	0,3	0,3	0,3	0,3	0,4	0,5	0,5	0,6	0,7	0,7	0,8
30	0,3	0,3	0,3	0,3	0,4	0,4	0,5	0,6	0,6	0,7	0,7
40	0,3	0,3	0,3	0,3	0,4	0,4	0,5	0,5	0,6	0,6	0,7
50	0,3	0,3	0,3	0,3	0,4	0,4	0,4	0,5	0,5	0,6	0,6
60	0,3	0,3	0,3	0,3	0,3	0,4	0,4	0,5	0,5	0,6	0,6
70	0,3	0,3	0,3	0,3	0,3	0,4	0,4	0,5	0,5	0,5	0,6
80	0,3	0,3	0,3	0,3	0,3	0,4	0,4	0,4	0,5	0,5	0,5
90	0,3	0,3	0,3	0,3	0,3	0,4	0,4	0,4	0,5	0,5	0,5
100	0,3	0,3	0,3	0,4	0,4	0,5	0,6	0,7			
110	0,3	0,3	0,3	0,4	0,4	0,5					
120	0,3	0,3	0,3	0,4							
130	0,3	0,3	0,3								
140	0,3	0,3	0,3								

Humidity at LNE-CETIAT (2/2)

- Secondary realization
  - Mixing ratio based on dilution principle



$$r_{evap} = \frac{m_{water}}{m_{MFC\,1}} = \frac{\dot{m}_{water}}{\dot{m}_{MFC\,1}}$$

$$r_{dilu} = \frac{\dot{m}_{MFC\,2} \cdot r_{evap}}{\dot{m}_{MFC\,2} + \dot{m}_{MFC\,3}}$$

from r_{dilu} to $\theta_{d/f}$

$$x_v = r_{dilution} \cdot \frac{M_{dry\,gas}}{M_{water}}$$

$$e' = x_v \cdot p$$

$$e = \frac{e'}{f(p, \theta_{d/f})}$$

$\theta_{d/f}$ D. Sonntag (EIT-90)

HAG / dilution (1/6)

- Schematic overview

1) Clean Dry Air (CDA) inlet,
2) pure water reservoir,
3) compact Coriolis mass flow controllers for liquids,
4) mass flow controllers for gases,
5) evaporator,
6) pressure controller,
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9) testing chamber or device under test,
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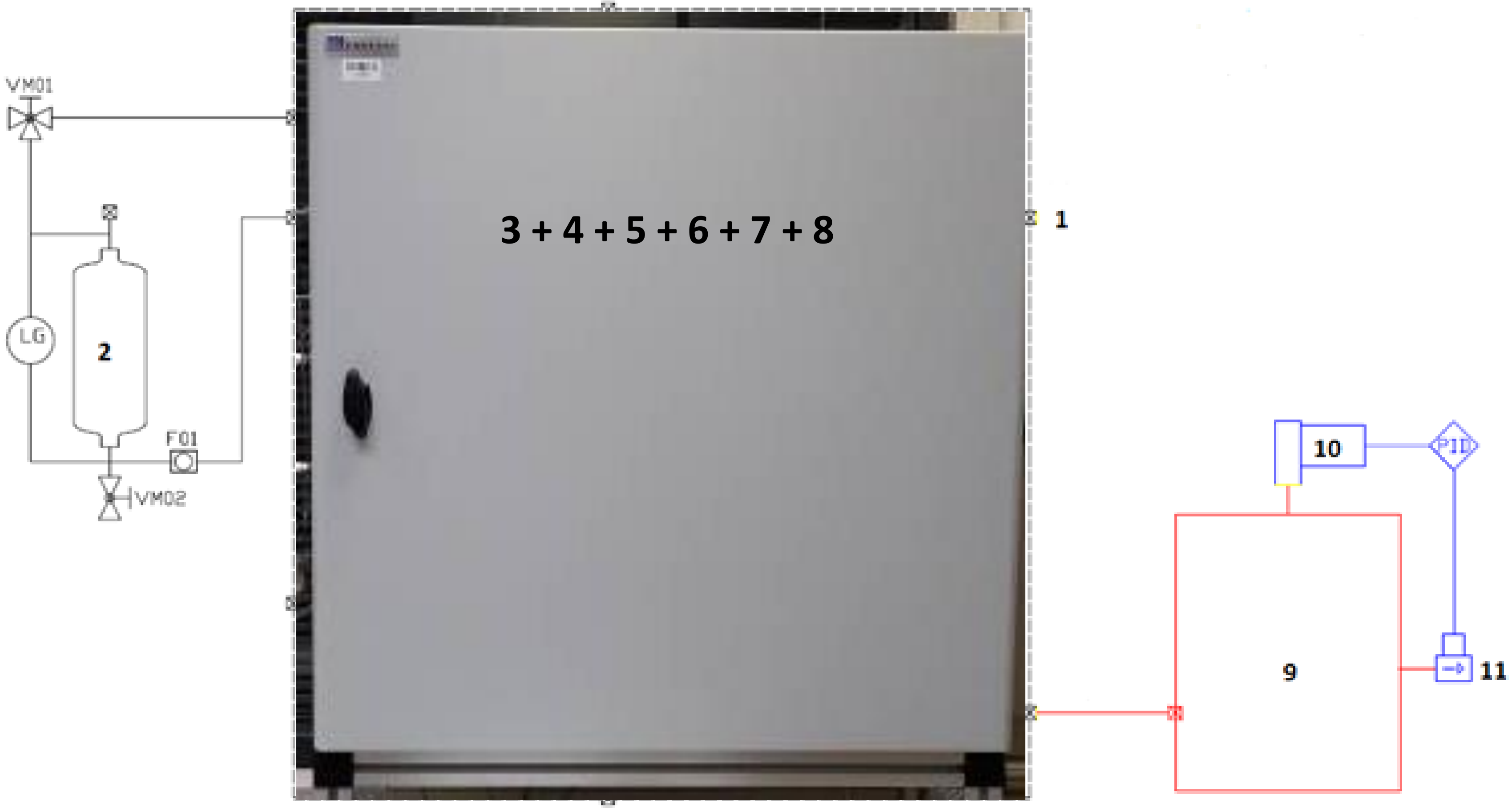

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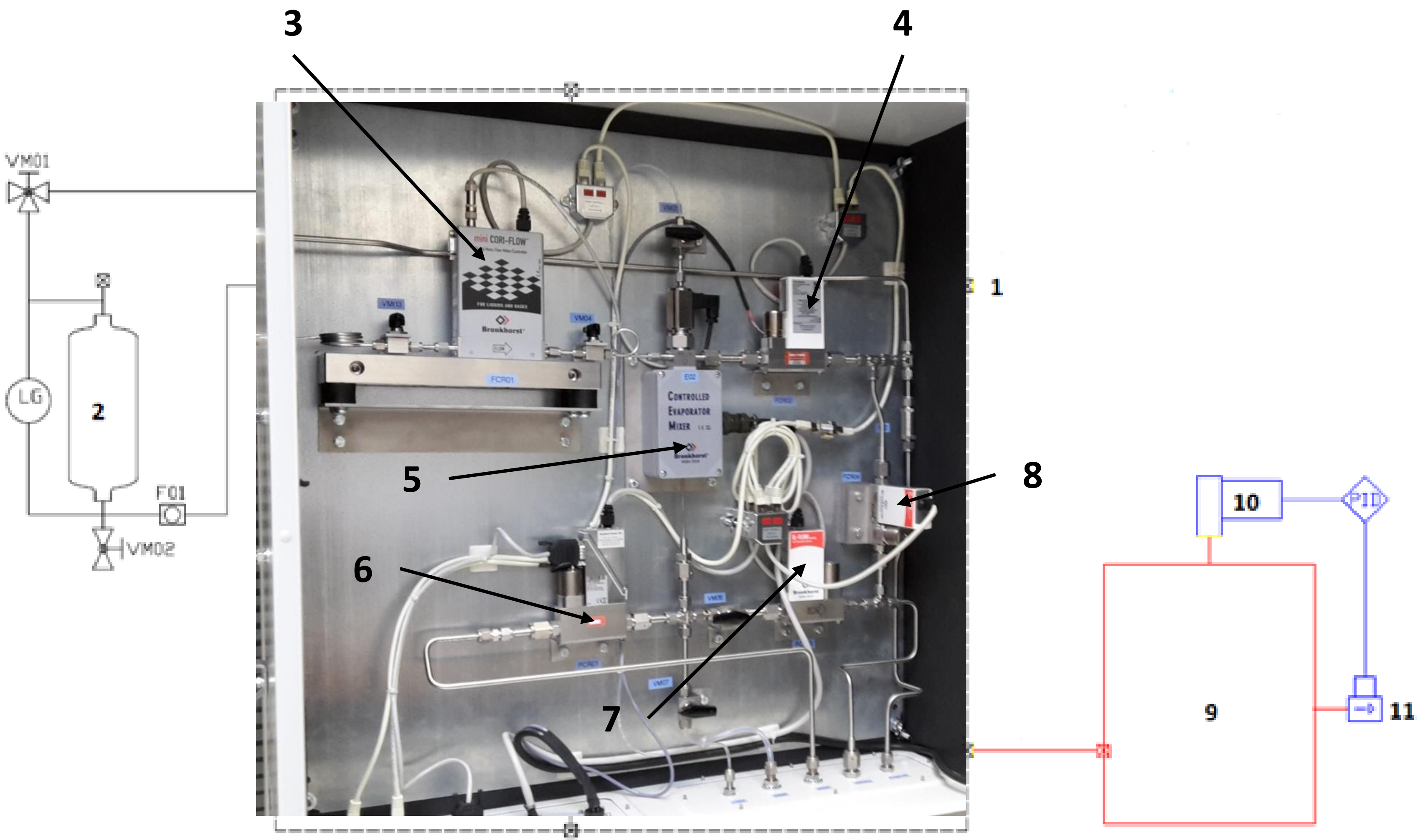

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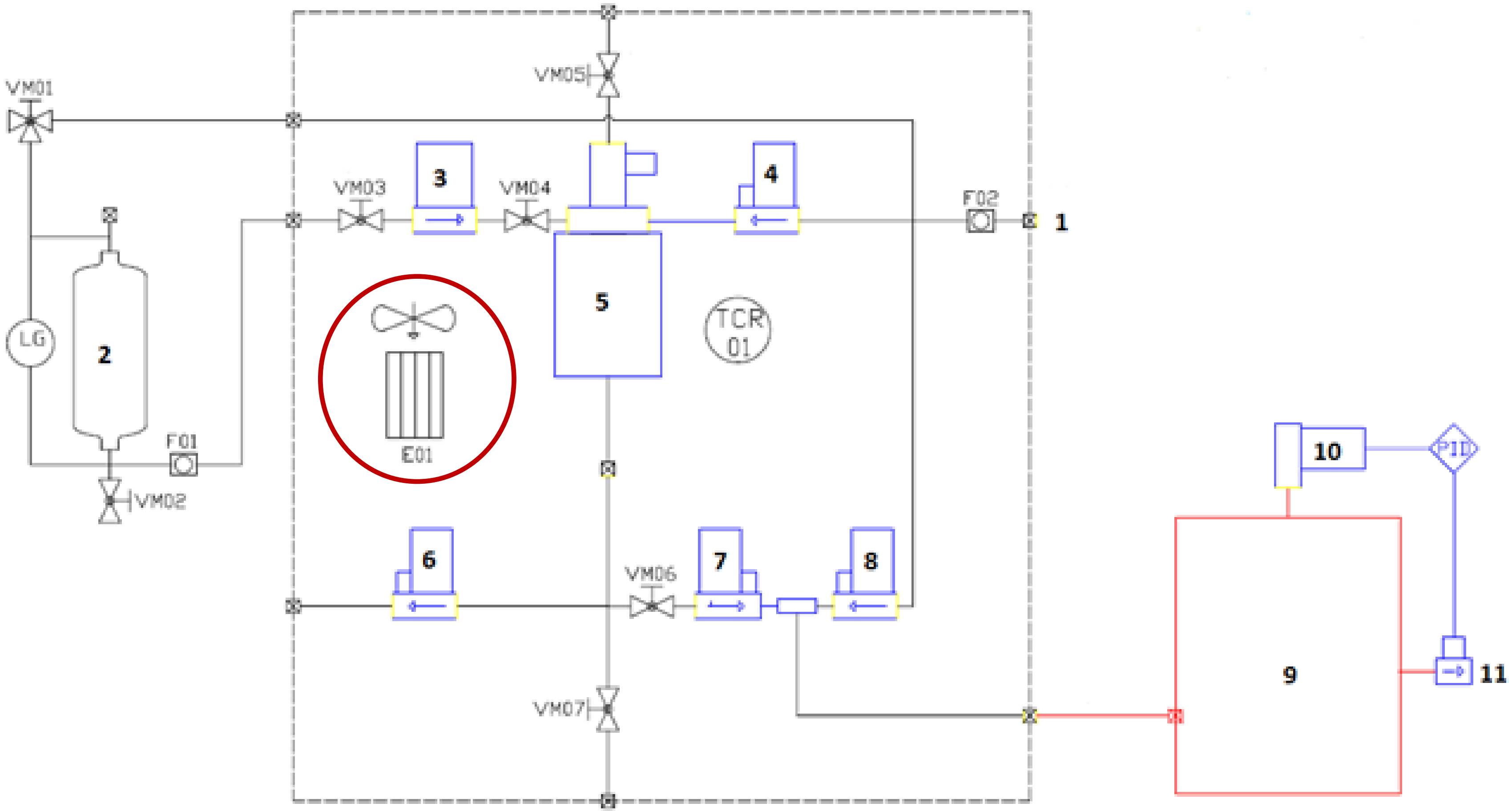

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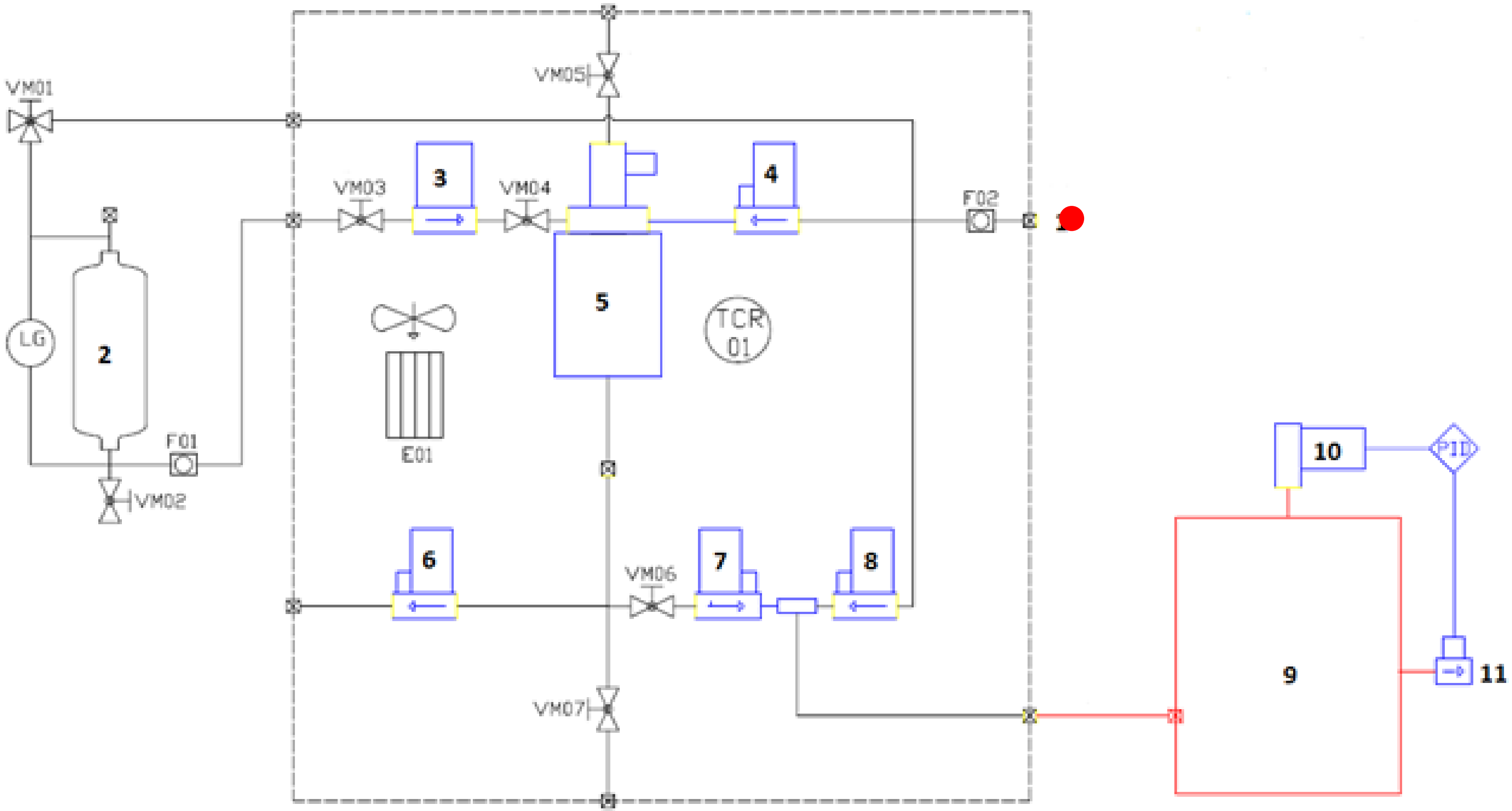

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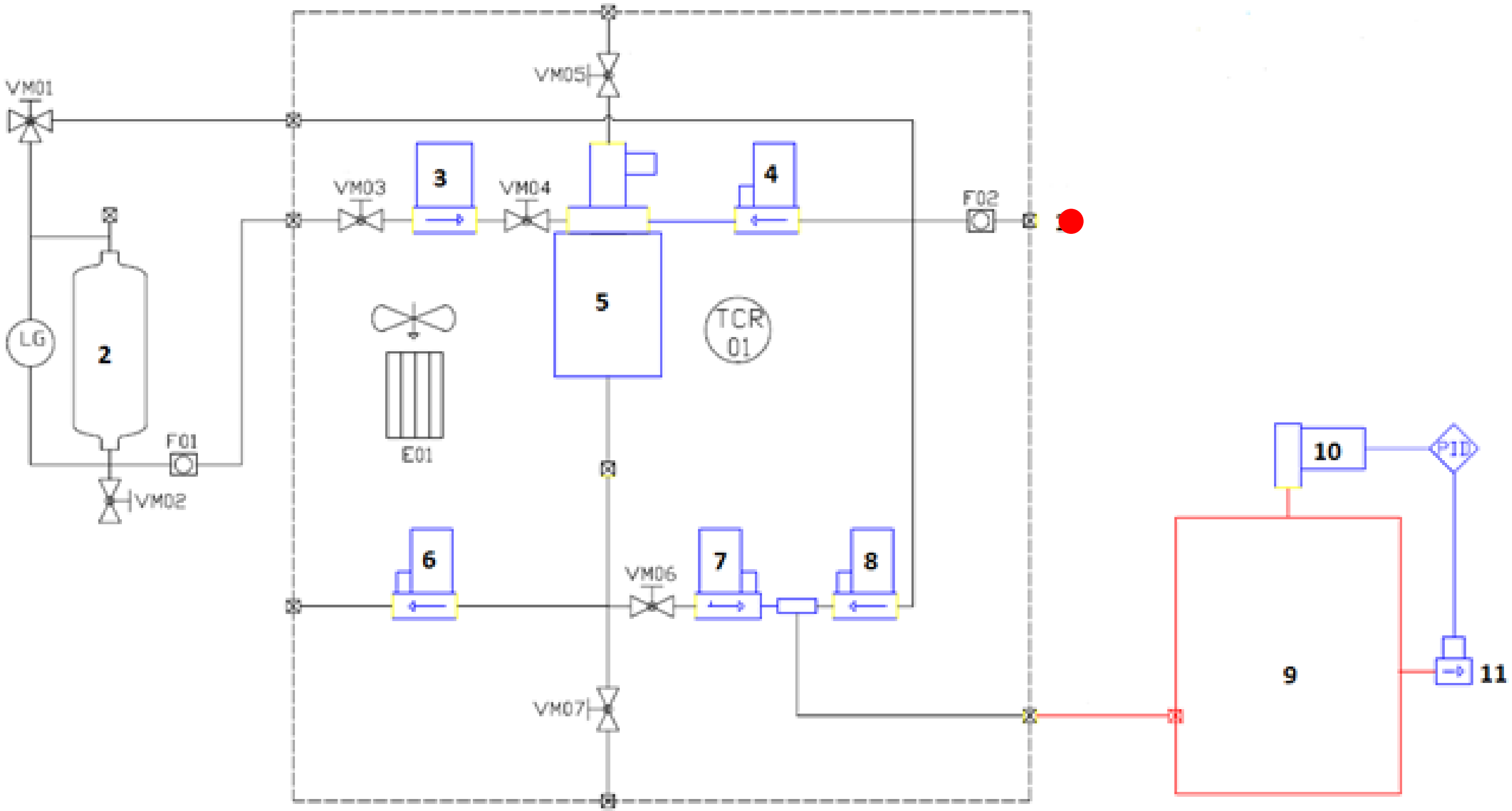

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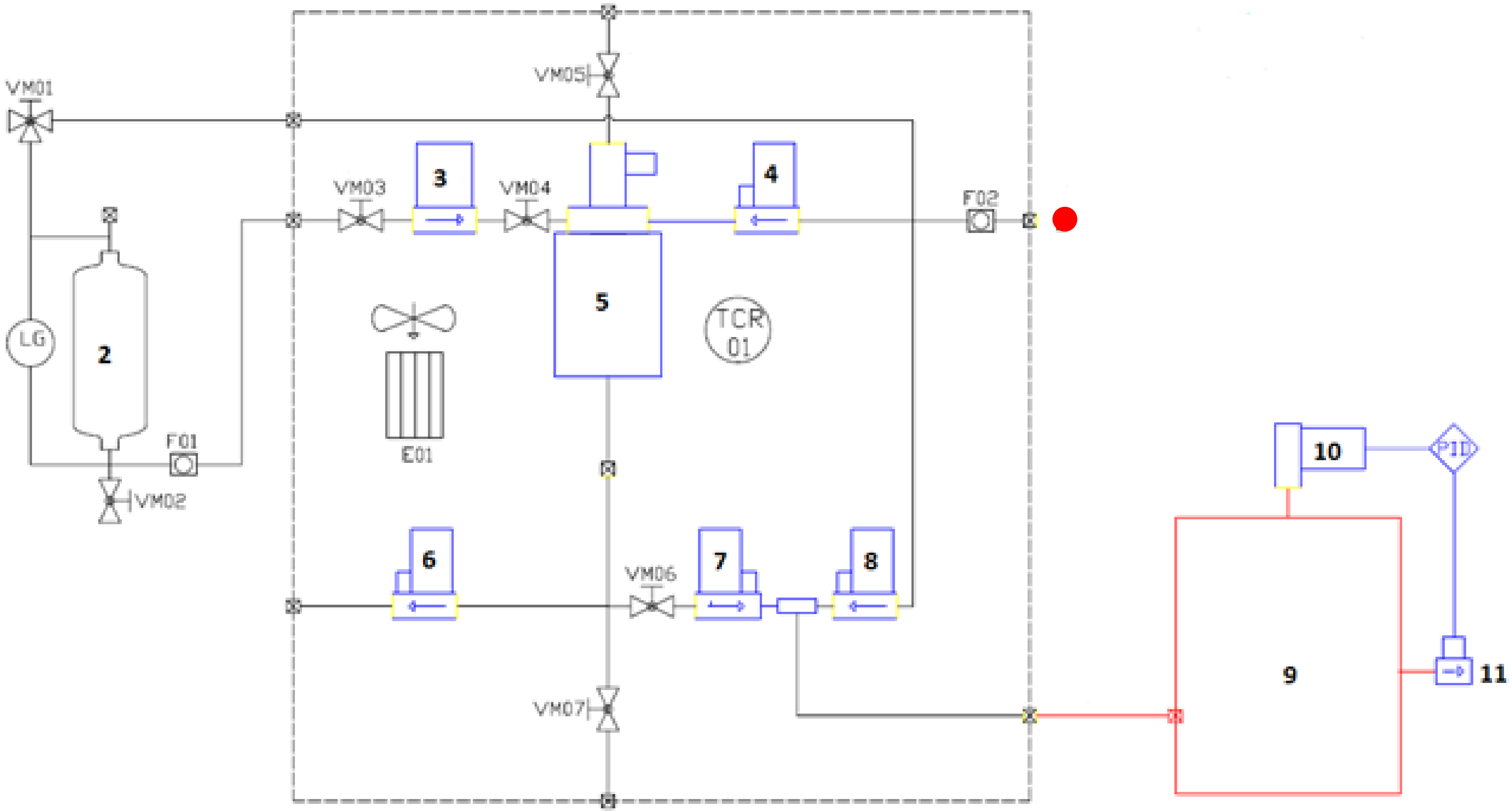

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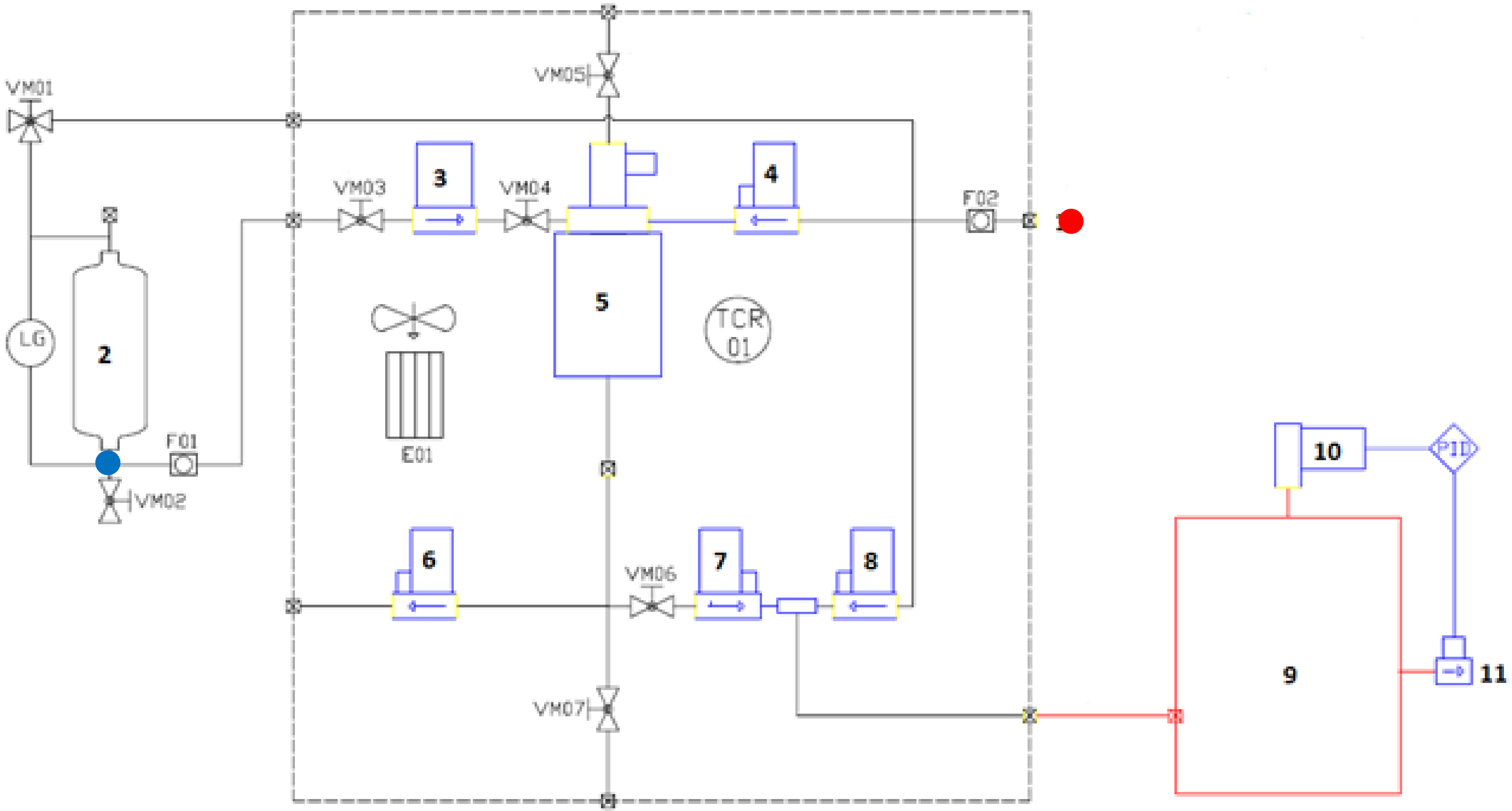

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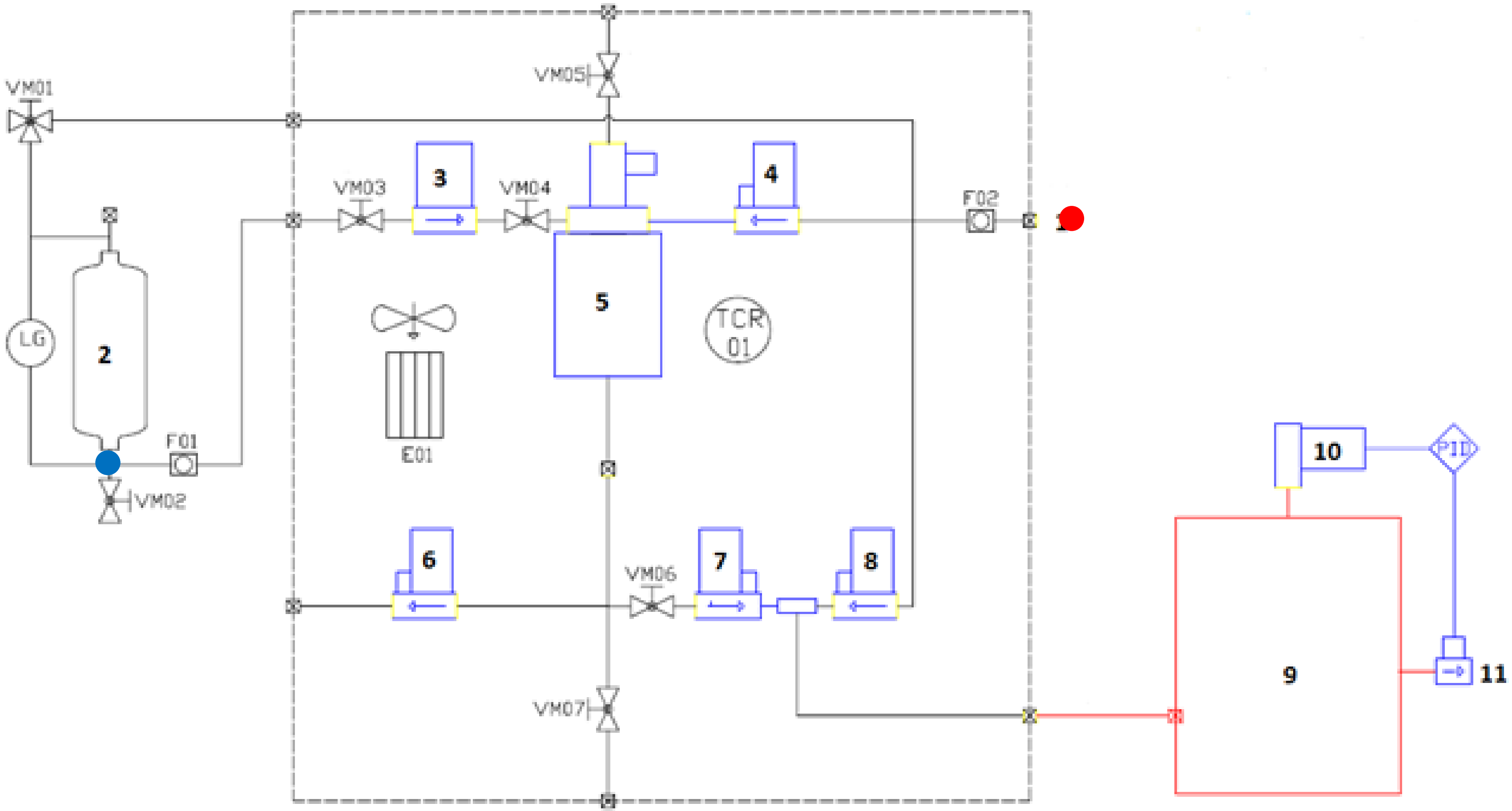

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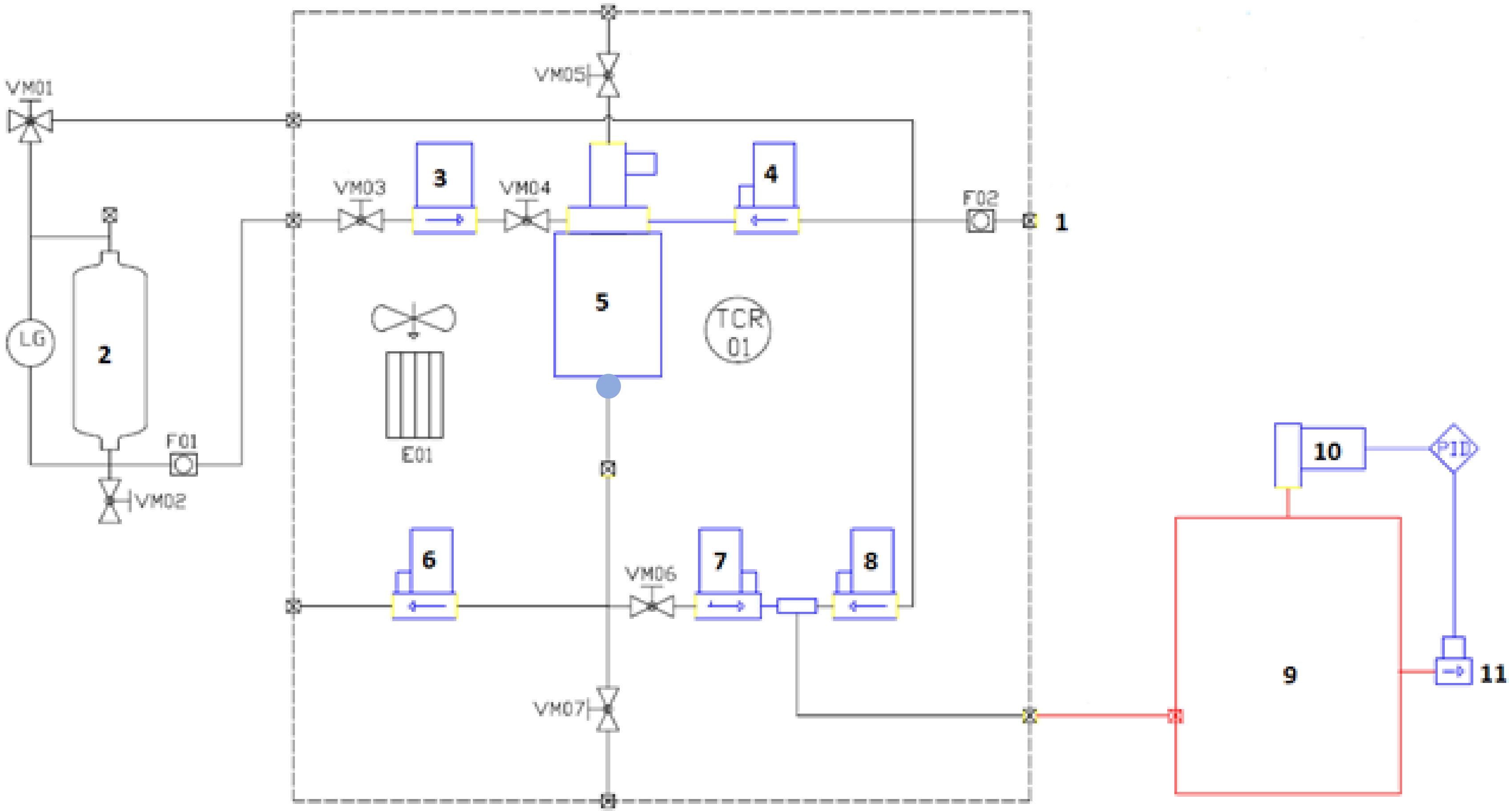

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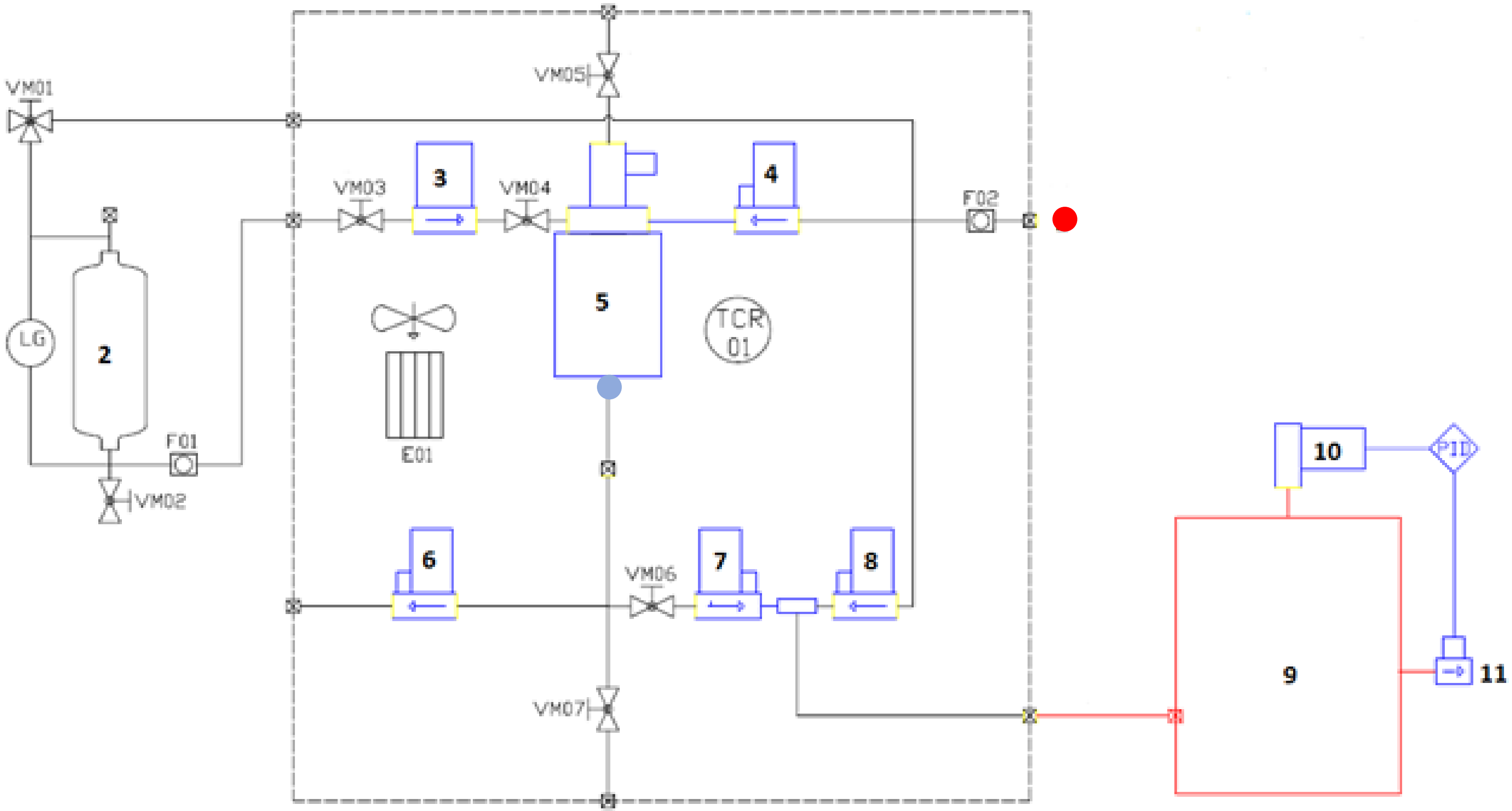

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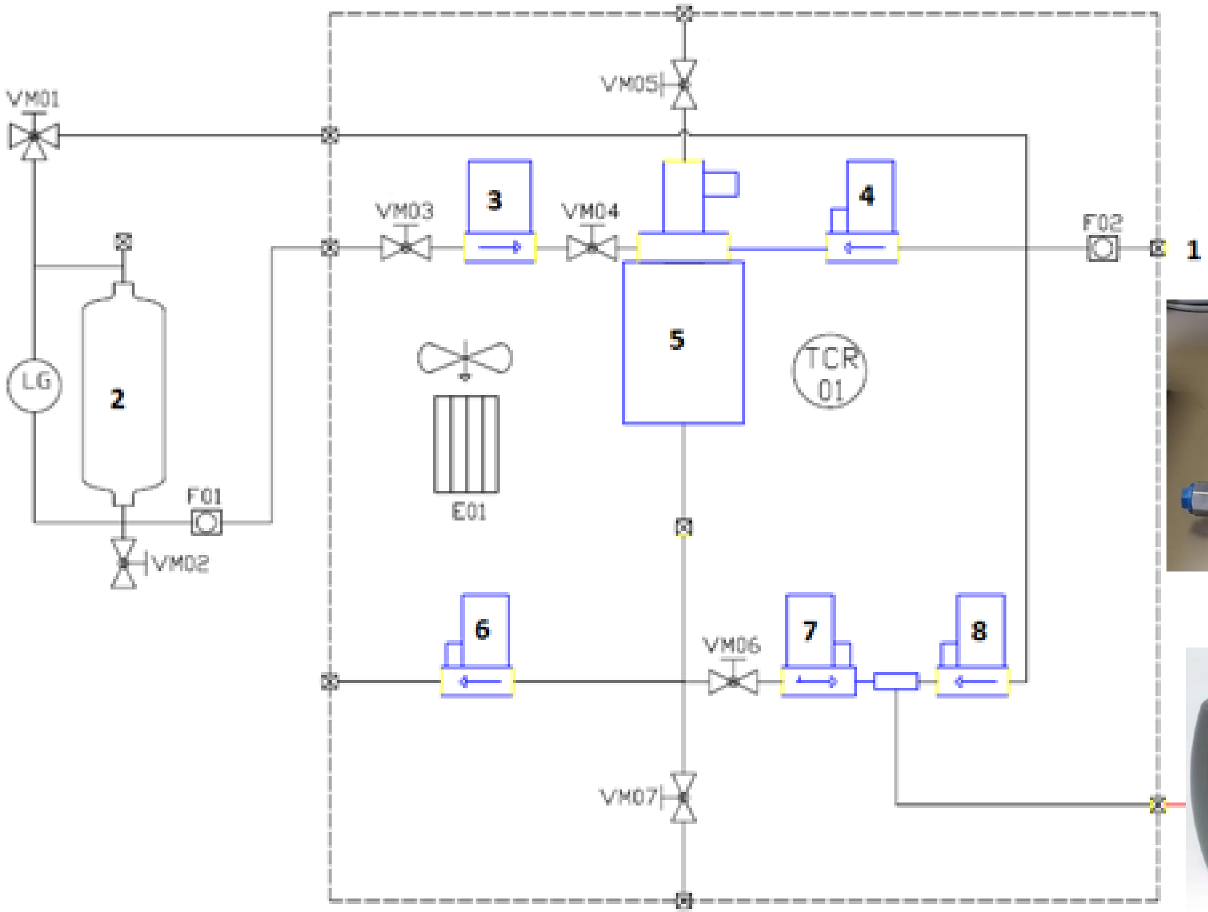

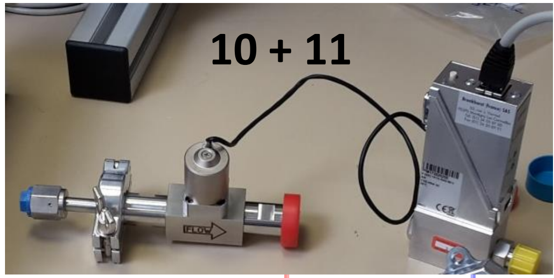

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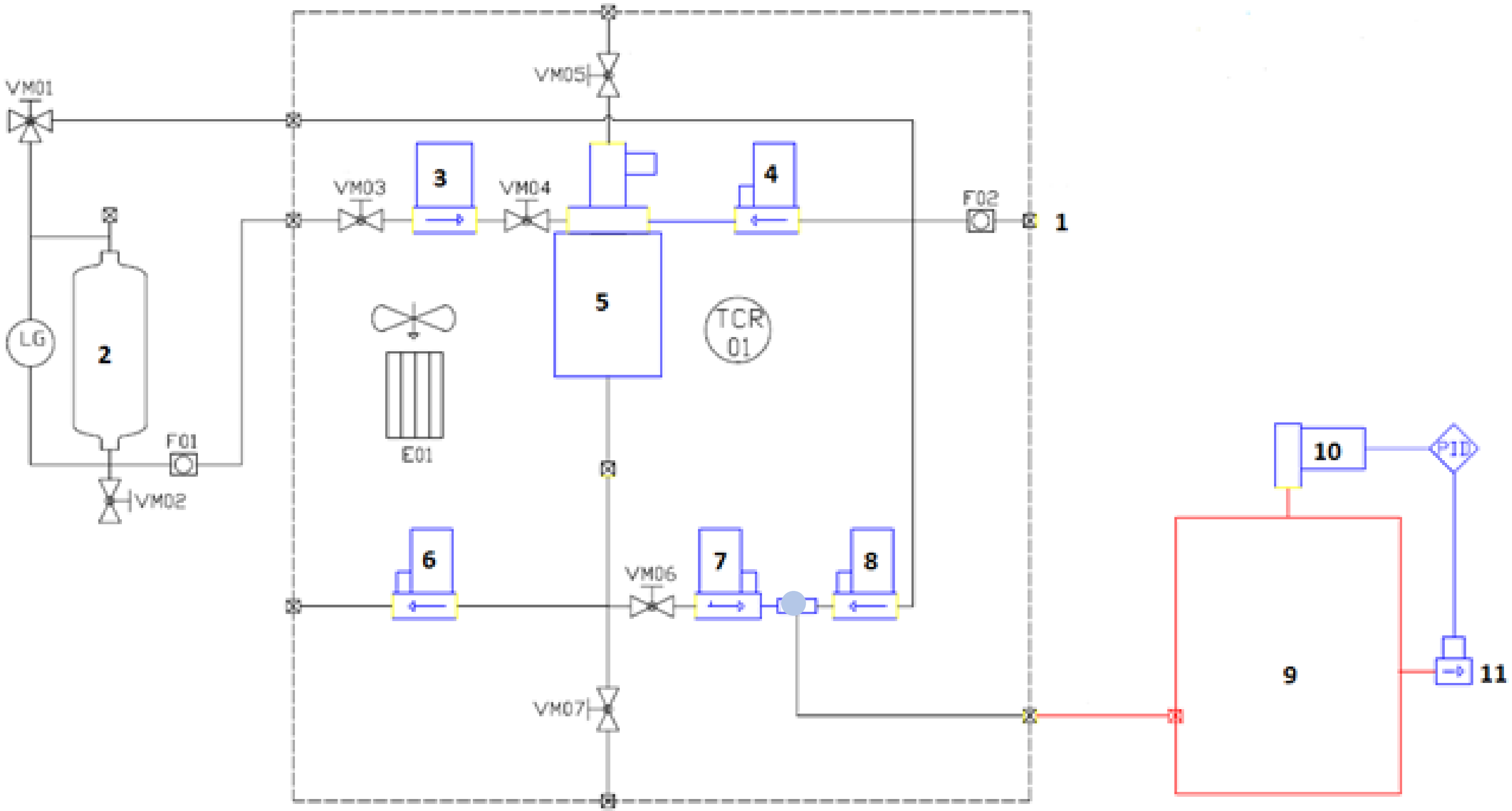

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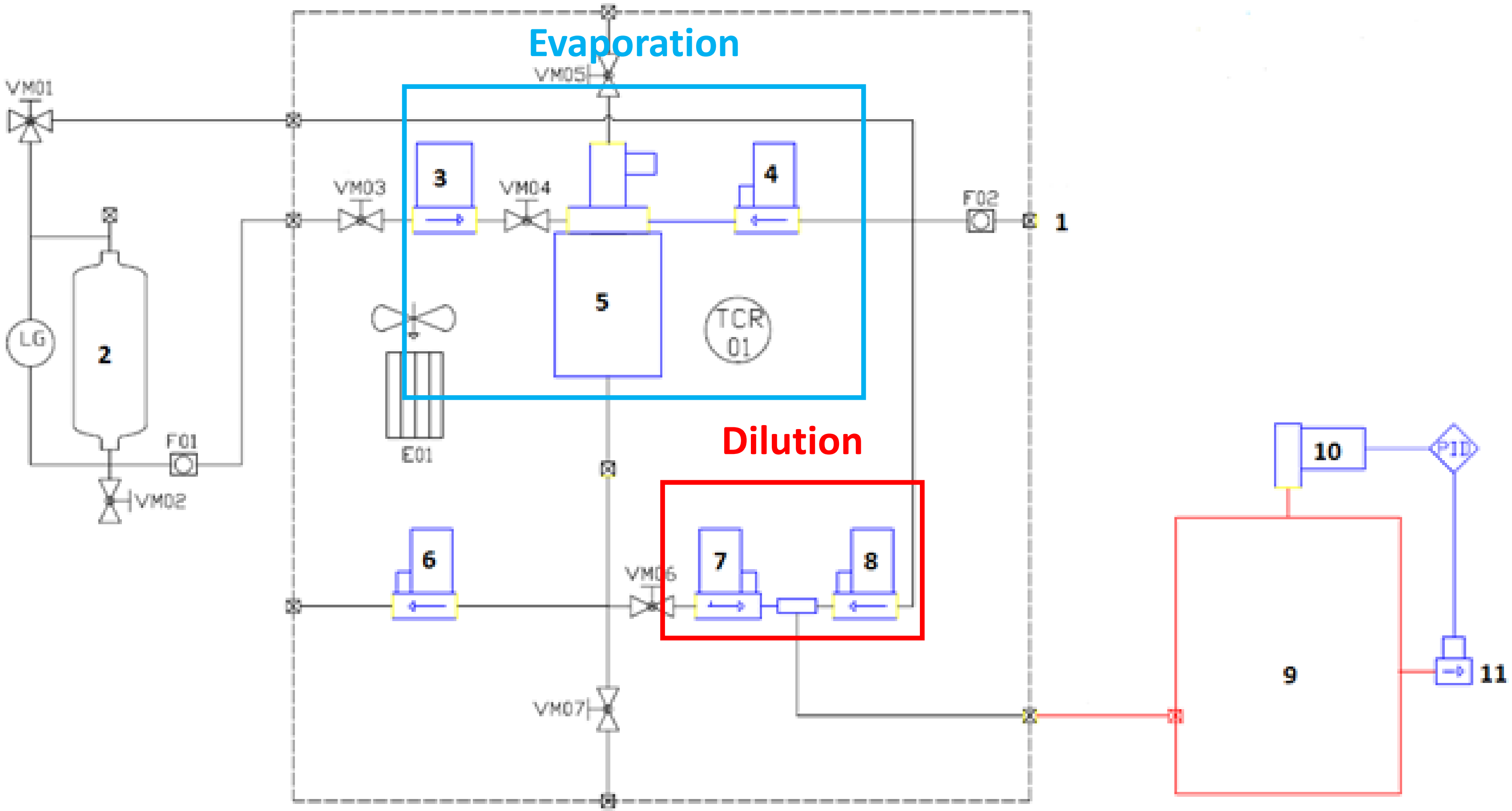


HAG / dilution (2/6)

- Ranges

Component's number	Component's name	Component's function	Range
3)	Coriolis mass flow controller	Injection of liquid water	1 g/h to 5 g/h
4)	Mass flow controller	Control of carrier gas flow	4,8 nl/h to 240 nl/h
6)	Pressure controller	Control of pressure before sampling	200 mbara to 10 bara
7)	Mass flow controller	Control of flow sample	4,8 nml/h to 240 nml/h
8)	Mass flow controller	Control of dilution gas flow	0,8 nl/h to 40 nl/h

HAG / dilution (3/6)

- Evaporation step

$$r_{evap} = \frac{m_{water}}{m_{MFC1}} = \frac{\dot{m}_{water}}{\dot{m}_{MFC1}}$$

$$u(r_{evap}) = \sqrt{\left(\frac{1}{\dot{m}_{MFC1}}\right)^2 \cdot u^2(\dot{m}_{water}) + \left(-\frac{\dot{m}_{water}}{(\dot{m}_{MFC1})^2}\right)^2 \cdot u^2(\dot{m}_{MFC1})}$$

Mesurand	Value		$U_{k=2}$
$\dot{m}_{water}$	5 g/h	$0,5.10^{-3}$ kg/h	4.10^{-5} kg/h
Q_{MFC1}	240 nl/h	0,31 kg/h	$1,2.10^{-3}$ kg/h
r_{evap}	$1,6.10^{-3}$ kg v./kg d.a.		$1,61.10^{-3}$ kg v./kg d.a.

HAG / dilution (4/6)

- Dilution step

$$r_{dilution} = \frac{\dot{m}_{MFC2} \cdot r_{evap}}{\dot{m}_{MFC2} + \dot{m}_{MFC3}}$$

$$u^2(r_{dilution}) = \left(\frac{\dot{m}_{MFC3} \cdot r_{evap}}{(\dot{m}_{MFC2} + \dot{m}_{MFC3})^2}\right)^2 \cdot u^2(\dot{m}_{MFC2}) + \left(-\frac{\dot{m}_{MFC2} \cdot r_{evap}}{(\dot{m}_{MFC2} + \dot{m}_{MFC3})^2}\right)^2 \cdot u^2(\dot{m}_{MFC3}) + \left(\frac{\dot{m}_{MFC2} \cdot \dot{m}_{MFC3} + \dot{m}_{MFC2}{}^2}{(\dot{m}_{MFC2} + \dot{m}_{MFC3})^2}\right)^2 \cdot u^2(r_{evap})$$

Mesurand	Value		$U_{k=2}$
Q_{MFC2}	8,3 nml/h	$1{,}07.10^{-5}$ kg/h	$1{,}1.10^{-5}$ kg/h
Q_{MFC3}	40 nl/h	$5{,}17.10^{-2}$ kg/h	$2{,}9.10^{-4}$ kg/h
r_{evap}	$1{,}6.10^{-3}$ kg v./kg d.a.		$1{,}61.10^{-3}$ kg v./kg d.a.
r_{dil}	$3{,}33.10^{-7}$ kg v./kg d.a.		$3{,}33.10^{-7}$ kg v./kg d.a.

HAG / dilution (5/6)

- From r_{dilu} to $\theta_{d/f}$

$r_{dilu} \rightarrow x_v \rightarrow e' \rightarrow e \rightarrow \theta_{d/f}$

$$x_v = r_{dilu} \cdot \frac{M_{dry\ gas}}{M_{water}}$$

$$e' = x_v \cdot p$$

$$e = \frac{e'}{f\left(p, \theta_{d/f}\right)}$$

$\theta_{d/f}$ - Wexler

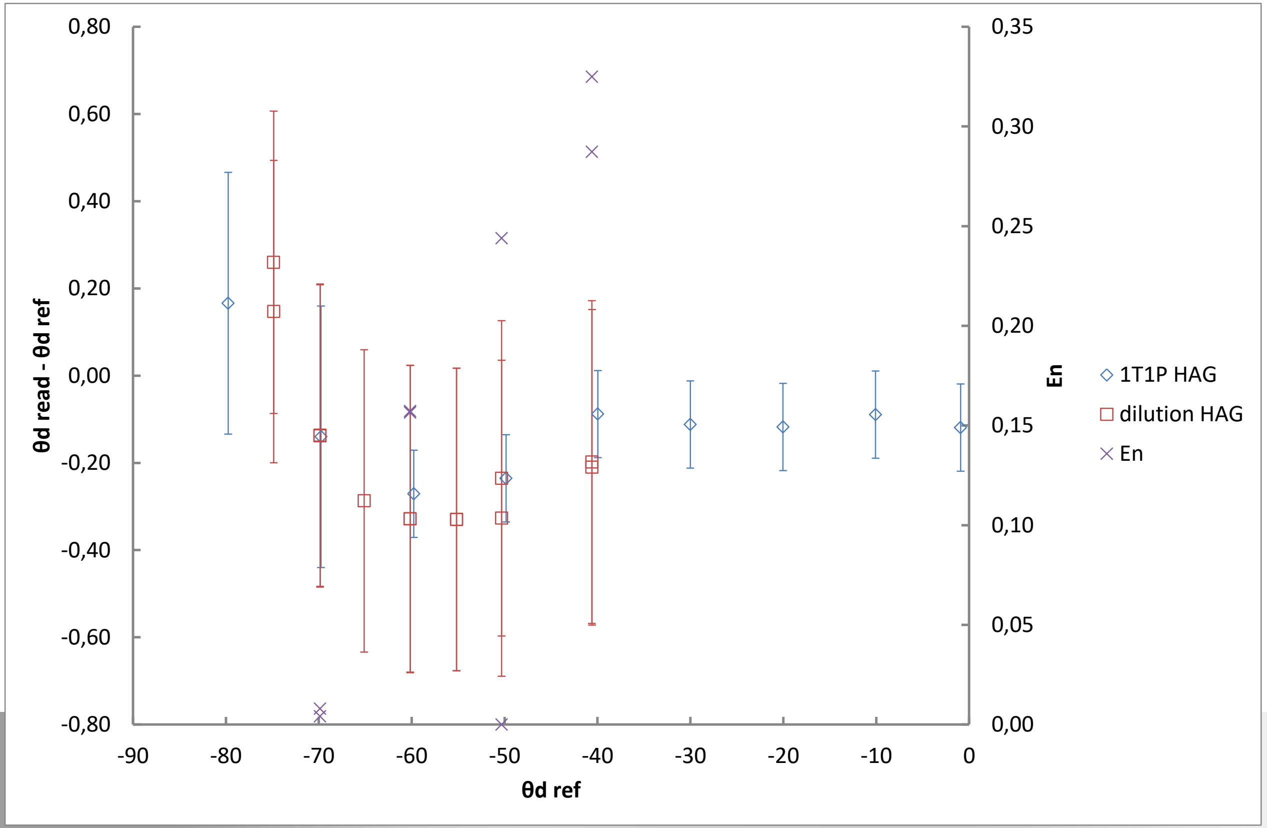
HAG / dilution (6/6)

- Expanded uncertainty

Mesurand	Value		$U_{k=2}$
$\dot{m}_{water}$	5 g/h	$0,5.10^{-3}$ kg/h	4.10^{-5} kg/h
Q_{MFC1}	240 nl/h	0,31 kg/h	$1,2.10^{-3}$ kg/h
Q_{MFC2}	8,3 nml/h	$1,07.10^{-5}$ kg/h	$1,1.10^{-5}$ kg/h
Q_{MFC3}	40 nl/h	$5,17.10^{-2}$ kg/h	$2,9.10^{-4}$ kg/h
p	101325 Pa		300 Pa
r_{evap}	$1,6.10^{-3}$ kg v./kg d.a.		$1,61.10^{-3}$ kg v./kg d.a.
r_{dil}	$3,33.10^{-7}$ kg v./kg d.a.		$3,33.10^{-7}$ kg v./kg d.a.
θ_{ref}	-80 °C		**0,35 °C**

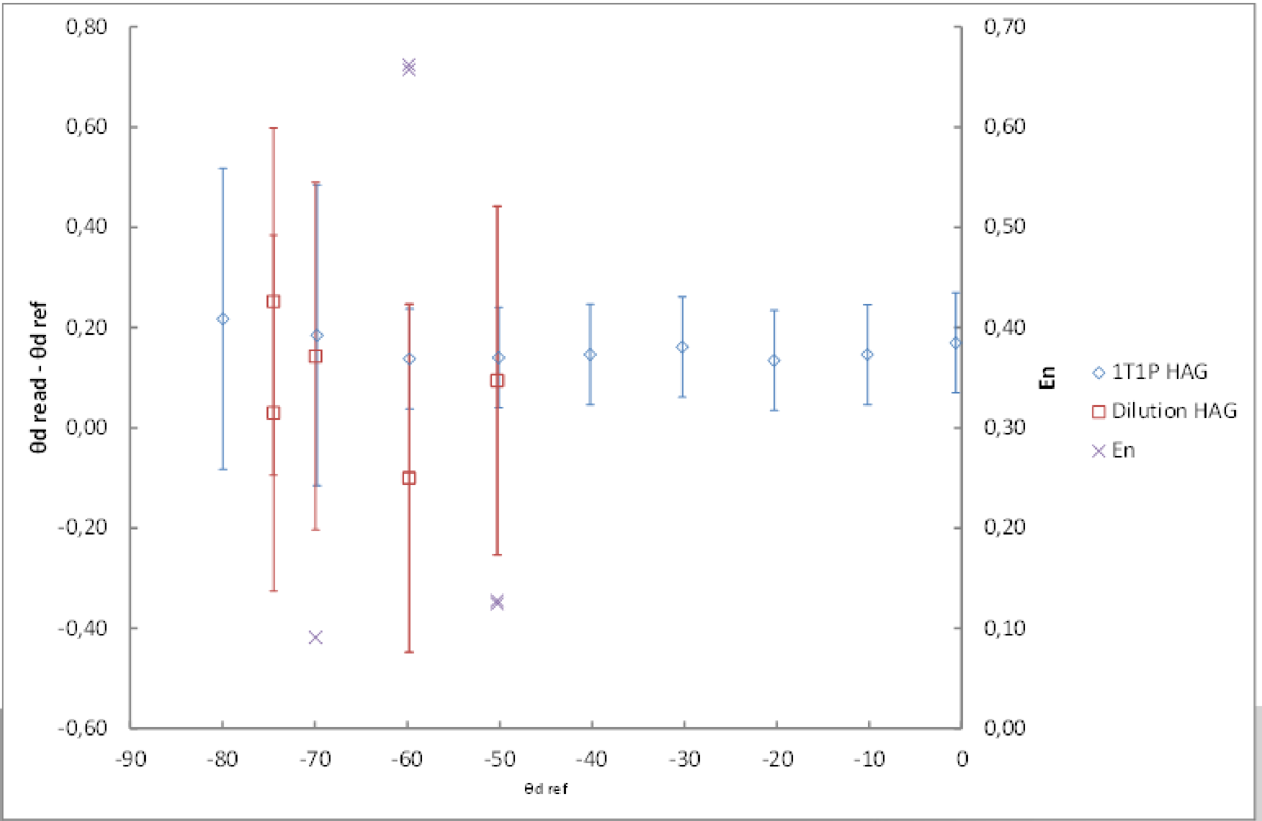
Results (1/3)

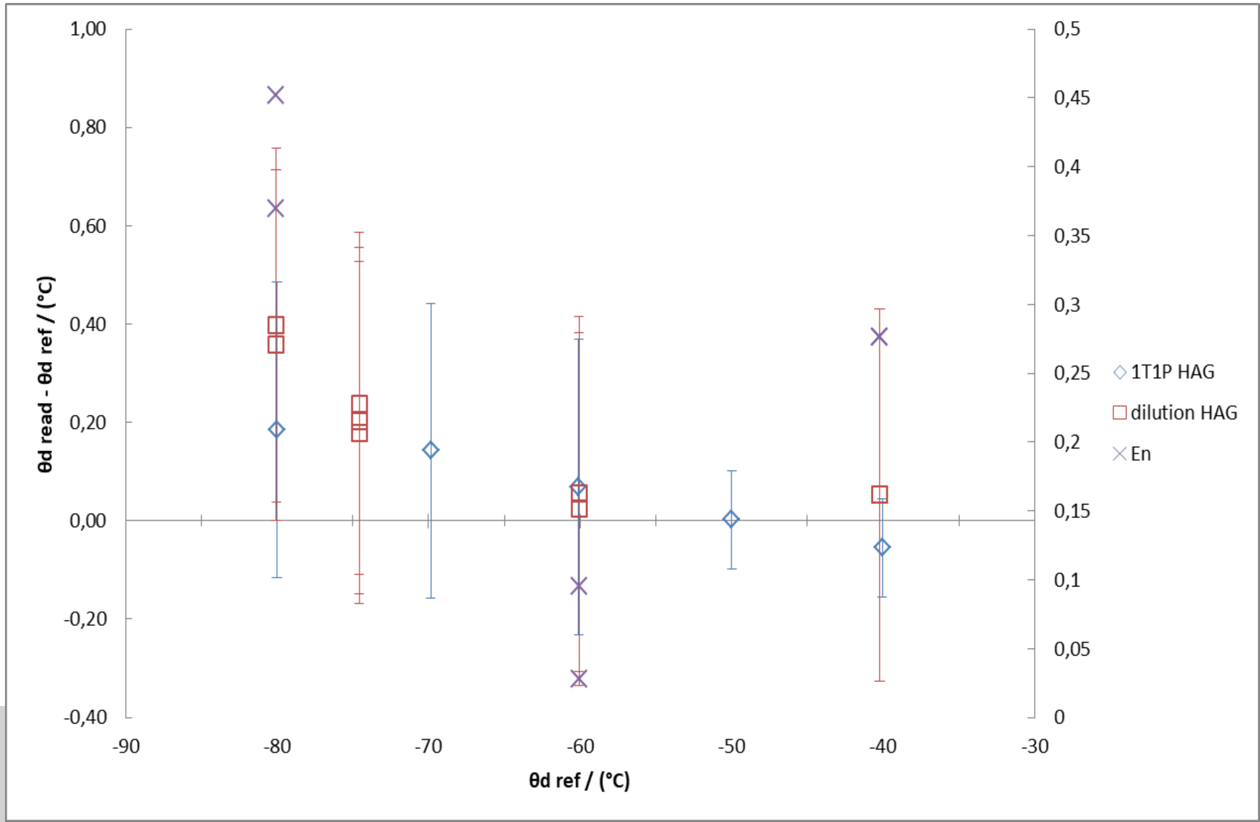
- Intra-laboratory comparison: 1T1P HAG vs HAG/dilution
  - Travelling standards:
    - MBW DP30



Results (2/3)

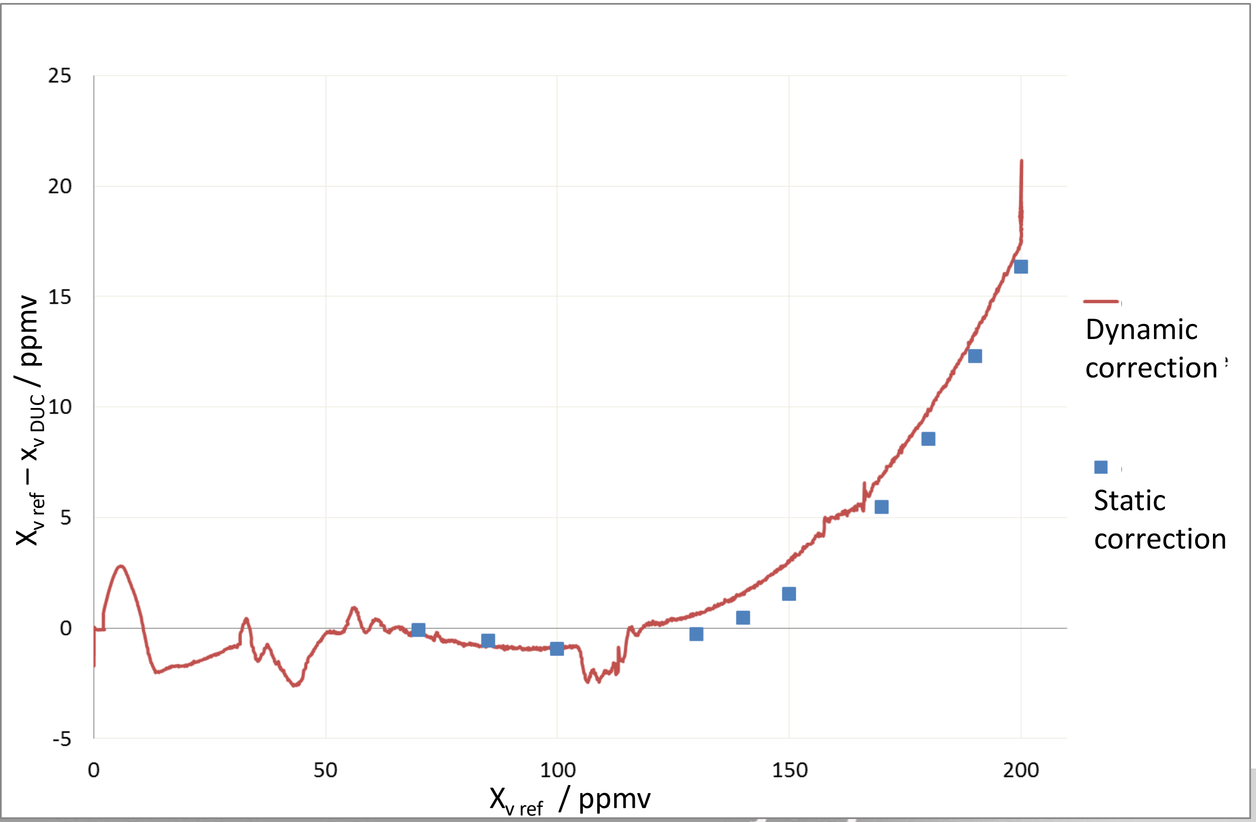
- Intra-laboratory comparison: 1T1P HAG vs HAG/dilution
  - Travelling standards:
    - MICHELL Instruments S8000 RS
    - MICHELL Instruments S8000 -100

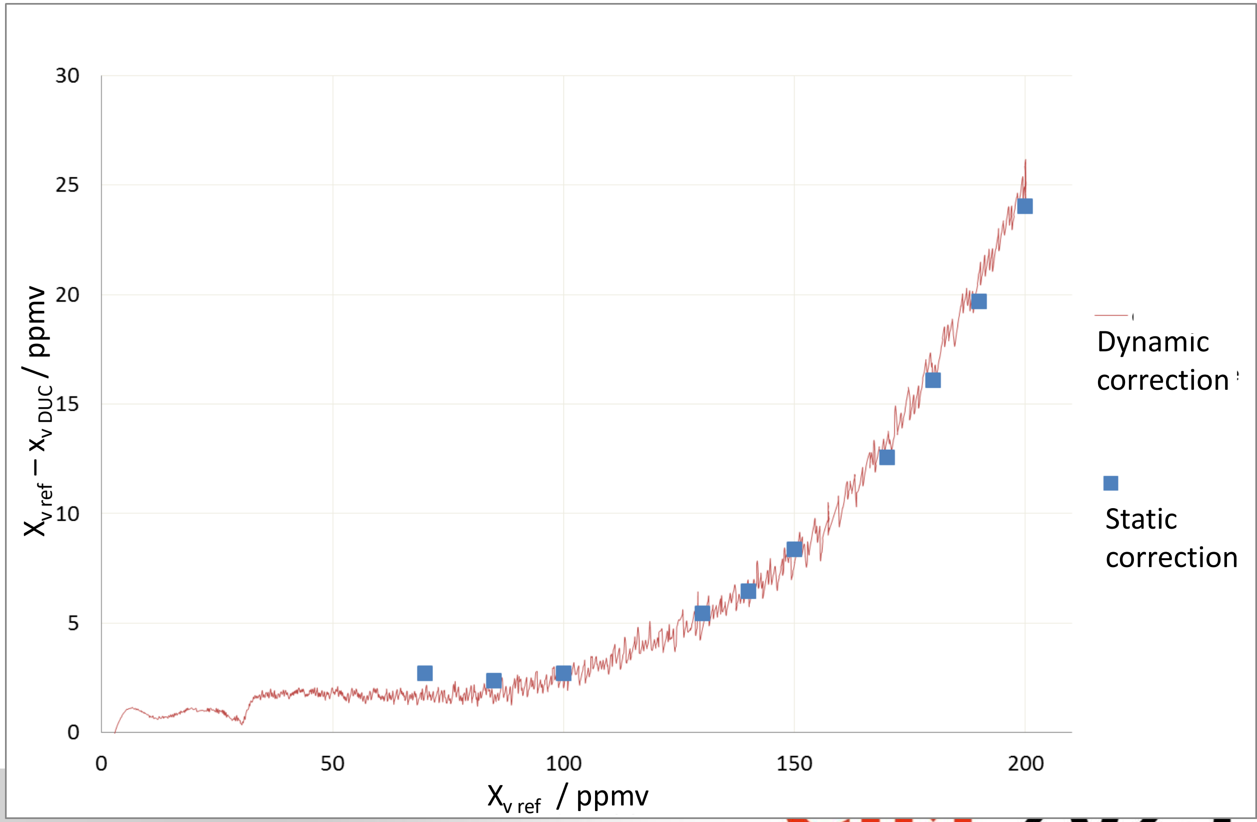




Results (3/3)

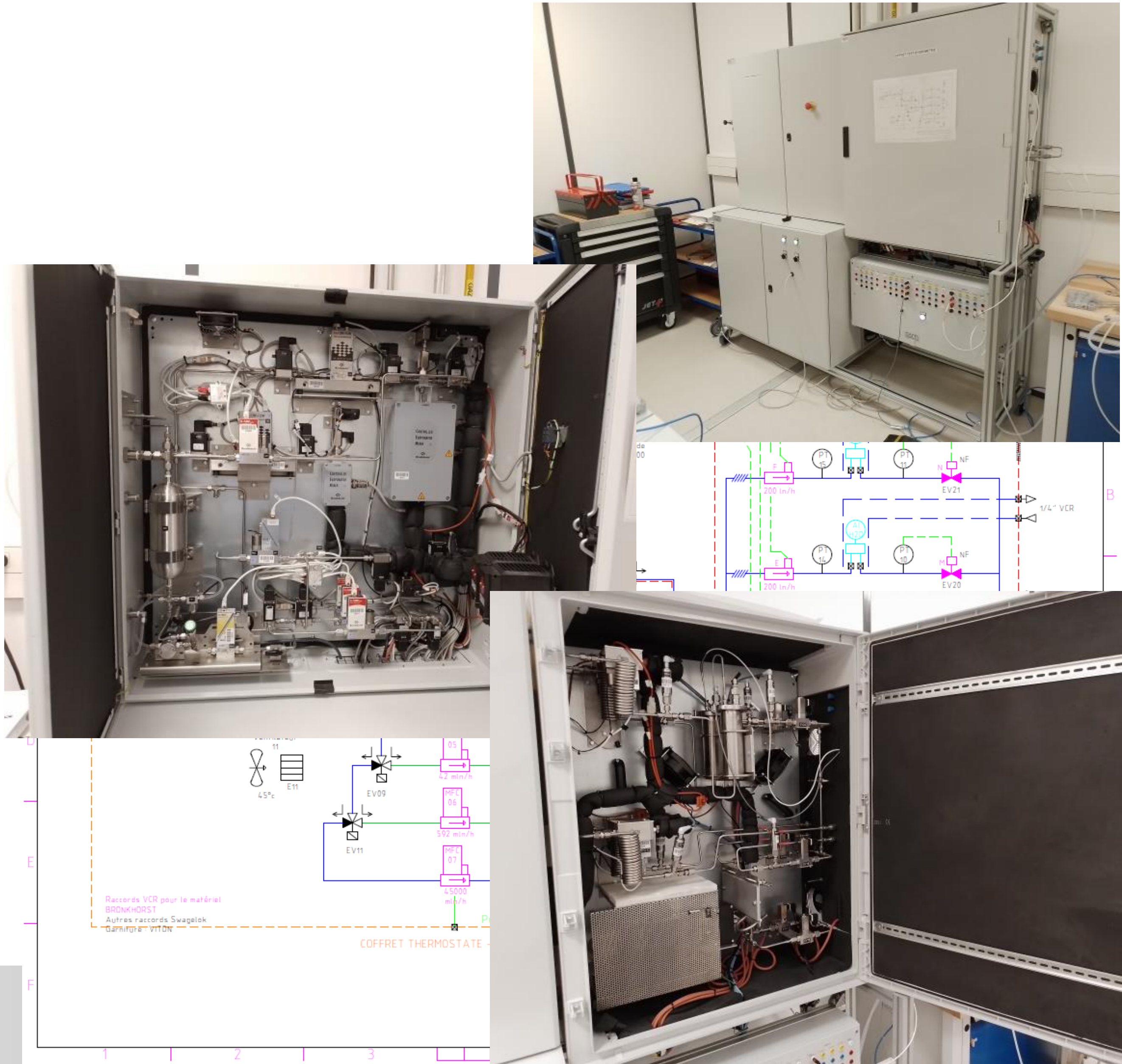
- Dynamique calibration
  - Based on the idea proposed by VTT-MIKES (JRP 14IND11 HIT)
  - Static calibration vs Dynamic calibration





Conclusion and next steps

- Validation has been done
  - Up to -80 °C
  - At atmospheric pressure
- Investigation of dynamic calibration
  - Promising perspectives have been observed
- Validate the evaporation HAG
  - Below -80 °C
  - Pressure up to 10 bar abs.
- Increase the calibration capabilities with HAG/dilution



Aknowledgments

- Institutions
  - EMPIR initiative, co-funded by European Union's Horizon 2020 research and innovation programme and the EMPIR participating States
  - French Metrology

The EMPIR initiative is co-funded by the European Union's Horizon 2020 research and innovation programme and the EMPIR Participating States

- Providers
  - Bronkhorst
  - 2MProcess
  - MICHELL Instruments

Thank you for your attention