ENERGY AND ENVIRONMENTAL PERFORMANCE OF 40% MONOETHANOLAMINE (MEA) AT PACT PILOT PLANT

Muhammad Akram
(m.akram@Sheffield.ac.uk)

K. Milkowski, J. Gibbins, M. Pourkashanian

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SYNOPSIS:

- Background to CO_2 capture
- Why this process (liquid solvents)
- Overall PACT facility
- Experimental setup
- Capture plant layout
- Measurements apparatus and techniques
- Test matrix
- Plant performance data
- Conclusions

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BACKGROUND:

- CO_2 is a problem
- Using biomass instead of fossils
- Renewables/ efficiency improvements / carbon capture can reduce emissions
- None of these can solve the problem on their own (technical, economical, social, availability issues)
- Every possible contender needs to play a part

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WHY THIS PROCESS:

- Post combustion capture by absorption using liquid solvents (mostly amines) is well understood process
- In the industry for over 6 decades (Urea plants, petrochemicals and gas sweetening plants)
- Can be retrofitted
- Mostly CO_2 been used for EOR
- Power and industrial CO_2 capture is new application
- **Sask power (BD3, Canada), Petra Nova (USA) are examples of commercial scale deployment is power sector**
- **AVR, a waste incineration company is building full scale plant in Netherlands using MEA**

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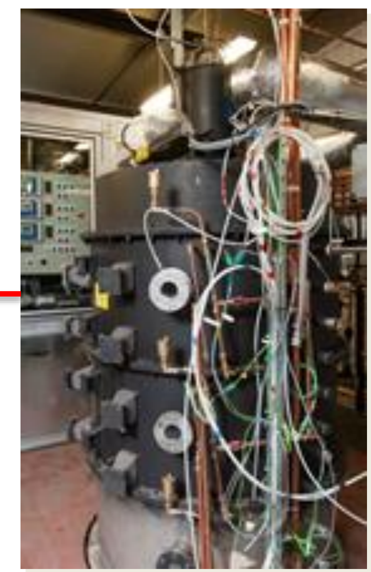
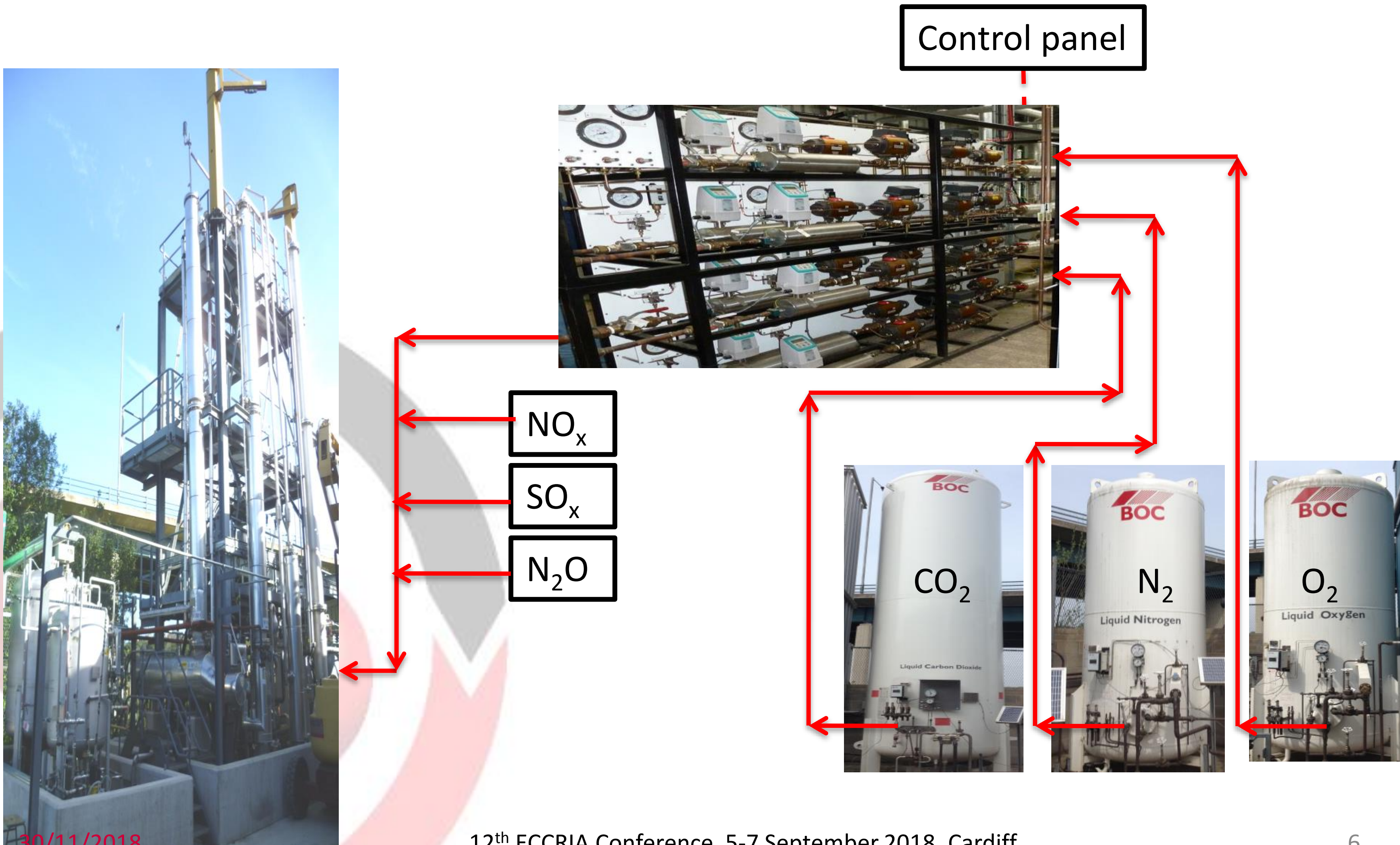
ACP Integration:

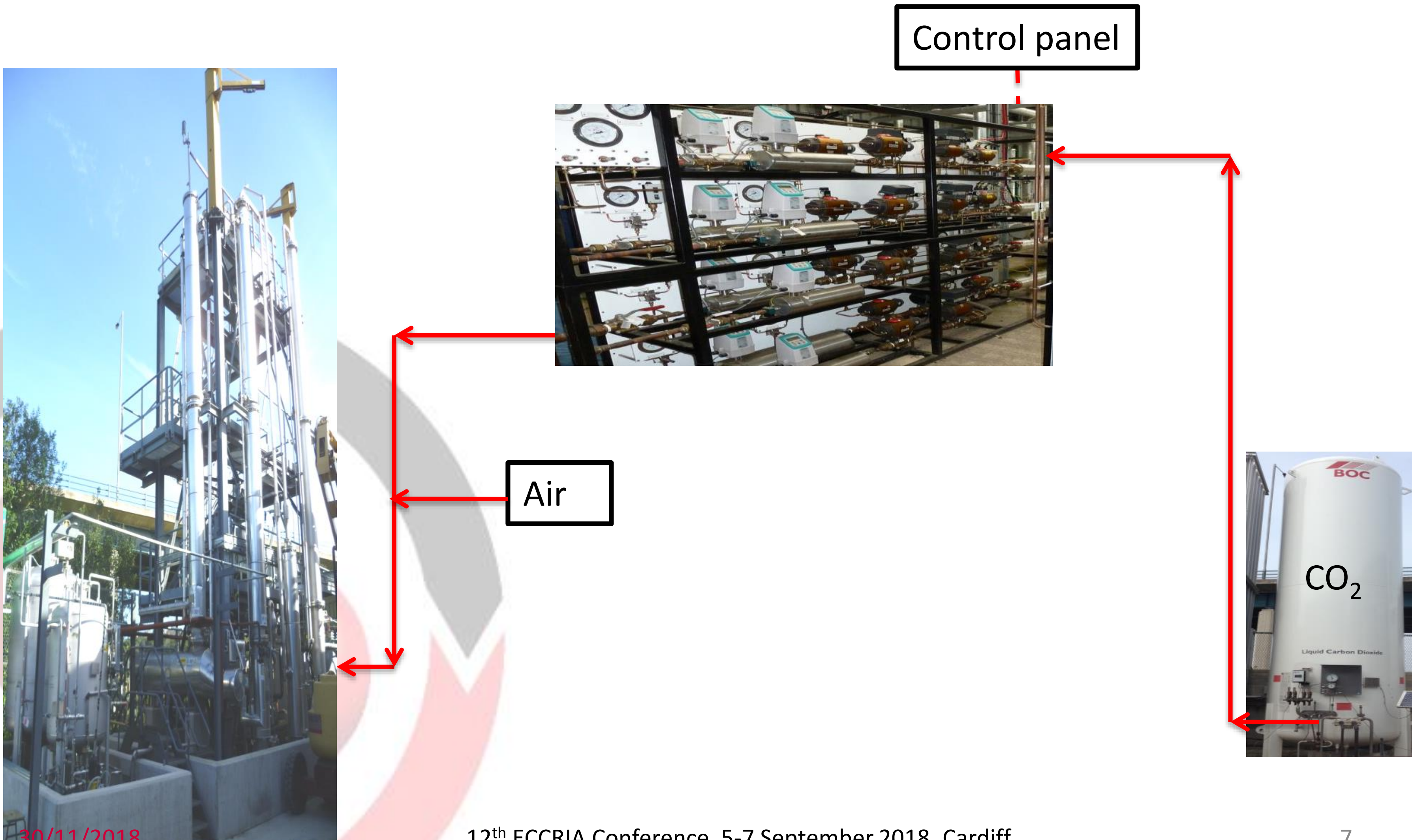


Synthetic flue gas

Synthetic set up



Experimental setup for this test campaign

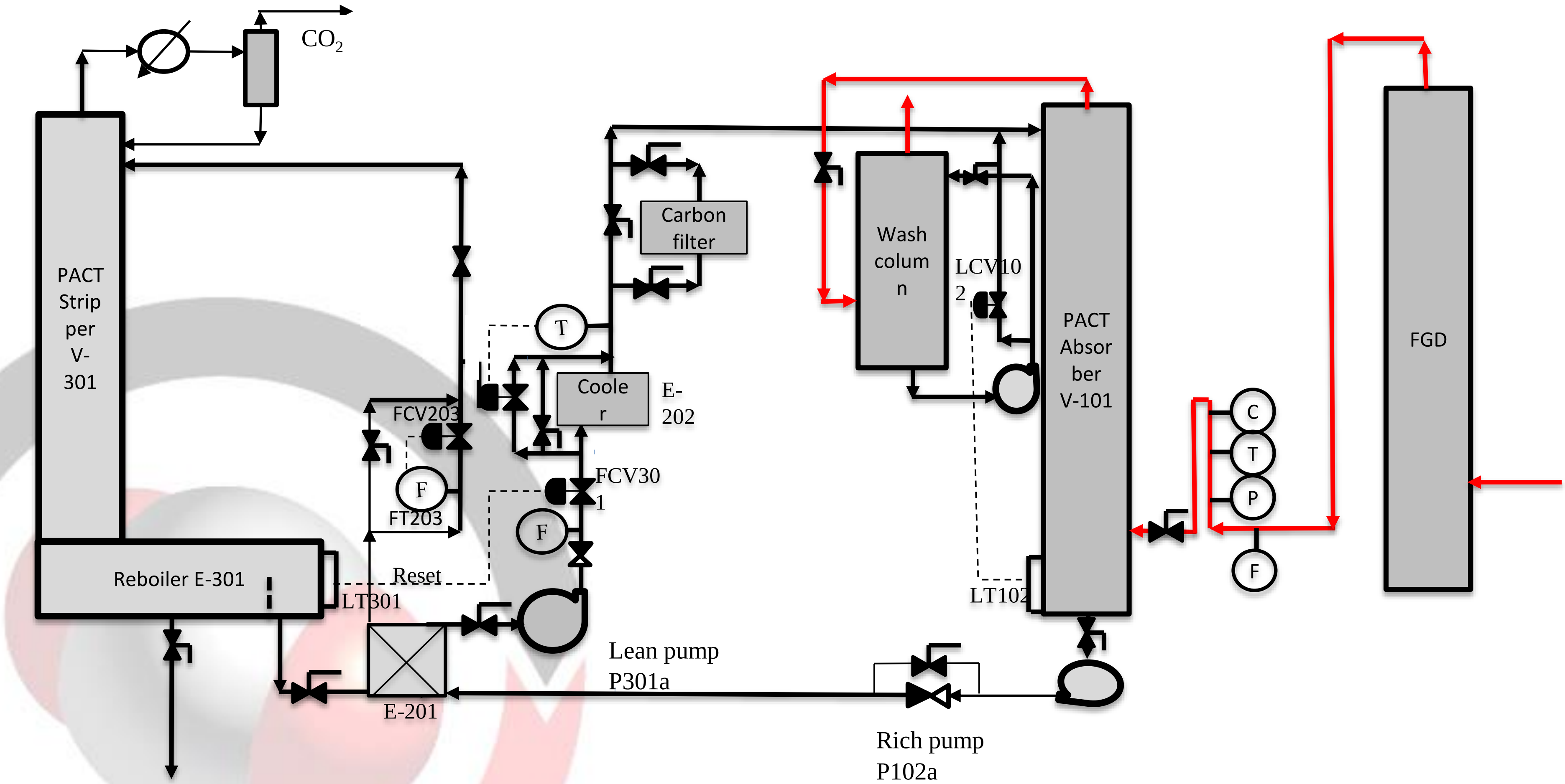


1TPD CO_2 Capture plant

- FGD for S removal
- Water wash column
- Absorber 300mm dia; 6.5m mellapak CC3 packing
- Stripper pressure up to 3.5bar capability
- Pressurised hot water for stripping (up to 130 ^{o}C)

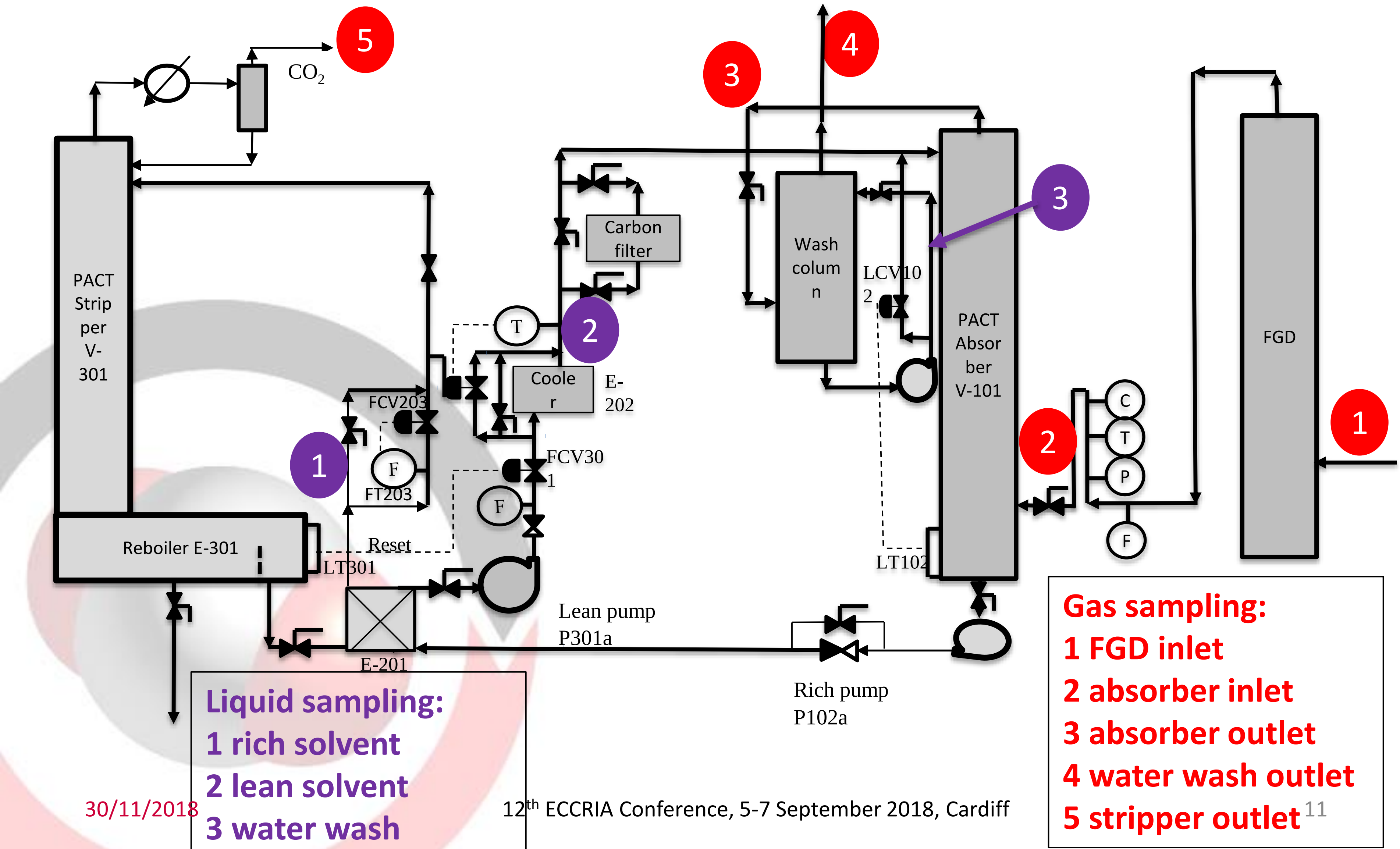
Process description

Layout:



CO2
PACT Strip per V-301
Reboiler E-301
LT301
Reset
FCV203
F
FT203
T
Coole r
E-202
Carbon filter
FCV30 1
F
E-201
Lean pump P301a
Wash colum n
LCV10 2
PACT Absor ber V-101
LT102
Rich pump P102a
C
T
P
F
FGD

Measurements:



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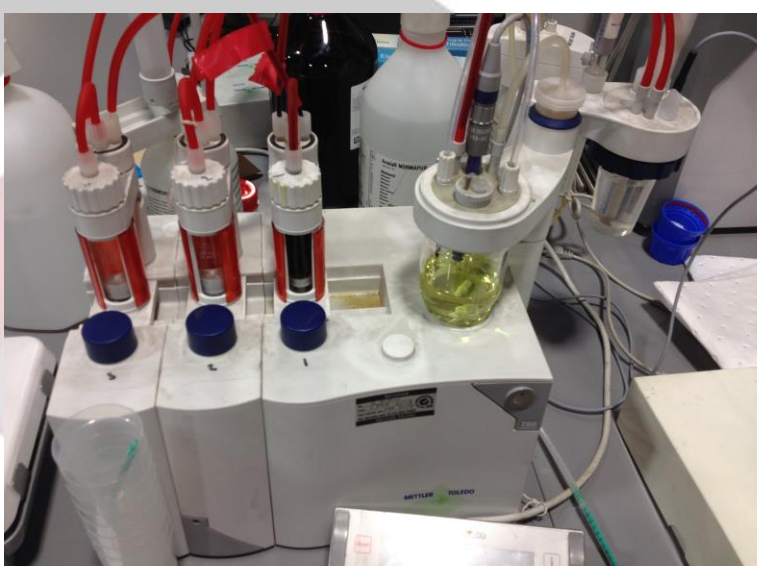
Gas Sampling System

FTIR measures: Concentrations of H_2O, CO_2, CO, NO, NO_2, N_2O, SO_2, NH_3,CH_4, C_2H_6, C_2H_4, C_3H_8, C_6H_{14}, Formaldehyde, MEA and TOC

Measurements

Auto-titrator:

- Solvent concentration
- CO_2 loading
- Water content (Karl Fischer Method)



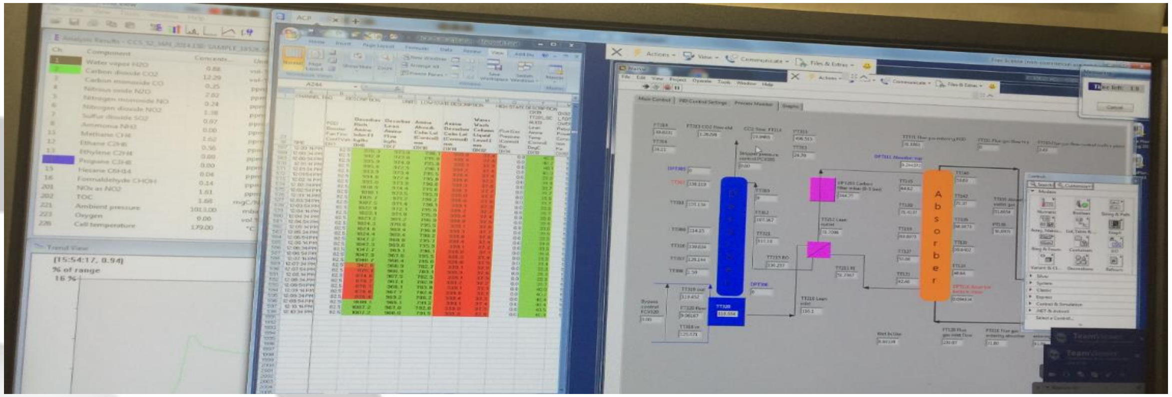
Absorber temperature profile by ten RTDS (resistance temperature detectors)

23.4 cm

Fe measurements (Corrosion):

Data Acquisition from the plant:

- Allen Bradley PLC – Controls the plant (solvent flows, stripper pressure, lean solvent temperature etc.)



- National Instruments Labview – records temperatures, pressures and flows (flue gas flow, CO2 flow, PHW flow)
- FTIR – Flue gas analysis
- Titration – Solvent analysis (COMCAT for continuous solvent monitoring

Test Matrix:

- Air + CO2 mixture
- MEA solvent for CO_2 capture (40wt%)
- Operational conditions varied
- Samples taken manually at the end of each test run
- Mettler Toledo auto-titrator used for titrations for CO_2 loading and solvent concentration

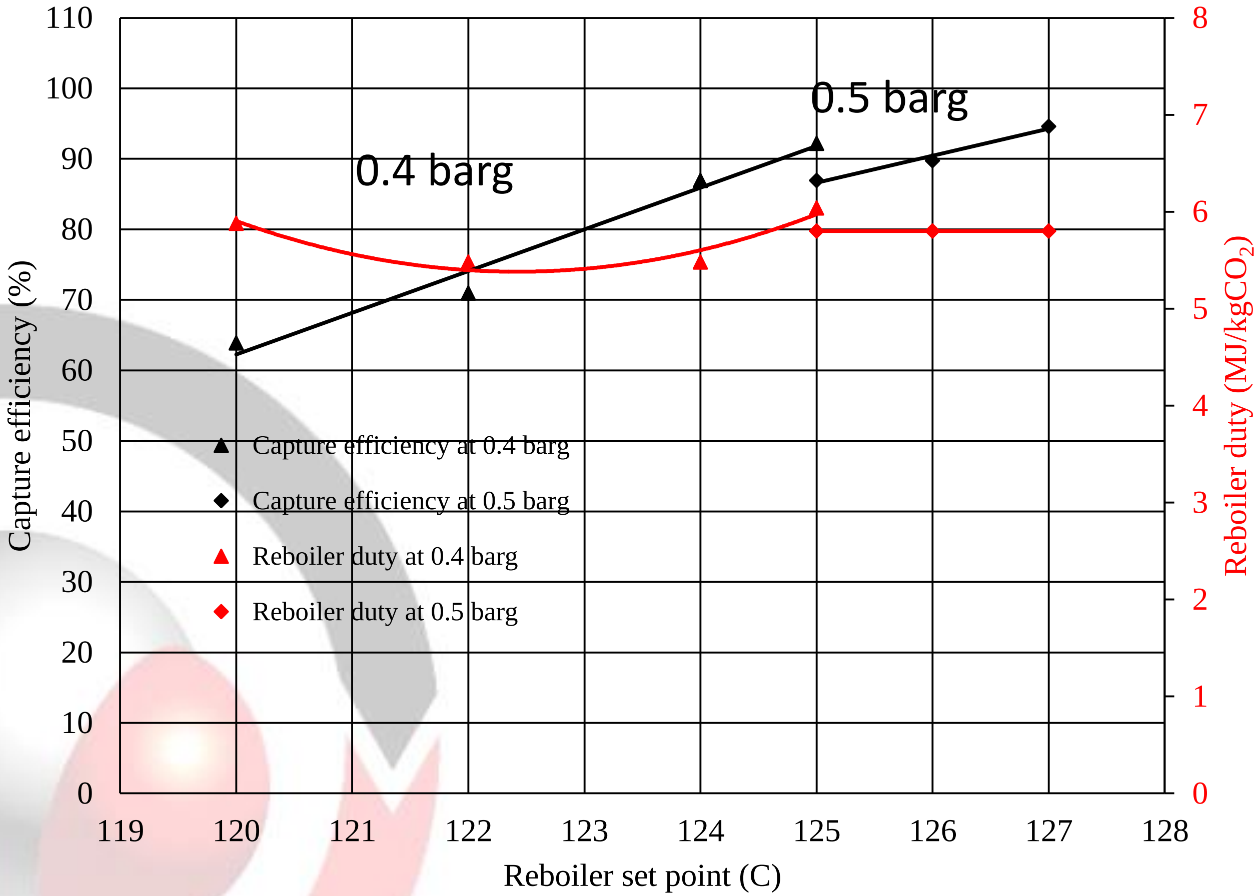
Following parameters were fixed for the tests (unless reported):

- Stripper pressure = 1.5 bara
- Reboiler temperature set point = 128 ^{0}C
- PHW flow to the reboiler = 10-10.5 m^3/h
- Lean solvent temperature = 40 ^{0}C
- Flue gas temperature = 40 ^{0}C

Effect of reboiler temperature

Test No	20	21	22	23
Flue gas fow (m3/h)	162.39	159.08	160.6	163.59
H2O (%) in	1.79	1.2	1.27	1.26
CO2 (%) in	11.83	11.99	11.55	11.52
Tin (C)	33.82	39.42	38.1	35.4
H2O (%) out	11.3	12.29	13.53	14.51
CO2 (%) out	4.18	3.38	1.47	0.87
Lean Temp	40	40	40	40
Stripper pressure	0.4	0.4	0.4	0.4
Solvent flow (kg/h)	700.5	690.2	698.9	695.1
Hot water setpoint C	120	122	124	125
Hot water in C	121.11	123.43	125.46	126.28
Hot water out C	118.06	120.39	121.82	121.93
Reboiler Temp C	117.32	119.44	120.5	120.4
Calculated rich loading	0.51	0.41	0.36	0.299
Rich loading (mol/mol)	0.493	0.467	0.436	0.411
Lean loading (mol/mol)	0.407	0.291	0.223	0.147
MEA (%)	42.5	40	40.5	40
L/G (kg/kg)	3.56	3.64	3.64	3.52
Capture rate (%)	65.84	72.19	87.68	92.73
Reboiler duty (MJ/kg)	5.88	5.48	5.48	6.04
Reduction		4%	4%	
Lean inlet (C)	113.07	114.97	115.72	115.49
Rich inlet (C)	43.24	45.16	47.35	47.87
Lean oulet (C)	62.75	64.19	66.7	66.42
Rich outlet (C)	87.18	89.46	91.55	91.9

Reboiler Temp. Vs. reboiler duty



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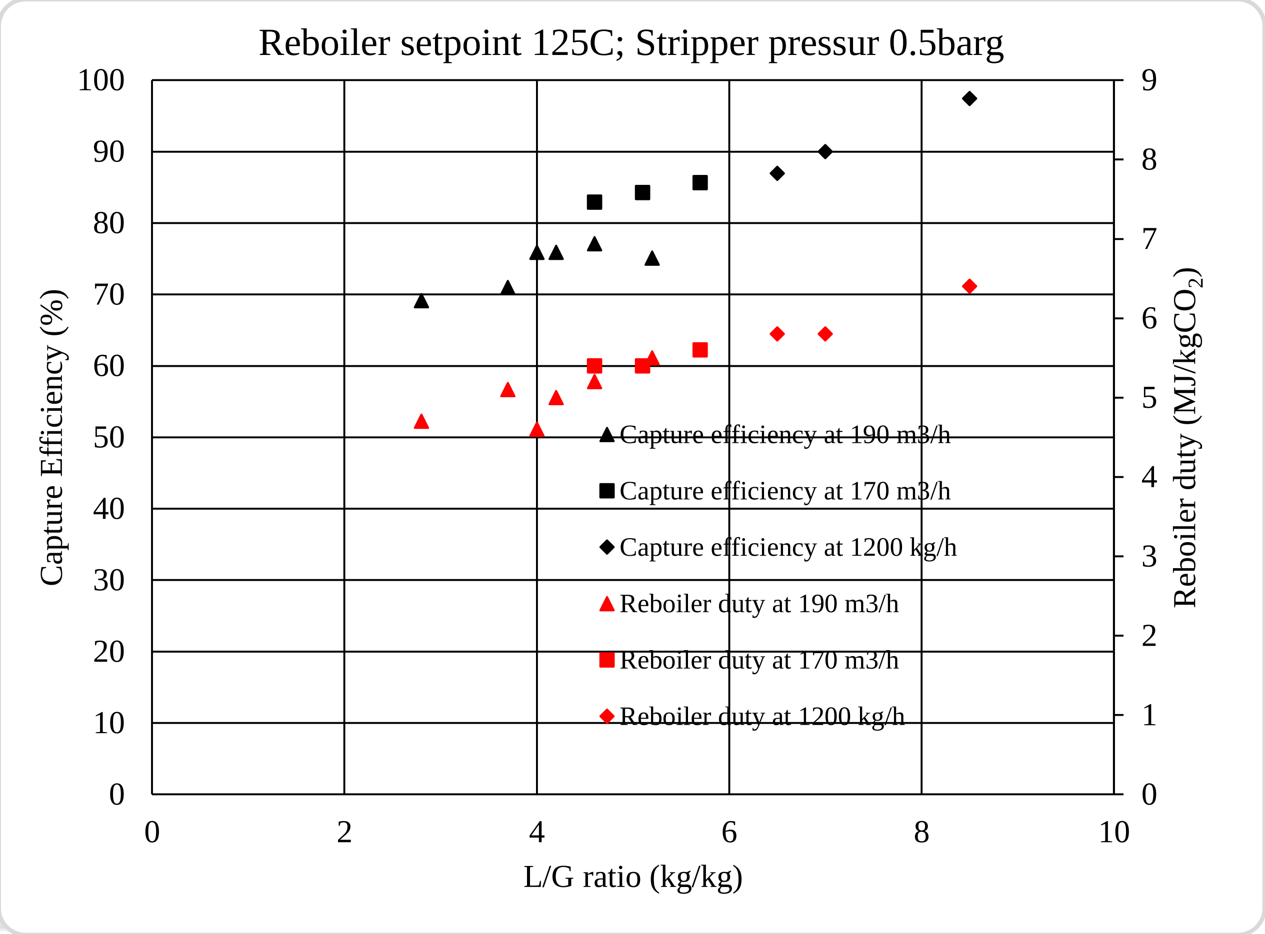
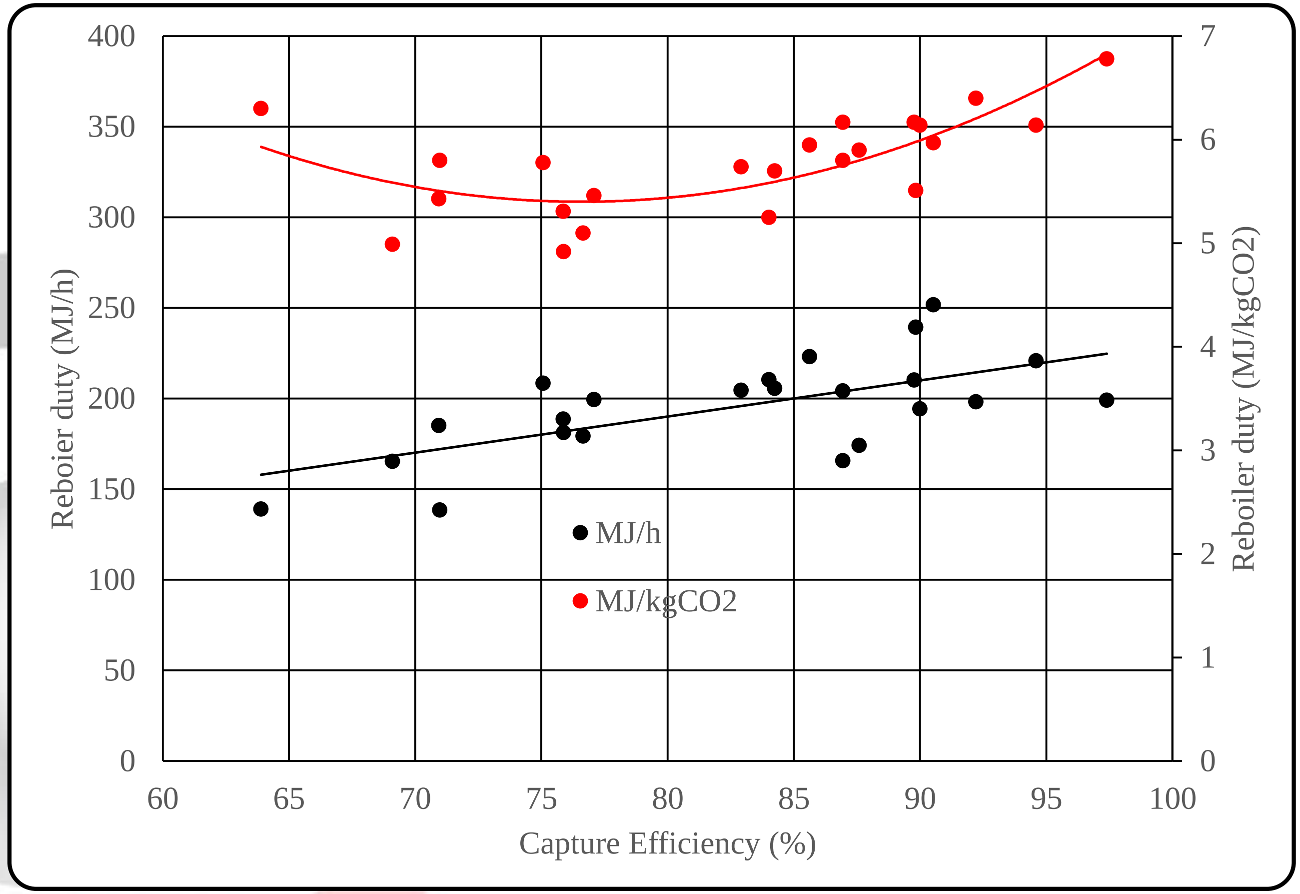
Effect of L/G ratio; lean loading = 0.26

Test No	5	3	8	9	10	17	15
Flue gas fow (m3/h)	190.98	190.36	187.09	189.92	170.95	152.47	117.46
H2O (%)	1.96	1.38	2.18	2.18	1.97	1.95	2.15
CO2 (%)	14.36	14.14	14.21	14.21	14.06	14.16	14.48
Tin (C)	40.2	33.62	41.4	42.59	35.58	38.06	34.01
Lean Temp	35	35	35	35	35	35	35
Stripper pressure	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Solvent flow (kg/h)	858.8	945.1	940.5	1050.7	1060.1	1199.3	1220.9
Hot water setpoint	125	125	125	125	125	126	125
Rich loading (mol/mol)	0.45	0.447	0.429	0.451	0.439	0.389	0.382
Lean loading (mol/mol)	0.26	0.26	0.256	0.258	0.26	0.265	0.264
MEA (%)	39	39.9	40	39.5	39	40.5	39.5
L/G (kg/kg)	3.7	4	4.2	4.6	5.1	6.5	8.5
Capture rate (%)	72	77.1	76.6	77.7	84.8	89.97	97.5
Reboiler duty (MJ/kg)	5.1	4.6	5	5.2	5.4	5.8	6.4
Lean inlet (C)	115.83	115.92	117.23	117.06	116.61	116.09	116.36
Rich inlet (C)	46.65	46.94	49.67	50.69	51.63	54.89	54.74
Lean oulet (C)		65.91	68.57	69.92	70.23	71.42	72.01
Rich outlet (C)	89.64	89.9	91.6	92.08	92.03	92.24	93.21

Capture efficiency vs. L/G ratio



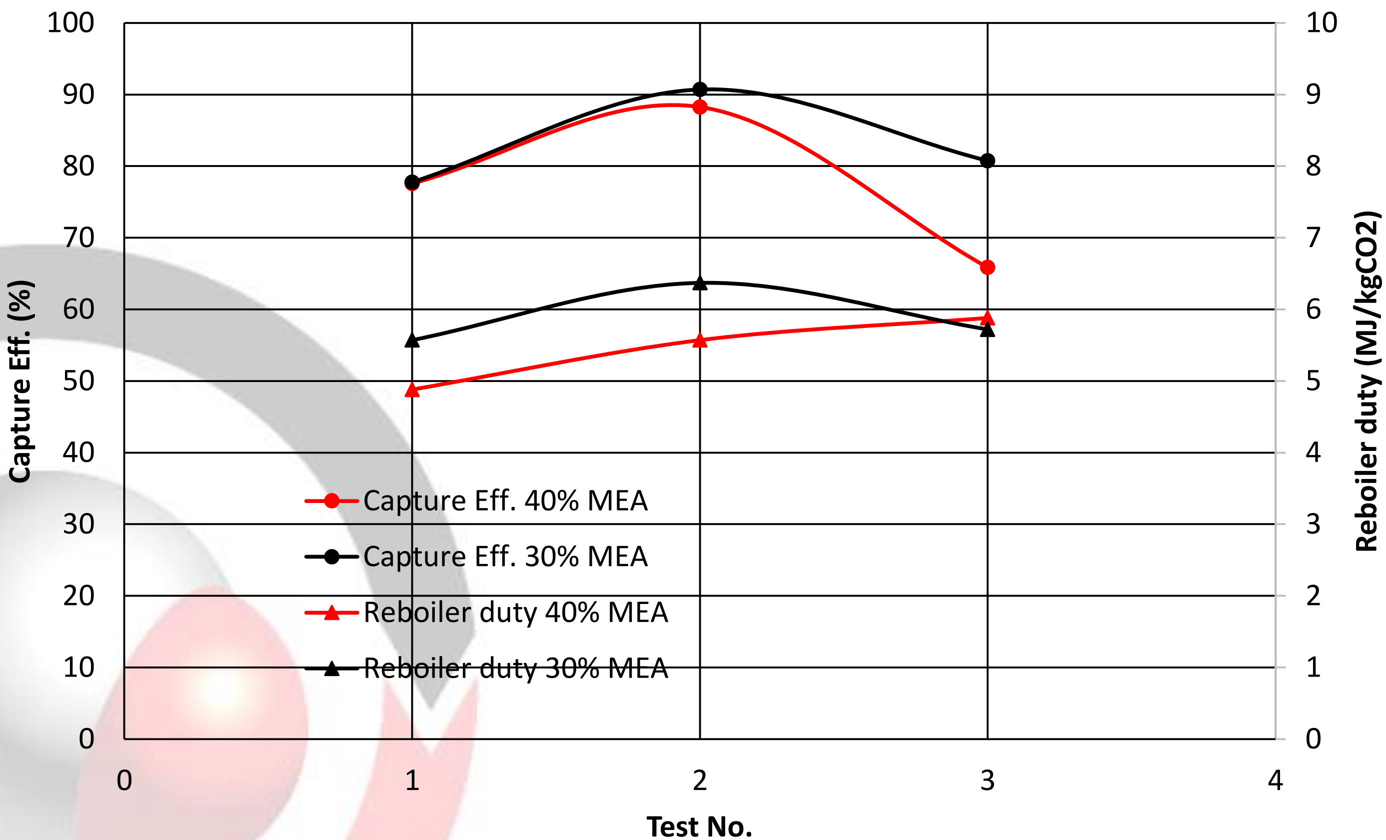
Capture efficiency vs. reboiler duty



Comparison of 30% and 40% MEA

Test No	40%	30%	40%	30%	40%	30%
Flue gas fow (m3/h)	197.87	196.95	161.05	158.51	162.39	158.45
H2O (%) in	1.79	0.7	1.79	0.82	1.79	0.83
CO2 (%) in	13.19	13.14	11.83	12.11	11.83	11.93
Tin (C)	42.73	41.88	38.38	34.94	33.82	36.41
H2O (%) out	14.18	12.56	13.79	11.79	11.3	10.86
CO2 (%) out	3	3.08	1.44	1.21	4.18	2.43
Lean Temp	40	40	40	40	40	40
Stripper pressure	0.2	0.2	0.2	0.2	0.4	0.4
Solvent flow (kg/h)	897	890.7	709.7	677.9	700.5	684.6
Hot water setpoint C	120	120	120	120	120	120
Hot water in C	121.36	120.76	121.2	120.95	121.11	121.04
Hot water out C	117.42	114.56	117.3	116.26	118.06	117.39
Reboiler Temp C	115.4	114.4	115.39	115.62	117.32	117.84
Calculated rich loading	0.369		0.367	0.364	0.51	0.403
Rich loading (mol/mol)	0.464		0.445	0.432	0.493	0.444
Lean loading (mol/mol)	0.236		0.224	0.209	0.407	0.272
MEA (%)	40		39.5		42.5	
L/G (kg/kg)	3.82		3.68		3.56	
Capture rate (%)	77.57	77.76	88.26	90.7	65.84	80.75
Reboiler duty (MJ/kg)	4.88	5.57	5.57	6.37	5.88	5.72
Reduction	12%		13%			
Lean inlet (C)	111.11	110.23	110.83	111.91	113.07	114.7
Rich inlet (C)	48.09	47.52	48.51	48.86	43.24	45.9
Lean oulet (C)	67.28	65.06	64.73	64.49	62.75	64.39
Rich outlet (C)	87.45	93.65	86.84	93.46	87.18	95.45

Comparison of 30% and 40% MEA



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Comparison of 30% and 40% MEA

Test No	18 30% MEA		19 30% MEA		20 30% MEA	
Flue gas fow (m3/h)	197.87	196.95	161.05	158.51	162.39	158.45
H2O (%) in	1.79	0.7	1.79	0.82	1.79	0.83
CO2 (%) in	13.19	13.14	11.83	12.11	11.83	11.93
Tin (C)	42.73	41.88	38.38	34.94	33.82	36.41
H2O (%) out	14.18	12.56	13.79	11.79	11.3	10.86
CO2 (%) out	3	3.08	1.44	1.21	4.18	2.43
Lean Temp	40	40	40	40	40	40
Stripper pressure	0.2	0.2	0.2	0.2	0.4	0.4
Solvent flow (kg/h)	897	890.7	709.7	677.9	700.5	684.6
Hot water setpoint C	120	120	120	120	120	120
Hot water in C	121.36	120.76	121.2	120.95	121.11	121.04
Hot water out C	117.42	114.56	117.3	116.26	118.06	117.39
Reboiler Temp C	115.4	114.4	115.39	115.62	117.32	117.84
Calculated rich loading	0.369		0.367	0.364	0.51	0.403
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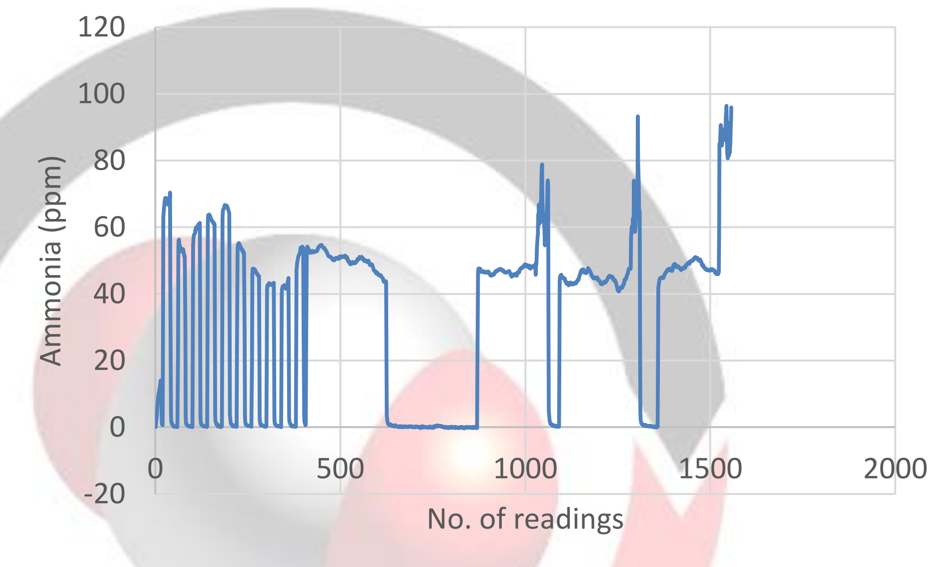
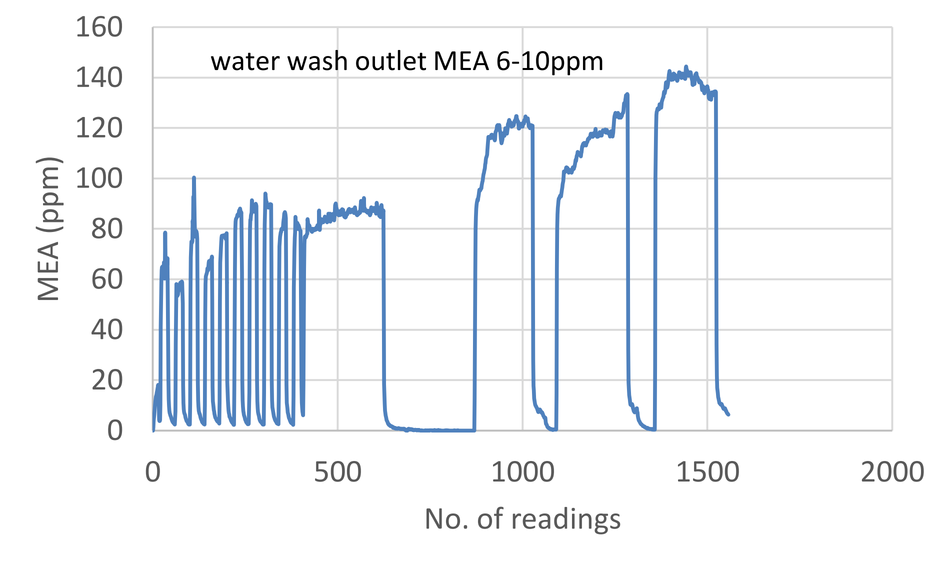
Reboiler duty (MJ/kg)	4.88	5.57	5.57	6.37	5.88	5.72
Reduction	12%		13%			
Lean inlet (C)	111.11	110.23	110.83	111.91	113.07	114.7
Rich inlet (C)	48.09	47.52	48.51	48.86	43.24	45.9
Lean oulet (C)	67.28	65.06	64.73	64.49	62.75	64.39
Rich outlet (C)	87.45	93.65	86.84	93.46	87.18	95.45

Emissions:

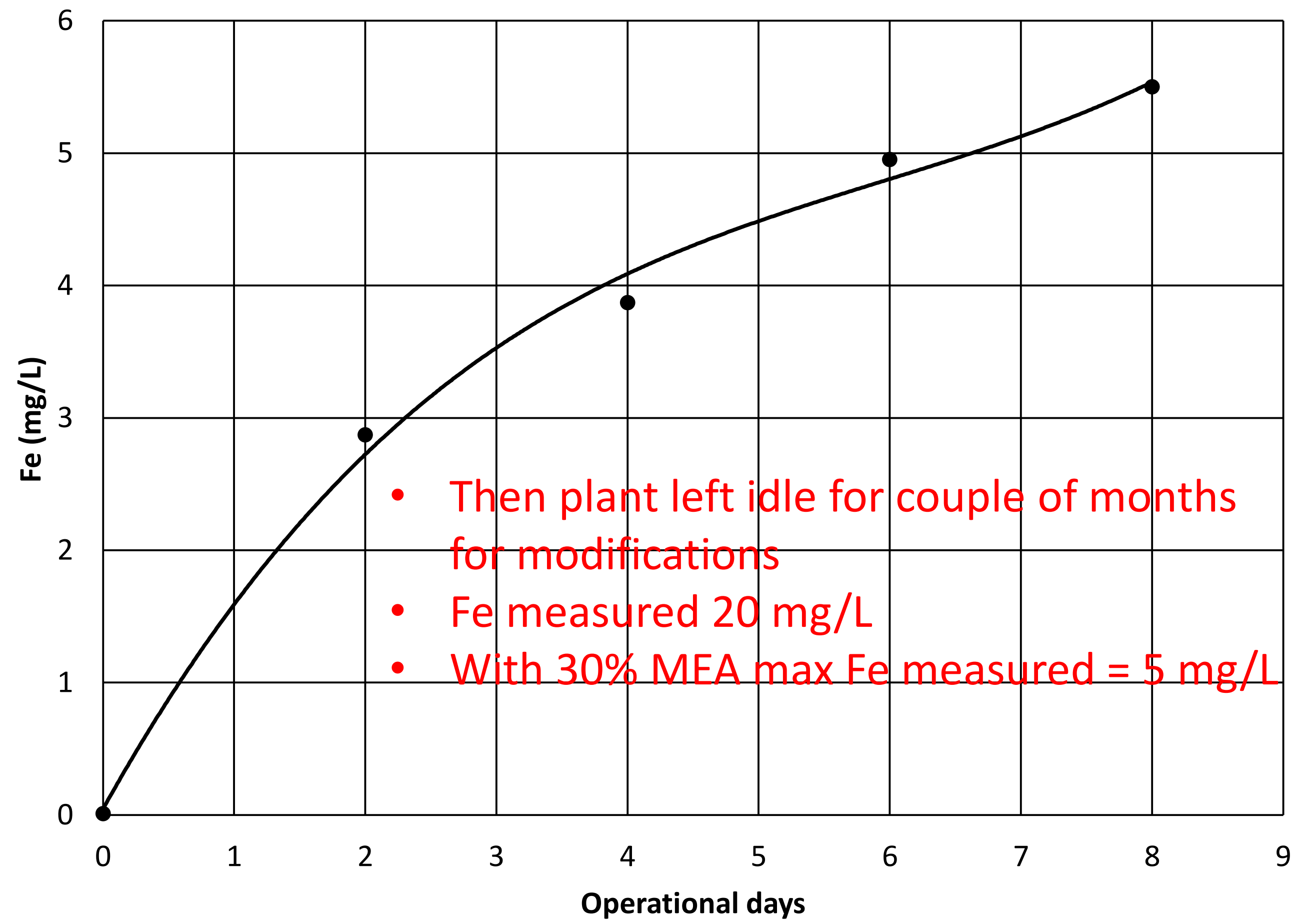
- Ammonia emissions = 25-100 ppm
- MEA emissions
  - Absorber outlet 30-140 ppm (also observed up to 500ppm)
  - water wash outlet always below 15 ppm





X-axis readings every 20 seconds; 1620 = 9hrs

Fe measurements (Corrosion):



- Then plant left idle for couple of months for modifications
- Fe measured 20 mg/L
- With 30% MEA max Fe measured = 5 mg/L

Conclusions:

- No obvious major handling differences from 30% w/w MEA
- Relative energy consumption ~12% lower under favourable conditions
- Lean loading more sensitive to pressure and temperature for 40% MEA
- Emissions higher than 30% MEA
- Corrosion rate needs to be considered when using high concentrations of MEA and operation particularly RPBs
- Absolute energy consumption higher due to short absorber column – planning to add a second column in series

Publications

- Paul Tait, Bill Buschle, Kris Milkowski, Muhammad Akram, Mohamed Pourkashanian, Mathieu Lucquiaud, Flexible operation of post-combustion CO_2 capture at pilot scale with demonstration of capture-efficiency control using online solvent measurements, International Journal of Greenhouse Gas Control, Volume 71, April 2018, Pages 253-277
- Usman Ali, Muhammad Akram, Carolina Font-Palma, Derek B Ingham, Mohamed Pourkashanian, (2017), "Part-load Performance of Direct-firing and Co-firing of Coal and Biomass in a Power Generation System Integrated with a CO_2 Capture and Compression System", Fuel. Volume 210, 15 December 2017, Pages 873-884
- Akram M., Ali U, pourkashanian M, font palma C.,Comparaive potential of NaturalGAs, Coal and Biomass Fired Power Plants with Post Combustion CO_2 capture and Compression, International Journal of Greenhouse Gas Control. Volume 63, August 2017, Pages 184–193.
- Ali U., Font Palma C., Nikpey Somehsaraei H., Mansouri Majoumerd M., Akram M., Finney K.N., Best T., Mohd Said N.B., Assadi M., Pourkashanian M., (2017), Benchmarking of a micro gas turbine model integrated with post-combustion CO_2 capture, Energy, 126. pp. 475-487. ISSN 0360-5442 .
- Maria Elena Diego, Muhammad Akram, Jean-Michel Bellas, Karen N. Finney, Mohamed Pourkashanian, (2017), Making gas-CCS a commercial reality: The challenges of scaling up, Greenhouse Gases: Science and Technology.
- Akram, M., Ali U., Best T., Finney K.N., Blakey S., Pourkashanian M., (2016), "Performance evaluation of PACT capture plant for CO_2 capture from gas turbines with exhaust gas recycle", International Journal of Greenhouse Gas Control", Volume 47, April 2016, Pages 137–150.
- Rezazadeh F., Gale W.F., Akram M., Hughes K.J., , Pourkashanian M., (2016), "Performance evaluation and optimisation of post combustion CO_2 capture processes for natural gas applications at pilot scale via a verified rate-based model", International Journal of Greenhouse Gas Control, Volume 53, October 2016, Pages 243–253.

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QUESTIONS ?

m.akram@sheffield.ac.uk