THE UNIVERSITY of EDINBURGH

12th September 2017, UKCCSRC biannual, Sheffield, UK

Towards more flexible power generation with CCS:

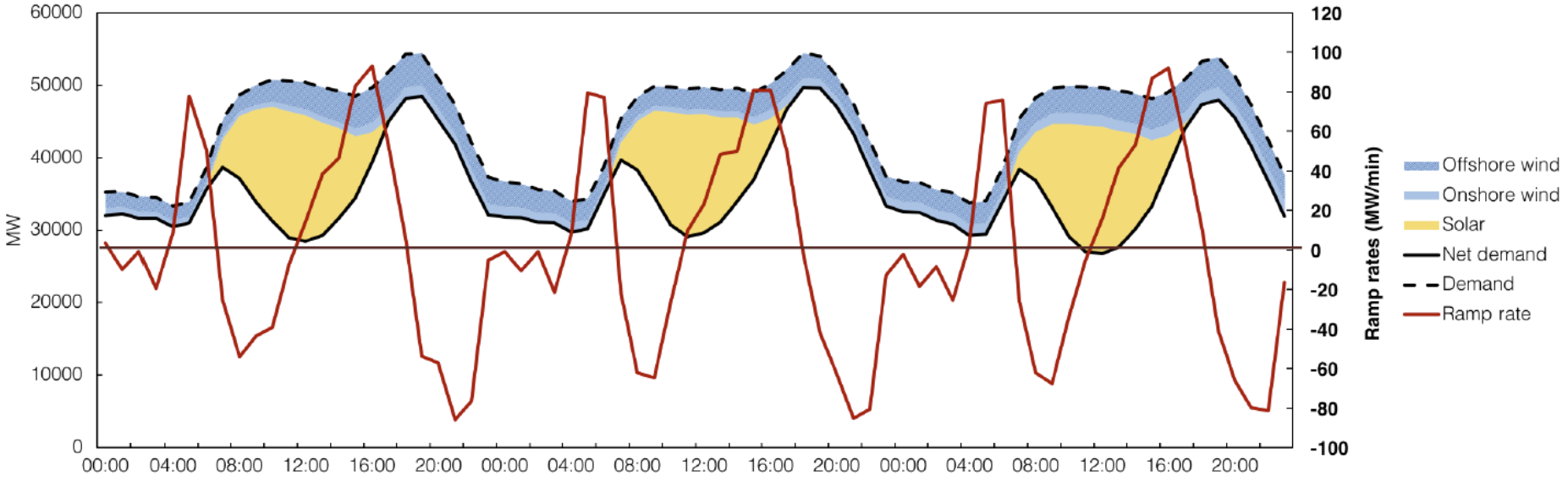
Pilot plant test campaigns for best practice guidelines for post-combustion capture

Mathieu Lucquiaud, Bill Buschle, Paul Tait
Institute for Energy Systems, School of Engineering, University of Edinburgh
m.lucquiaud@ed.ac.uk

Operational flexibility of CCS power plants

- The challenges of low-carbon electricity grids with variable renewable energy
- Scenario: Electricity demand for 3 consecutive days in March 2010 with 30GW wind & 30GW solar installed capacity (currently 15 & 12 GW resp.), UCED models available at Edinburgh
- Ramp rates for all other capacity on grid: nuclear, CCS, unabated gas, energy storage, virtual plants for demand side reduction

  -> 80-100MW/min up twice a day, 80MW/min down twice a day



Vazquez (2017) MSc dissertation, Edinburgh University

Operational flexibility of CCS power plants

- CCS power plants: Can we superimpose capture to power to increase ramp rates?
- Ramp rate up
- Ramp rate down
- Number and frequency of start-ups

- Thermal power plants without CCS
  - CCGT ramp rate 10%/min
  - Pulverised Coal 3-4%/min

Towards more flexible power generation with CCS

Funder: UKCCSRC

Budget: £69,252 at 100% FeC. Equipment and test campaigns

+ significant contribution in-kind

- No staff costs included (UKCCSRC accounting rule)
- From industrial partners: Sulzer ChemTech

Dates: Sep 2014 to Mar 2017 (initially 12 months)

Institution: University of Edinburgh

Investigator(s): Mathieu Lucquiaud, Prashant Valluri (Edinburgh)

Researchers: Paul Tait & Bill Buschle

Project objectives

- Demonstrate, at pilot scale, flexible operation of post-combustion CO2 capture
- Characterise ramp rate at pilot scale
- Demonstrate, at pilot scale, advanced operating strategies, e.g. to trade electricity vs CO2 emissions
- Develop fit-for-purpose process instrumentation to do so

The project fits within a larger programme

- ❑ COMCAT: 2011-2015 – Bill Buschle – PhD funded by ETP & Doosan

-> instrument prototype

-> Demo at Ferrybridge CCPilot100+ & US National Carbon Capture Centre

- ❑ TRANSPACC: 2012-2016 – Paul Tait – PhD funded by ETP & Sulzer

-> credible operating scenarios, test campaign #1 at Sulzer, Switzerland

- ❑ GAS-FACTS: 2012-2015, EPSRC, instrument development
- ❑ This project: 2014-2016, UKCCSRC

-> test campaign #2 at UKCCSRC PACT,UK

- ❑ Impact Acceleration Award: 2016, EPSRC

-> Test campaign at CCTF Sask power

-> Demonstration without knowledge of commercial solvent composition

- ❑ Going forward:

-> Towards advanced control of post-combustion capture

-> Commercialisation of instrument: Shell, Boundary Dam, US NCCC

Project objectives

- Demonstrate, at pilot scale, flexible operation of post-combustion CO2 capture
- Characterise ramp rate at pilot scale
- Demonstrate, at pilot scale, advanced operating strategies, e.g. to trade electricity vs CO2 emissions
- Develop fit-for-purpose process instrumentation to do so

- Specifically with UKCCSRC support
- Plan, execute and analyse a 10-day pilot plant test campaign at UKCCRC PACT focused on dynamic operation of the amine plant
- Build & deploy new instrumentation at UKCCSRC PACT
- Demonstrate, at pilot-plant scale, real-time control of process during transient operation between set points

Scope of pilot scale test programme

Five dynamic scenarios of CCS power plants

- Power plant start-up
- Power plant shut-down
- CO_2 capture bypass
- Reboiler steam shutdown
- Frequency response

Representative boundary conditions of coal & gas fired power plants and CO2 compression imposed to CO2 capture pilot plants: gas flow rate, reboiler energy, reboiler temperature, desorber pressure

Test campaigns at two pilot plant facilities

- Sulzer DRABS, Winterhtur, Switzerland (GAS)
- UKCCSRC PACT amine plant, Sheffield (COAL)

Process instrumentation philosophy for CO2 capture solvents

Instrument Design

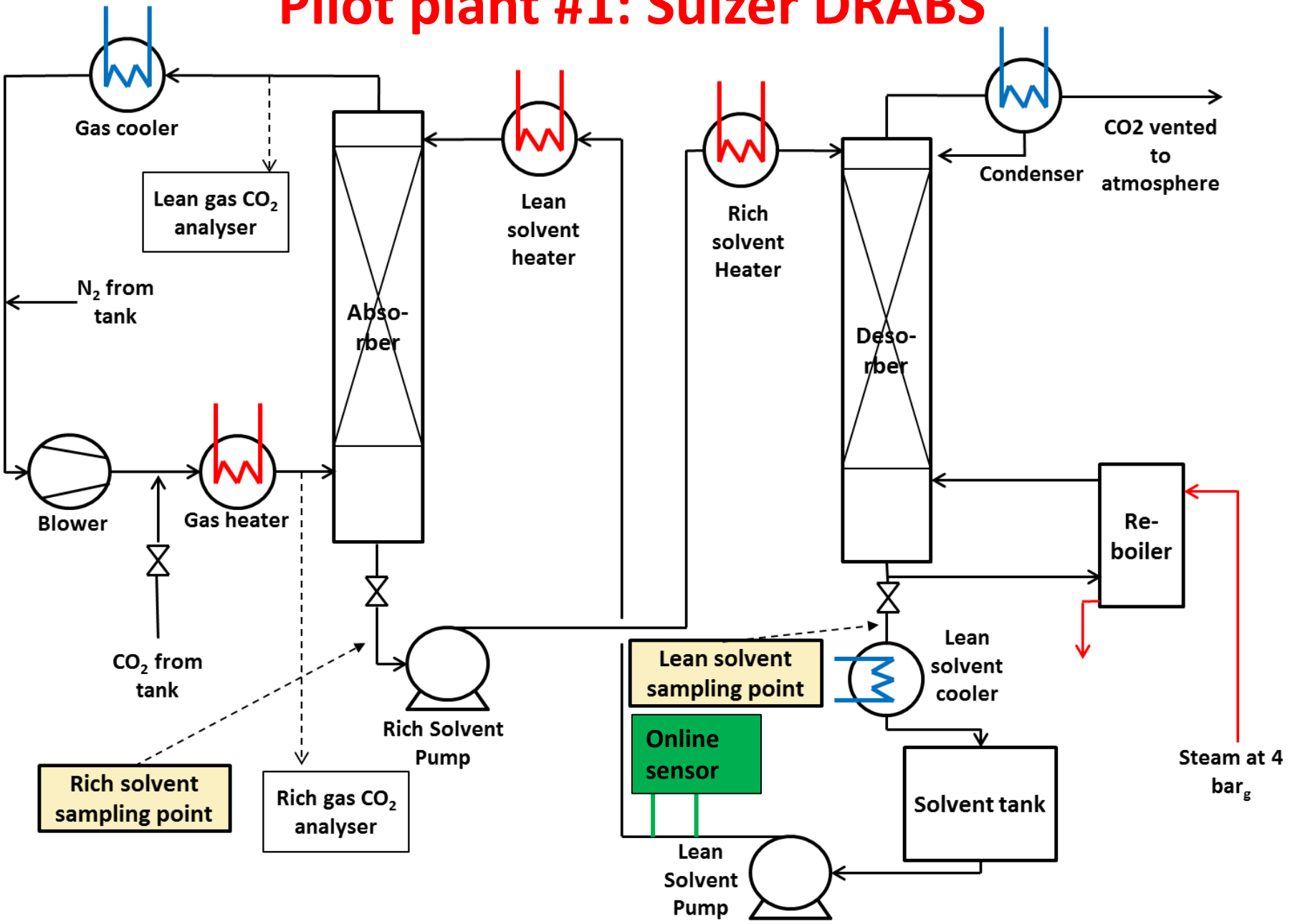
- Accurate & Precise
- Fast
- Solvent Versatile
- Robust
- Cost effective

Traits of Measurement Technology:

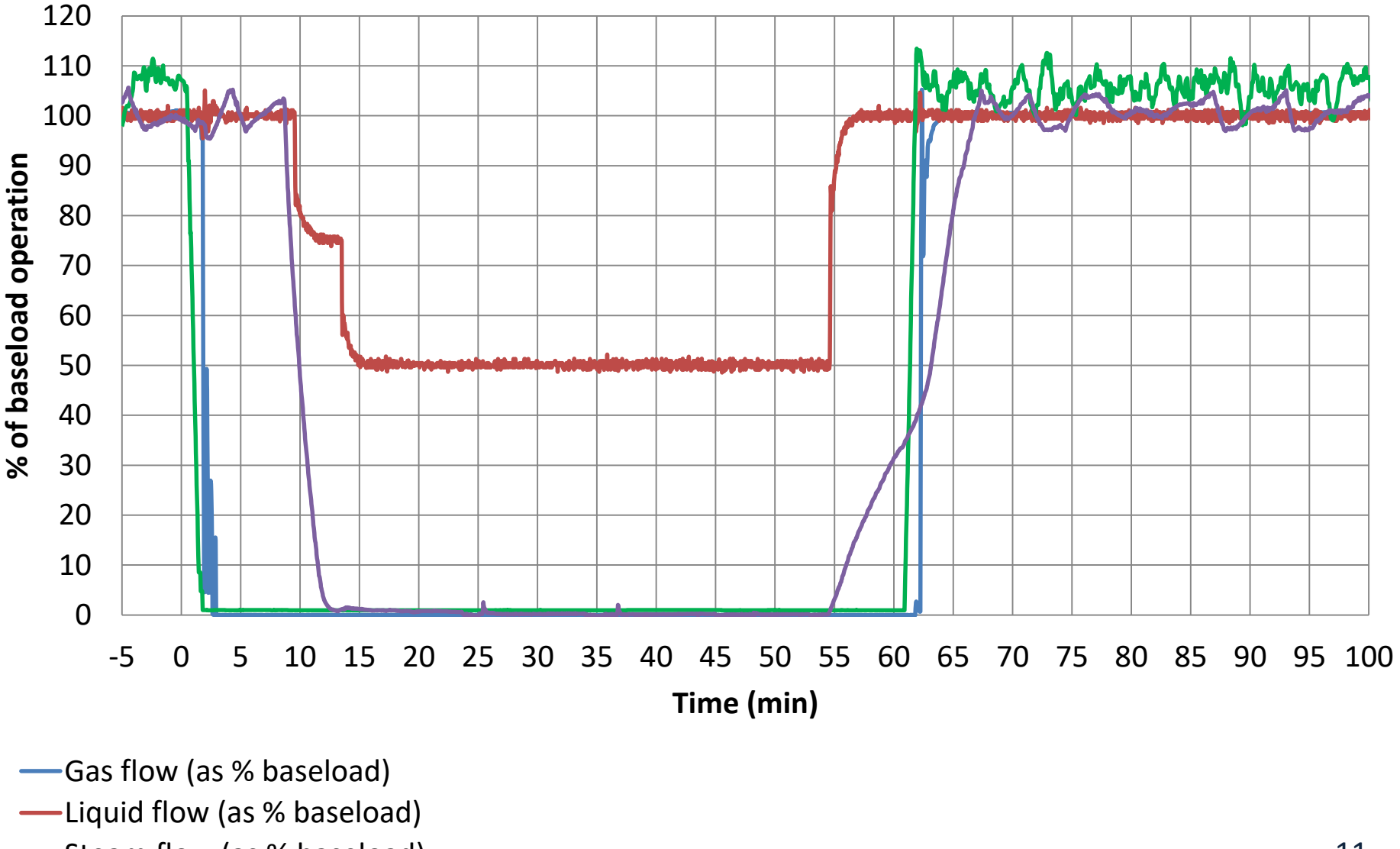
Speed	• Continuous • Online
Robust	• Field Tested • Industrial Standard
Simple	• Field Calibration • No solvent IP
Safe	• Contained • Safety Standards
Accurate	• Higher accuracy + sensitivity • Maintain performance in all scenarios
Economical	• Long Life • Non-Destructive

Novel sensor system redesign – January 2016

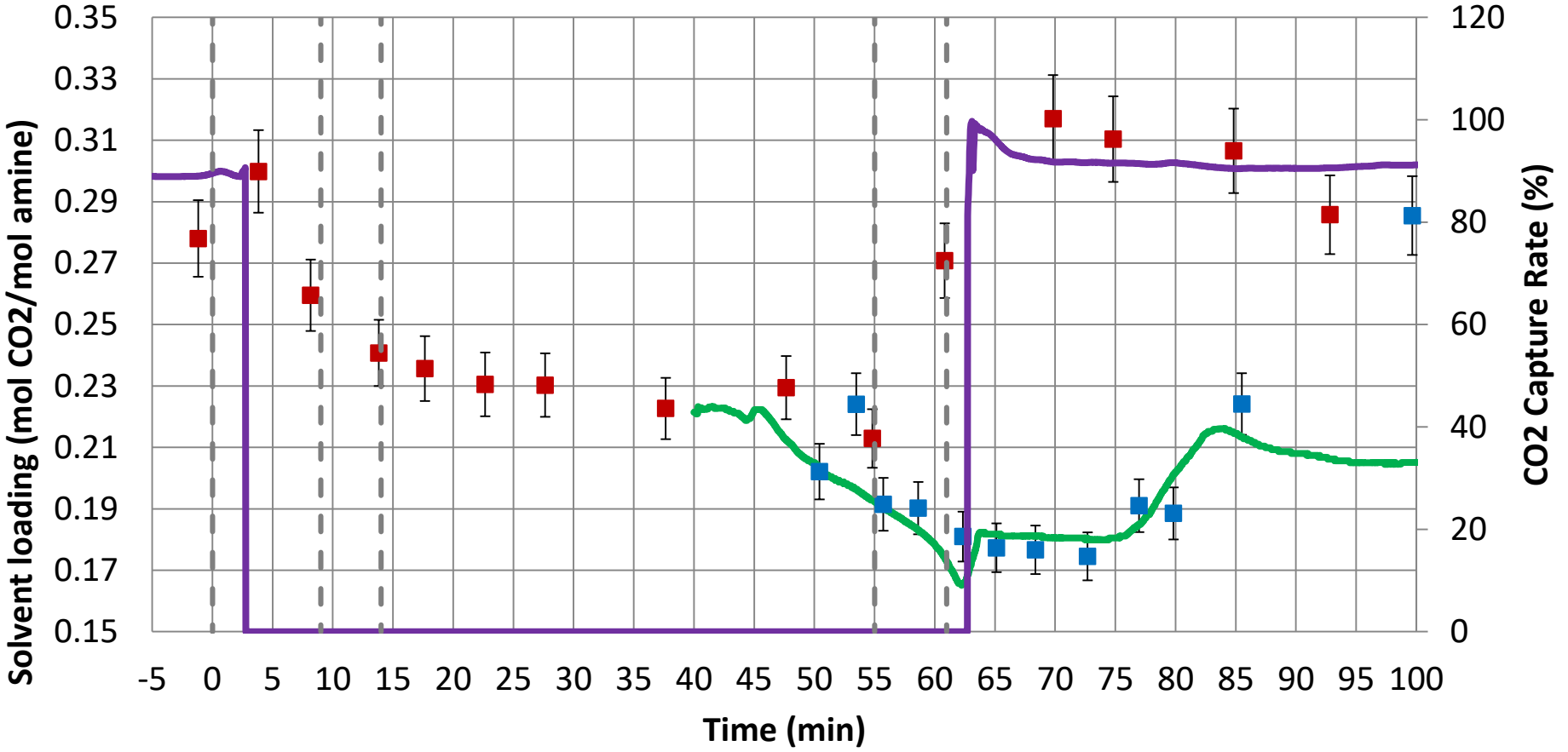
Pilot plant #1: Sulzer DRABS



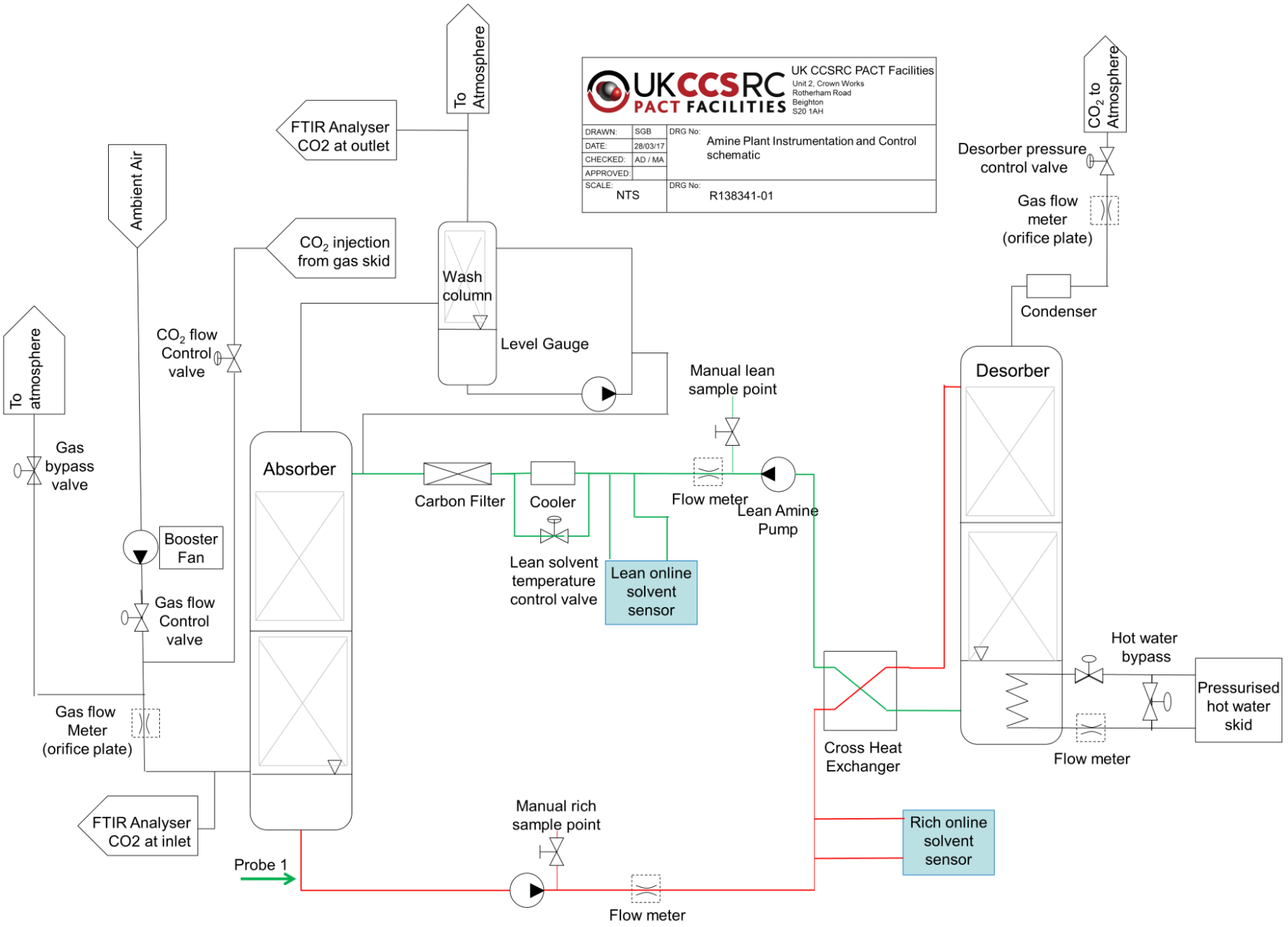
Enhanced flexibility scenario – Power output maximisation via capture plant decoupling



Enhanced flexibility scenario – Power output maximisation via capture plant decoupling

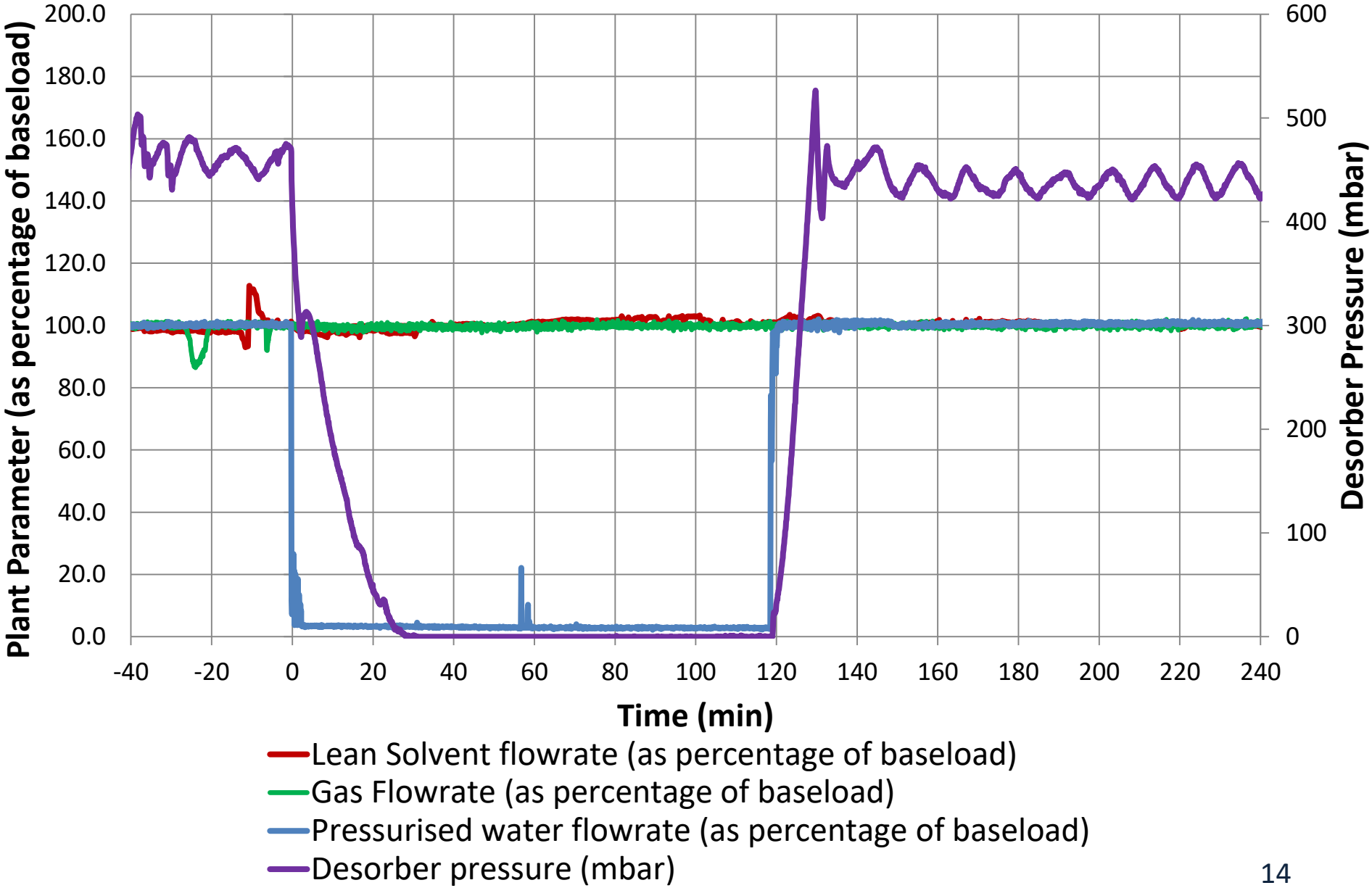


Pilot plant #2: UKCCSRC PACT



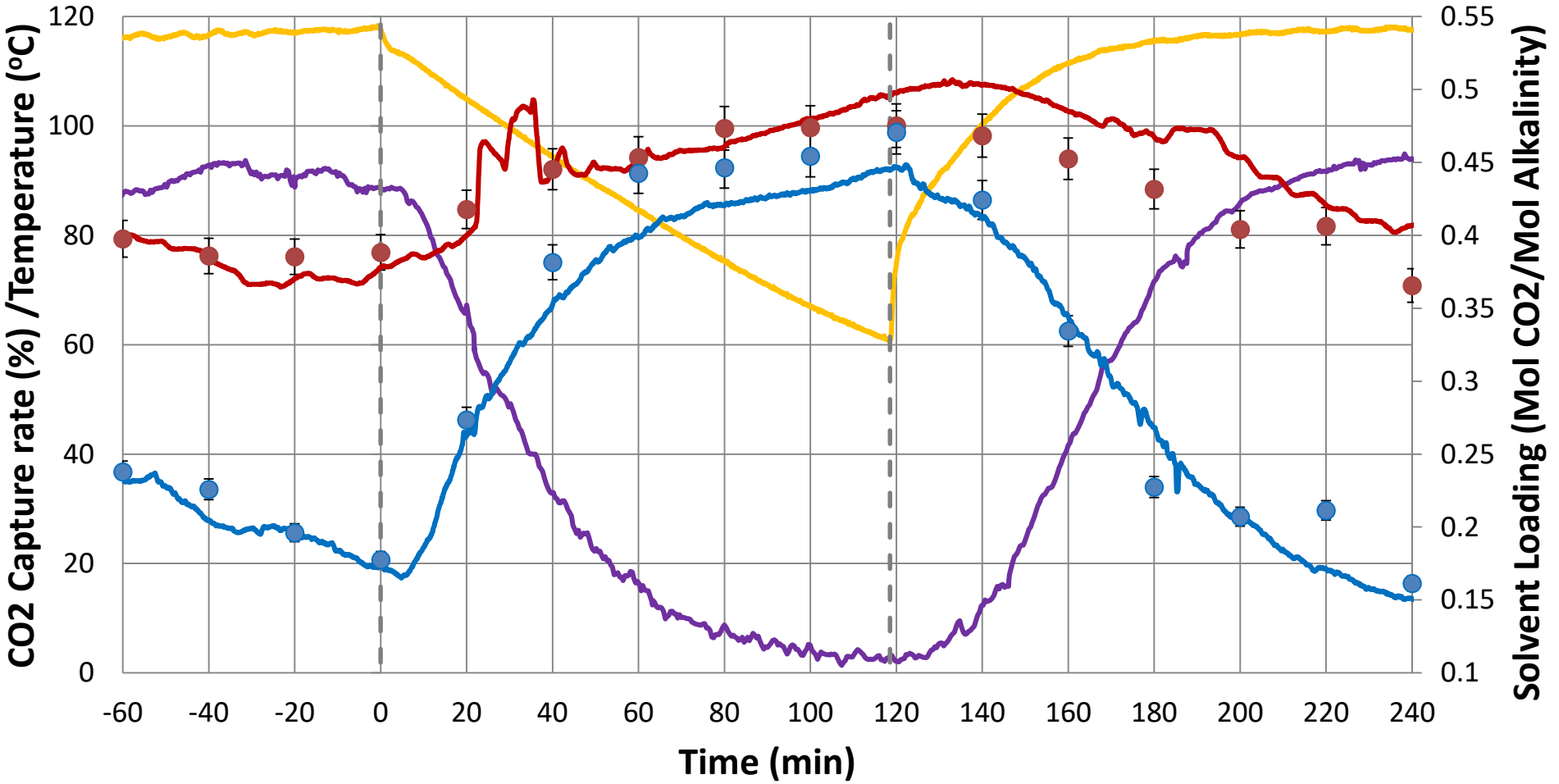
Real-time control using online solvent measurement

Step 1. Monitoring

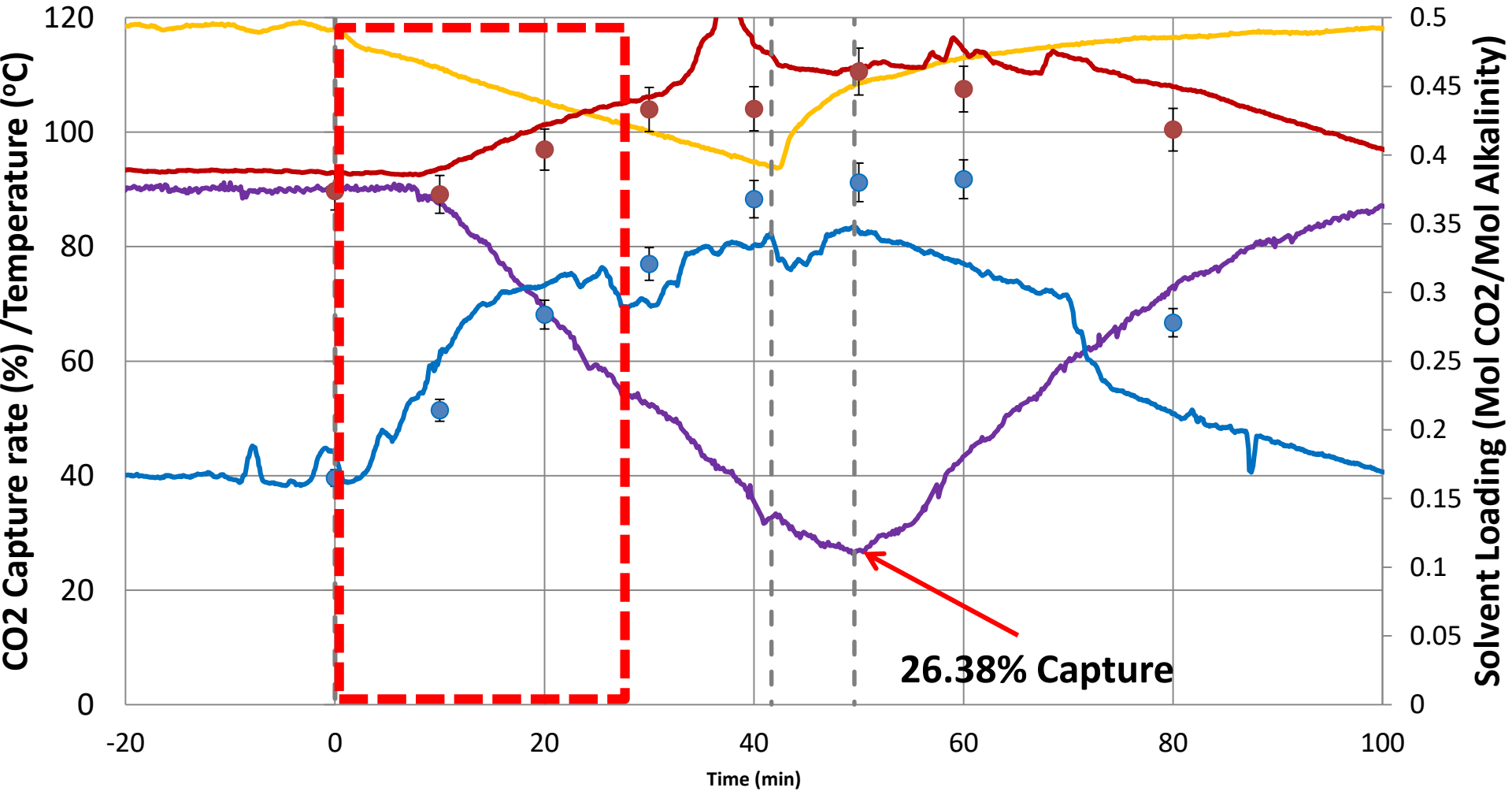


Real-time control using online solvent measurement

Step 1. Monitoring



CAPTURE RATE CONTROL



FINDINGS

- No significant barriers to flexible operation for post-combustion capture
- **Solvent inventory & circulation times** have an effect on plant response.
- **Capture rate response is delayed** by solvent circulation times and possibly mixing effects.
  - Large solvent inventory = **large total capacity**, **long circulation times.**
  - Small solvent inventory = **short circulation times**, **low total capacity, rapid equilibration of rich and lean due to mixing**.
- Understanding of **solvent mixing** in PCC plant is important but difficult to implement accurately in models.
- **Real-time solvent measurement** could become a control variable in **advanced control** systems for PCC.

FINDINGS

- No significant barriers to ADVANCED flexible operation for post-combustion capture, such as capture by-pass, frequency response.
- Understanding of **solvent mixing** in PCC plant is important but difficult to implement accurately in models.
- **Online real-time solvent measurement** could become a control variable in **advanced control** systems for PCC
- May remove need for complex model predictive control in otherwise straightforward to operate process

IMPACT

- State-of-the-art process solvent measurement (auto-titration) are not fit for purpose for dynamic operation
- A credible solution has been developed and demonstrated at 4 pilot plants in USA, Canada, Switzerland, UK
- Guidelines for scale up for flexible operation at power plant scale

- Fit for purpose instrumentation: can be widely applied to any solvent-based capture process, and to any solvent

COLLABORATIONS

- West Virginia University

-> validation of dynamic models developed by CCS Simulation Initiative funded by DOE

- Shell Cansolv

-> demonstrated sensor capabilities on third party commercial solvent

-> collaboration to widen the sensor application to FGD and natural gas sweetening

- Saskpower -> Research license for online solvent monitoring at Boundary Dam
- US National Carbon Capture Centre -> commercialisation under discussion

- Going forward: TCM Mongstad? UKCCSRC PACT?
- Process Control community

THE UNIVERSITY of EDINBURGH

12th September 2017, Sheffield, UK

Towards more flexible power generation with CCS:

Pilot plant test campaigns for best practice guidelines for post-combustion capture

Dr Mathieu Lucquiaud,
Senior Lecturer & Royal Academy of Engineering Research Fellow,
Institute for Energy Systems, School of Engineering, University of Edinburgh
m.lucquiaud@ed.ac.uk