CF4 RECUPERATION SUMMARY
RICH2 - LHCB

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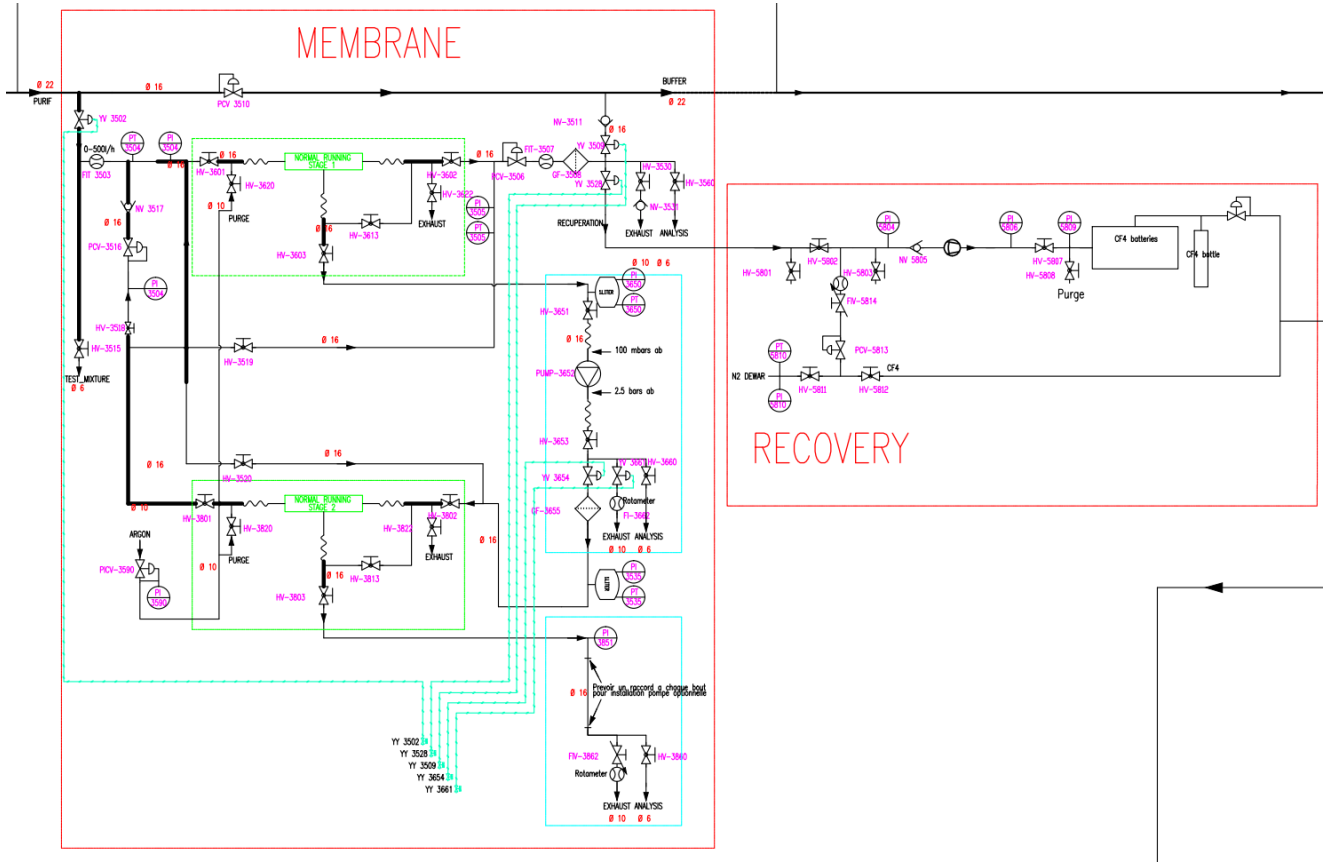
October 2019

RICH2 – CF4 RECUPERATION SYSTEM

RICH2 CF4 recuperation System is composed by:

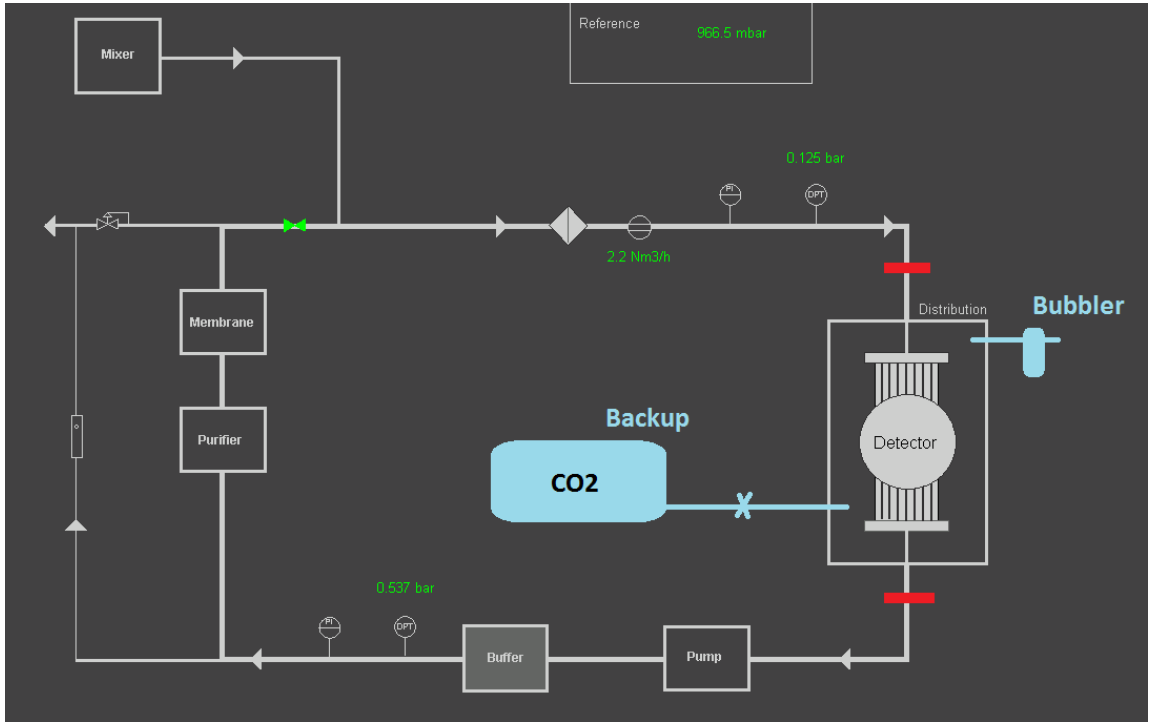
- Membrane Module:
  contains separating membranes (2) originally for N2 separation
- Purifier Module:
  normally in the Loop, was moved after the Membrane module to increase purification of CF4 from residual CO2
- Recovery Module:
  allows the actual recuperation of the purifier CF4 into a battery



GAS SYSTEM STOP – BACKUP ACTION

RICH2 gas system was stopped in Dec 2018, leaving as safety measure the bubbler and the CO2 backup line

- **Bubbler:**
  if Patm decreases, the pressure inside the chamber increases, and gas mixture will exhaust from the bubbler to keep it stable
- **CO2 Backup:**
  if Patm increases, the pressure inside the chamber decreases, CO2 will flow through the valve regulated by pressure difference, filling the chamber up to stable pressure



GAS SYSTEM STOP – BACKUP ACTION

Looking at the Patm trend, we can estimate how much CO2 was injected from the backup, taking the positive pressure variations and converting the pressure difference in CO2 volume

Patm increase [mbar] = Injected CO2 [mbar]

Total System Volume = 100’000 liters

>> 1 mbar Δp = 100 liters CO2

Sum of positive Δp over the period Dec2018 – March2019 gives a total variation of about 270 mbar

=27’000 liters of CO2 injected

GAS SYSTEM STOP – BACKUP ACTION

For 27’000 liters of CO2 injected, about 24’300 liters of CF4 went to the exhaust

Leaving the system in STOP with the Backup for four months
cost the loss of about 25’000 liters of CF4!

Gas Mixture	Before YETS	March 2019
Air %	2	2
CF4 %	**90**	**60**
CO2 %	8	38

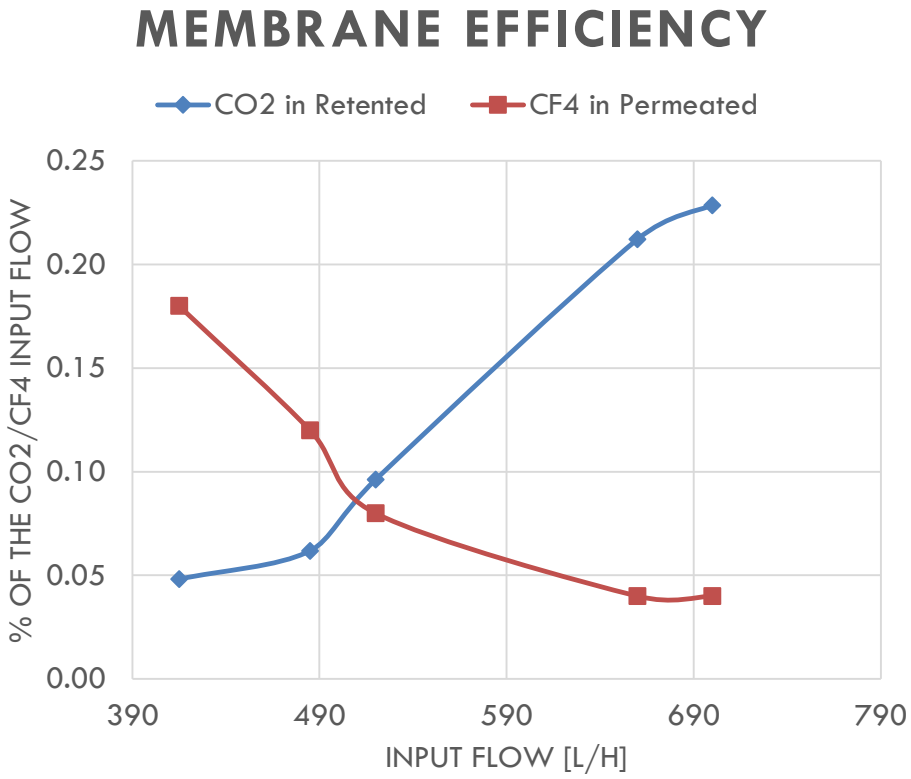
MEMBRANE RACK TESTS

- Many tests were done on the membrane rack between May and July 2019
- Membranes already present in the rack (old LHCb) were found to be either leaking (M2 old) or not with optimal efficiency (M1 old)
- A new membrane was installed, from CMS CSC CF4 Recovery

  > **membrane CO-C10 from UBE**
- Efficiency of UBE membrane found to be good
- Not much improvement when operating the UBE membrane + M1 old

MEMBRANE RACK TESTS

- Membranes have a different efficiency depending on the input gas flow rate
- The higher is the flow, the less is the CF4 lost in the permeated gases, but the higher is the CO2 that passes into the retented gases
- Compromise has to be found, taking into account that is important to have the least possible CO2 in the recuperated batteries



From old Roberto's test

MEMBRANE RACK TESTS

Summary of operation in different configurations

Input Flow [l/h]	Membrane	%flow Ret	%CF4 Ret	%CO2 Ret	%Air Ret	%CF4 Mix	%CO2 Mix	%Air Mix
265 l/h	M1old	49%	81%	3%	10%	97%	2.5%	0.5%
335 l/h	M1old	56.6%	81%	4%	17%	97%	2.5%	0.5%
415 l/h	M1old	53%	85%	5.5%	12.5%	95%	4%	1%
315 l/h	M1old+M2old	47%	77%	3.5%	8%	96.5%	3%	0.5%
430 l/h	M1old+M2old	52%	84%	6.5%	25%	94%	5%	1%
298 l/h	**M UBE**	**51%**	**85%**	**1%**	**17%**	**98%**	**1%**	**1%**
332 l/h	M UBE + M1old	53%	86%	3%	17%	97%	2.5%	0.5%

START OF RECUPERATION

- Effective recuperation starts in July 2019

  > during previous tests, the membrane output was reinjected in the system
- Operation starts with only one membrane, the UBE CO-C10
- Gas mixture composition in the different points is the following:

	Input	Output	Before Purifier	After Purifier	Permeate
Air	0.02	0.01	0.01	0.009	0.02
CF4	0.38	0.97	0.97	0.989	0.08
CO2	0.60	0.02	0.02	0.002	0.90

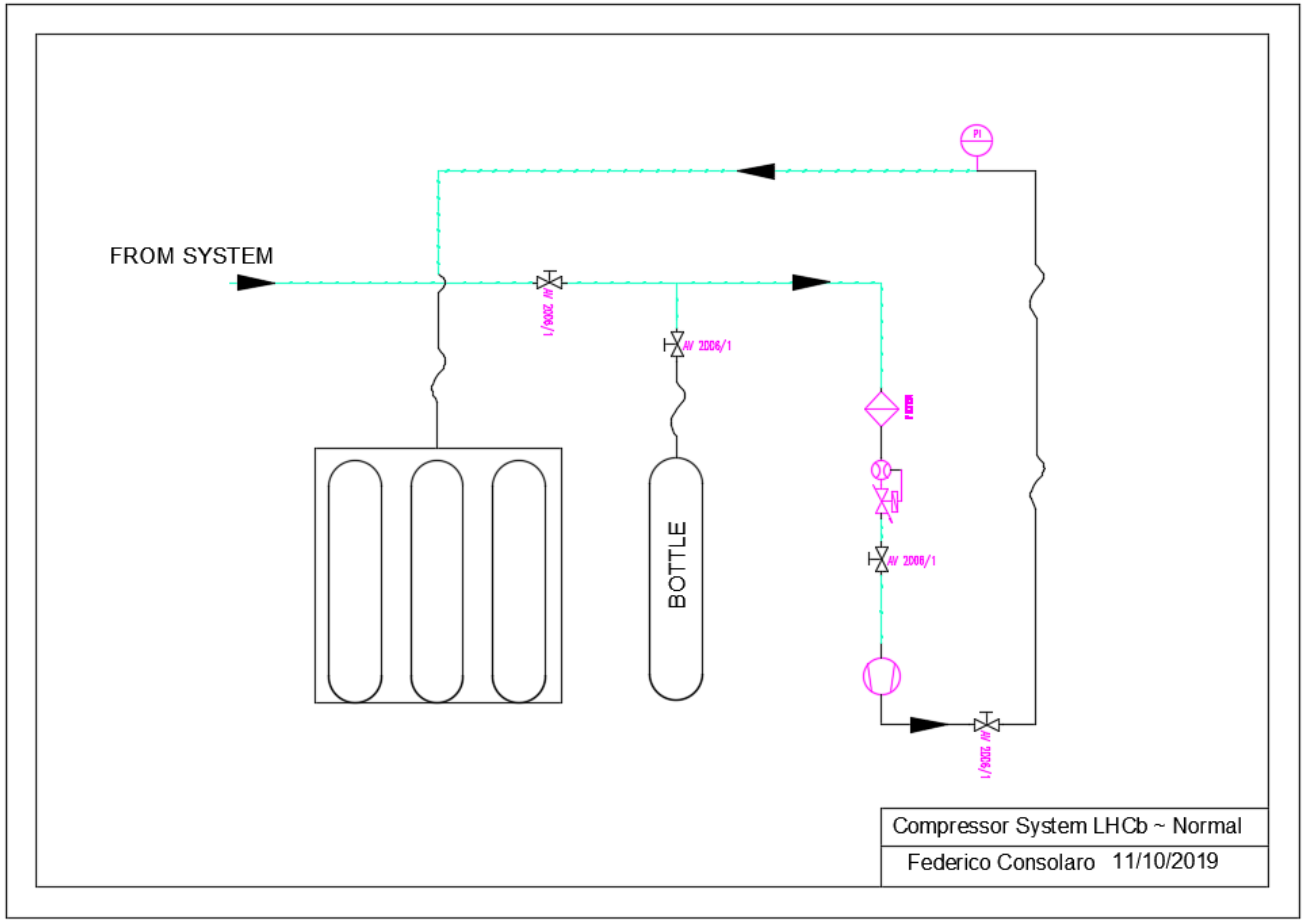
START OF RECUPERATION

- The *purifier module* position is changed, to be placed *after* the membrane module to adsorb remaining CO2 in the permeate mixture

- The initial configuration of the storage side is made with a compressor and a buffer volume (50l empty bottle), to allow the compressor to work in a suitable range of input pressure

- A first test is done sending the recuperated gas into a 50 liters bottle, and after that recuperation is started sending the gas to the 50litersX12 battery > battery starting pressure is 1.8bar (transferred from bottle)

START OF RECUPERATION



CF4 MEMBRANE EFFICIENCY CALCULATION

Input membrane reading (MFC calibrated for air)(m^3/h)

* 1000 → input membrane (MFC calibrated for air)(l/h)

* conversion factor (dependent by the mixture concentration)

* %CF4 in that day→ input concentration from GC analysis

= flow CF4 input membrane(corrected)(mix)(l/h)

Output membrane reading (MFC calibrated for air)(m^3/h)

* 1000 → output membrane (MFC calibrated for air)(l/h)

* 0.44, conversion factor dependent on mixture concentration (98% CF4; 2% CO2)

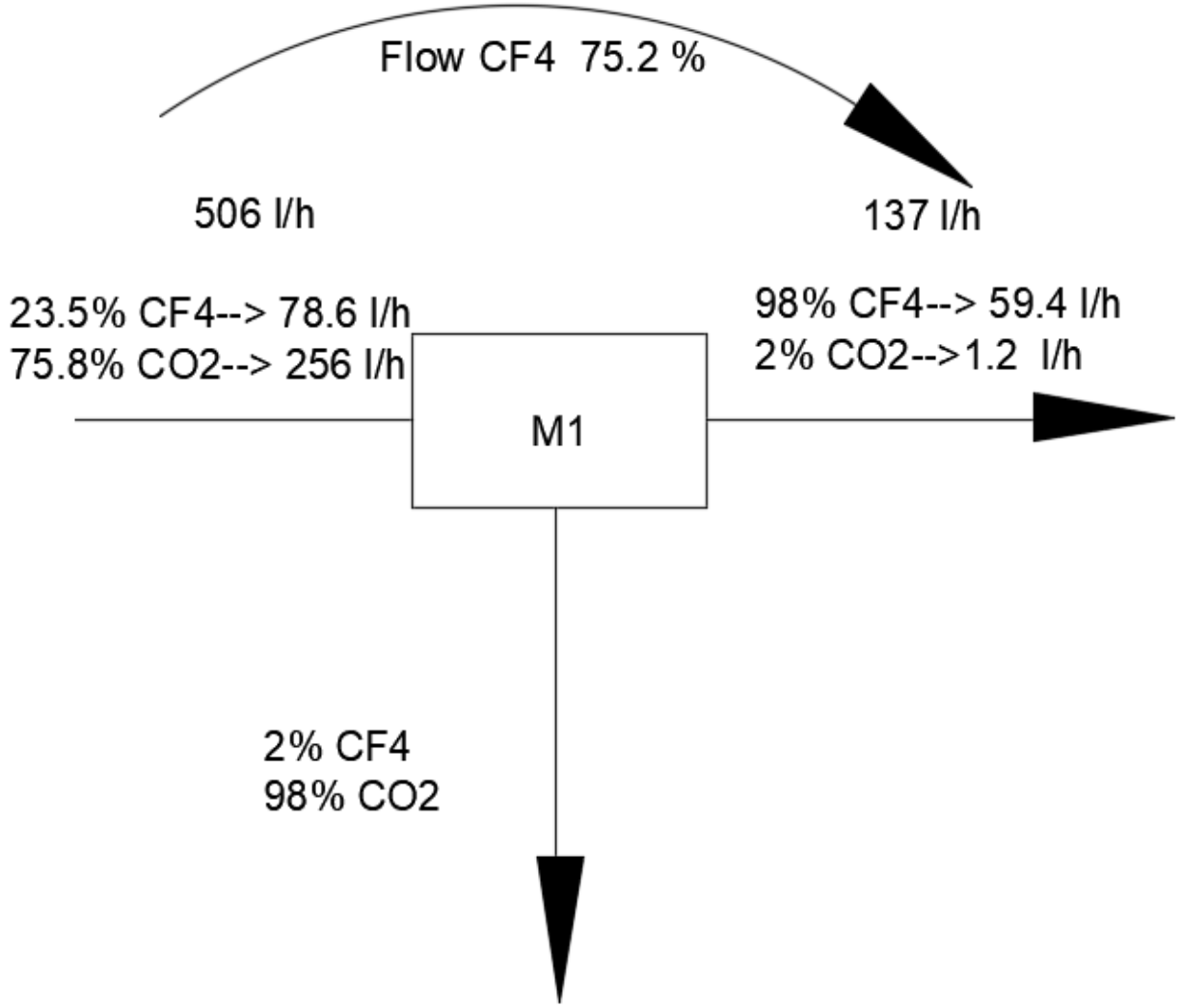
* 98% , CF4 concentration at output membrane

= flow CF4 output membrane(corrected)(mix)(l/h)

Output/Input*100 → Efficiency

EXAMPLE : 26 JULY 2019

Input CF4 %	**23.5 %**
Input CO2 %	75.8 %
Membrane CF4 Separation Efficiency	**75.83 %**
Input CF4 Flow	78.6 l/h
Output CF4 Flow	41.5 l/h
Permeate CF4 Flow	19 l/h
Operation Duration	123.5 hrs
Final Battery Pressure	38.15 bar

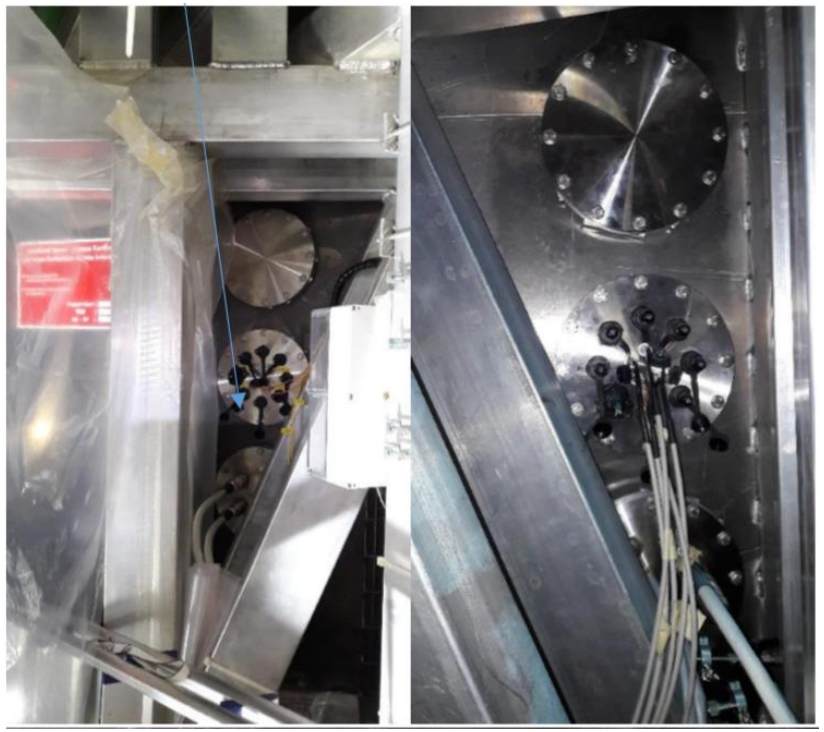


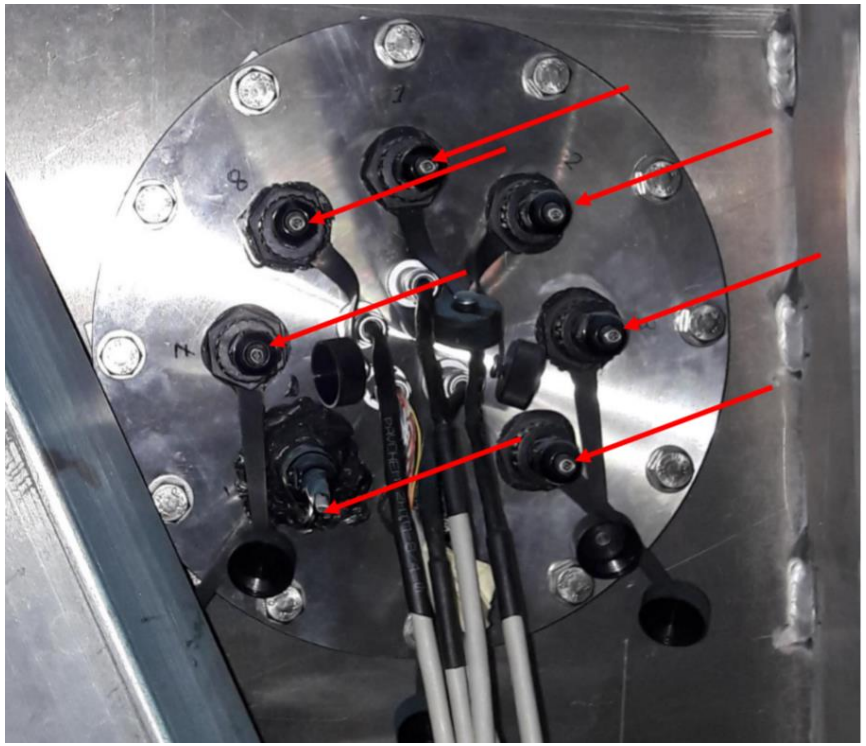
HISTORY

21/05 : end of Membrane Module tests
06/06 : system OFF
07/06 : membranes moved out of rack
10/06 : purifier module moved after membrane module
13/06 : recovery – 7.5 hrs
14/06 : recovery – 8 hrs
02/07 : recovery – 6.5 hrs
04/07 : recovery – 9.5 hrs
05/07 : recovery – 10 hrs
07/07 : system OFF
08/07 : recovery – 103 hrs
13-26/07 : leak from underground piping
26/07 : recovery – 123.5 hrs
08/08 : recovery - 24.5 hrs
13/08 : bypass from battery to compressor (no pressure cycle)
13/08 : recovery - 55 hrs
27/08 : recovery – 53 hrs
11/09 : change of Output MFC (lower range)
12/09 : recovery - 47.5 hrs
01/10 : recovery – 30 hrs

HISTORY

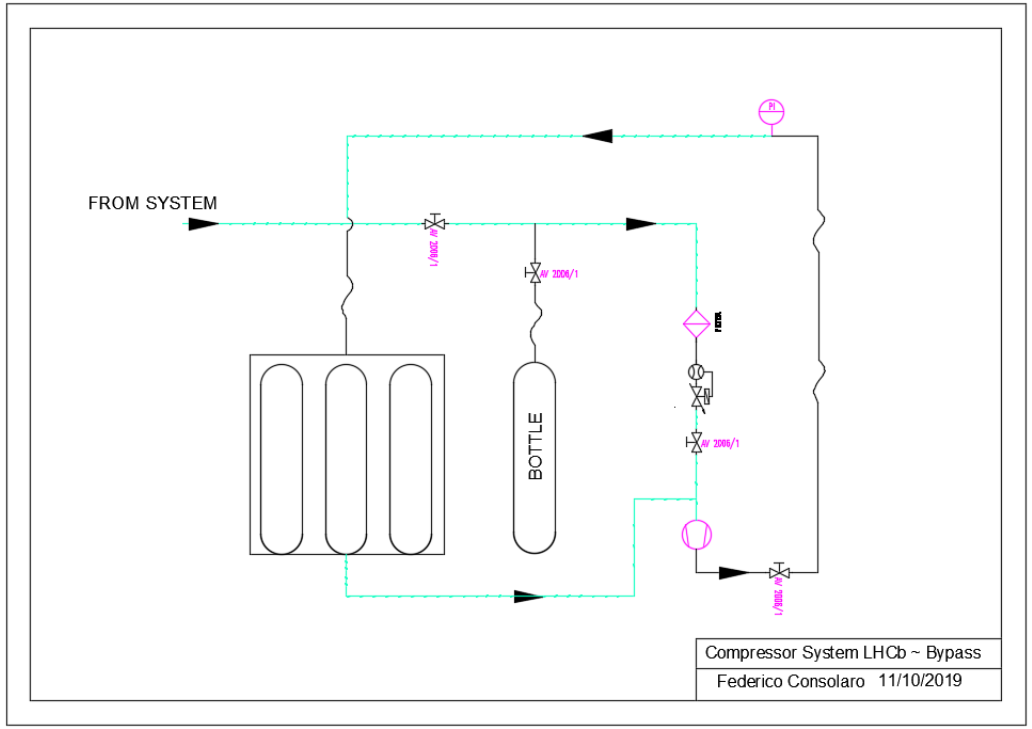
12-26 July : There were some problems with underground piping
> about 15m^3 of CF4 lost in underground cavern





HISTORY

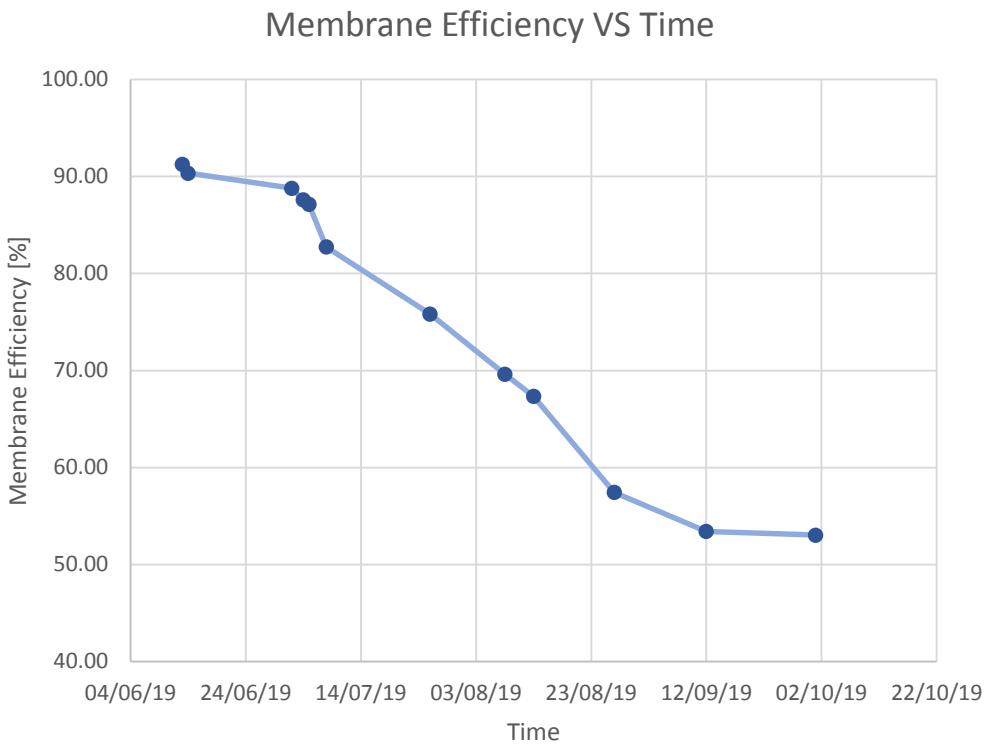
13/08 : bypass battery/compressor > To keep constant compressor operations

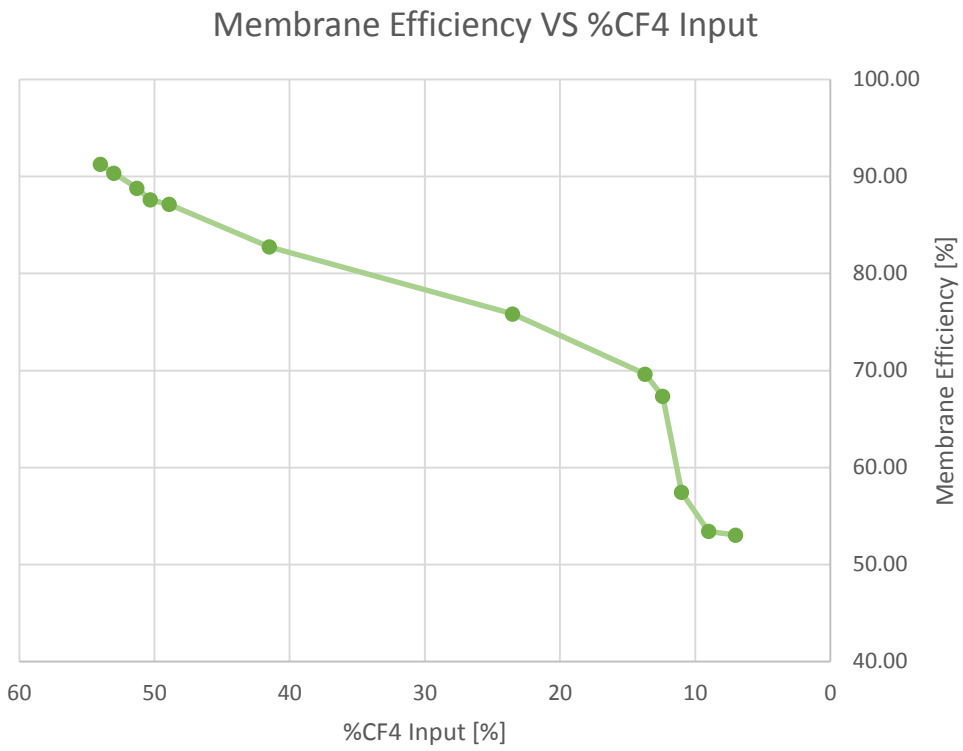


MEMBRANE PERFORMANCE

date	cf4 input [%]	input cf4 [l/h]	output cf4 [l/h]	permeate cf4 [l/h]	efficiency [%]
13/06/19	54	186.84	170.5	16.34	**91.25**
14/06/19	53	190.8	172.4	18.4	**90.36**
02/07/19	51.3	175.446	155.8	19.646	**88.80**
04/07/19	50.3	158.445	138.8	19.645	**87.60**
05/07/19	48.9	157.458	137.2	20.258	**87.13**
08/07/19	41.5	151.06	125	26.06	**82.75**
26/07/19	23.5	78.6	59.6	19	**75.83**
08/08/19	13.7	59.595	41.5	18.095	**69.64**
13/08/19	12.4	49.6	33.4	16.2	**67.34**
27/08/19	11	38.83	22.3	16.53	**57.43**
12/09/19	9	35.2	18.8	16.4	**53.41**
01/10/19	7	25.4	13.47	11.93	**53.03**

MEMBRANE PERFORMANCE

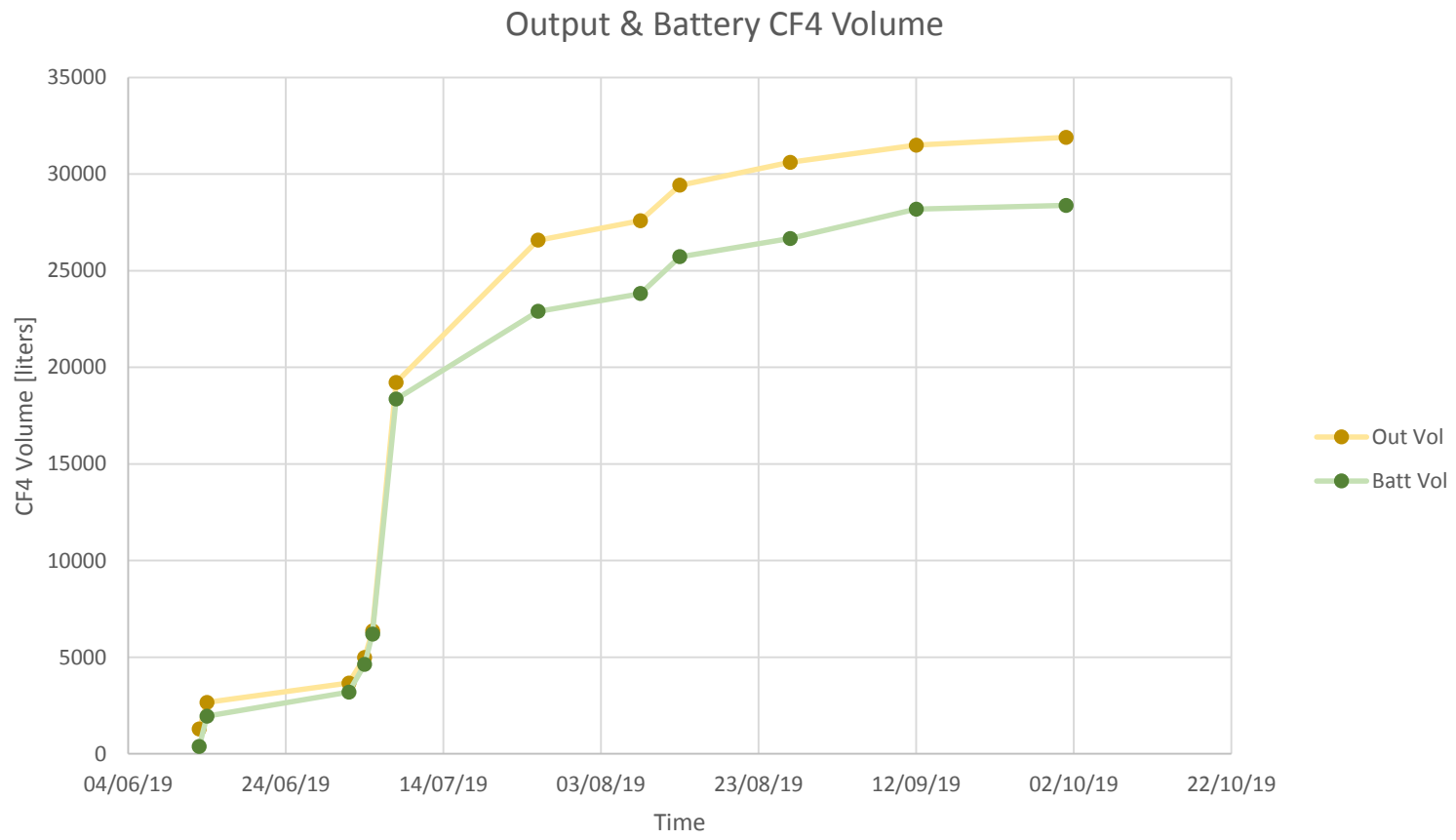




RECOVERY HISTORY

date	cf4 input [%]	efficiency [%]	output cf4 [l/h]	hrs	CF4 Volume [l]	CF4 Vol Progr [l]	Battery [bar]	Battery Vol Progr [l]	Battery Vol [l]
13/06	54	91.25	170.5	7.45	1270	**1270**	0.611	**367**	367
14/06	53	90.36	172.4	8	1379	**2649**	3.236	**1942**	1575
02/08	51.3	88.80	155.8	6.43	1002	**3651**	5.311	**3187**	1245
04/0	50.3	87.60	138.8	9.5	1319	**4970**	7.692	**4615**	1429
05/07	48.9	87.13	137.2	10	1372	**6342**	10.317	**6190**	1575
08/07	41.5	82.75	125	103	12875	**19217**	30.586	**18352**	12161
26/07	23.5	75.83	59.6	123.47	7359	**26576**	38.156	**22894**	4542
08/08	13.7	69.64	41.5	24.35	1011	**27586**	39.682	**23809**	916
13/08	12.4	67.34	33.4	54.8	1830	**29416**	42.857	**25714**	1905
27/08	11	57.43	22.3	53.15	1185	**30602**	44.444	**26666**	952
12/09	9	53.41	18.8	47.57	894	**31496**	46.973	**28184**	1517
01/10	7	53.03	13.47	29.73	400	**31897**	47.29	**28374**	190

RECOVERY HISTORY



RECUPERATION EFFICIENCY

- Difference between CF4 Output Membrane and CF4 in Battery
  > 31.9 m^3 - 28.4 m^3 = 3.5 m^3 total leak after Membrane
  > about 10% of the total CF4 at Membrane output was lost in the racks/piping/compressor
- Total CF4 available at starting point = 90 m^3
  CF4 loss caused by Patm variations (backup) = 24.3 m^3
  CF4 lost caused by underground pipes leaks= 15 m^3
  > Total CF4 available for recuperation = 50.7 m^3
- Total CF4 currently left inside detector = 7% = 7 m^3
- Total CF4 recuperated the battery = 28.4 m^3
- **CF4 Recuperation Efficiency = 28.4 / (50.7 - 7) = 65%**

RECUPERATION EFFICIENCY

- **CF4 Recuperation Efficiency = 65 %**
- The weighted average Membrane efficiency is 71%
  > weight used is number of hours of operation
  > the value is overestimated as the Membrane efficiency is considered to be constant over the recuperation periods, in reality it is slightly decreasing with decrease of CF4% in input
- Total duration of recuperation : 477 hours = about 20 days
- Total CF4 volume sent to exhaust : 9.15 m^3 >> average 20 liters/hour
- Total CF4 volume loss in piping/compressor leaks : 3.5 m^3 >> average 7 liters/hour

RECUPERATION STATISTICS

- Total duration of recuperation : 477 hours = about 20 days
- Time of R&D on Membrane/Recovery System = 88 hours = 11 working days
- Time of Office Work (calculation/data analysis) = 170 hours = 20 working days
- Time of GC Analysis = 175 hours = 22 working days
  > about 2000 GC analysis performed
- Time of Operation on System (FSU/Tech) = 58 hours = 7 working days
- Total Working Time = 480 hours = 60 working days