Progress Towards Final Design and Initial Operation of a SMART Test Unit

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Background and Intention

Where post combustion carbon capture is to be carried out on real flue gasses, there will inevitably be contaminants which are specific to the flue gas, fuel or industrial process upstream.

In 2022 Elliot, Benz and others proposed a **SMART** (**S**olvent **M**anagement **A**t **R**educed **T**hroughput) test rig be developed for investigation of thermal reclaiming of amine carbon capture solvents. Also, aspects relating to preventing releases of volatile degradation products with the absorber outlet gas. (Elliott et al., 2022)

Intention of these small rigs is to derisk full scale deployment. Revealing early any "Showstoppers" in the long-term behaviour of the solvents and to allow "boring" long term trials to be carried out at a reduced cost.

The showstoppers might include Emissions to atmosphere , - Emissions to water, Operator health and safety, higher-than-expected running costs, unexpected repair costs e.g. excessive rate of corrosion

UK Environmental Guidance

UK Environmental Agency Guidance for permitting of new post combustion CO2 capture facilities states:

"You must work out the performance of your solvent, including **reclaiming requirements** and modelling **emissions** to atmosphere. Determine this through realistic pilot (or full scale) tests using fully representative (or actual) flue gases and power plant operating patterns over a period of at least 12 months".
(Environment Agency, 2021)

The reclaiming method we have decided to use in our test rig is Thermal Reclaiming.

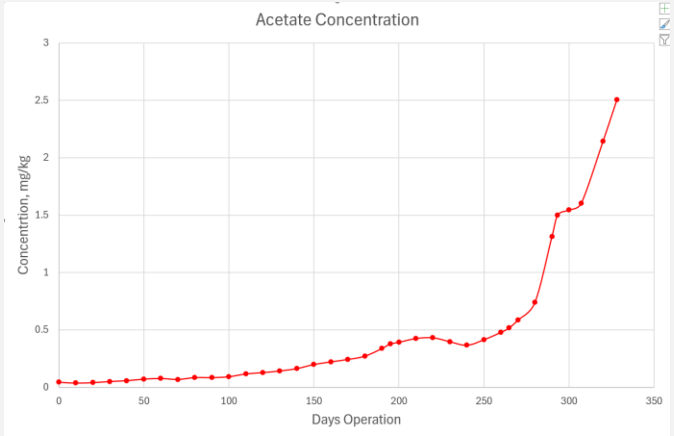
Thermal reclaiming can recover 95% MEA while able to reject all non-volatile degradation products.

Compared to Ion Exchange for example which can recover 99% of MEA and removes up to 90% of the heat Stable Salts BUT doesn't reject non-ionic thermal degradation products at all.

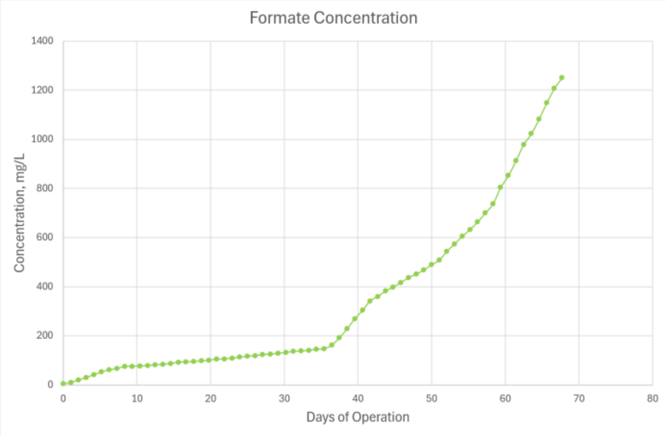
Accelerating Degradation

Long term pilot trials with solvent management on MEA have been carried out at pilots plants at Test Centre Mongstad (Morken2017) and Niederaussem (Moser, 2020). Both trials reported an initial linear degradation of the MEA amine. The trials then showed a sharp increase in degradation effects appearing after some time of operation.

The trials didn't show the same degradation rates even though the shape of the graph is very similar.



(Redrawn from Moser et al., 2020)



(Redrawn from Rieder and Unterberger, 2013)

Pilot Plant Scales

To produce definitive data, Elliot et al considered large pilot trials at around 10 T/day CO_2 would be needed. Those tests could have a trial cost of £ 10 MM or more.

The capacity of the envisioned SMART test rigs is 100 kg/day CO_2.

At this reduced scale, the test rigs can ensure that those "showstoppers" mentioned are screened out early.

The cost of a first industrial test rig at this scale can be orders of magnitude less. Our initial estimate of a transportable rig is in the order of £100K
At that cost, it might be possible to have multiple installations going through the long-term tests in parallel.

The reduced throughput for the SMART rig is 100 kg/day. We are not expecting this very small-scale testing to give exact values for energy requirement or capture performance, but we are expecting to avoid solvent management 'surprises' in larger scale operation.

Reduced Throughput

10 T/d -> 100 kg/d

Mikawa Pilot Plant,
10 tonnes/day, (Toshiba 2009)

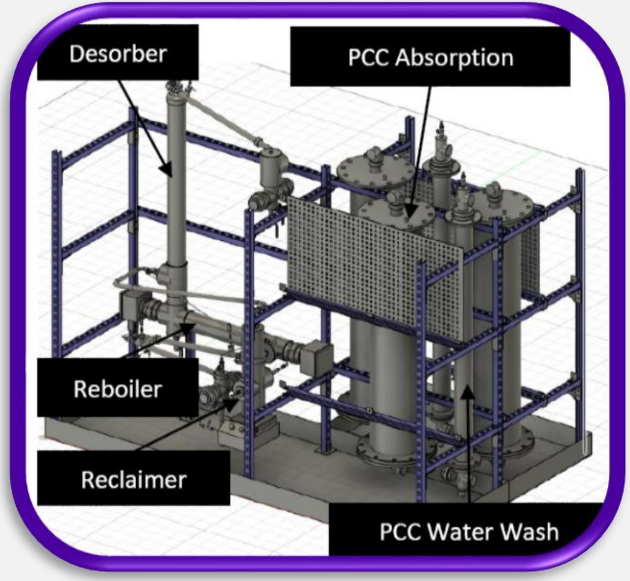
Himeji CO_2 Capture Pilot Plant,
5 tonnes/day, (Mitsubishi, 2025)

The photographs show extensive structure, foundations and access and platforms. That is before we begin to discuss columns vessels pumps heaters etc.

The SMART test unit for 100 kg/day of CO_2 , is a lot smaller.

It is not expected that realistic CO_2 capture levels or regeneration energy requirements can be measured at such a small scale.

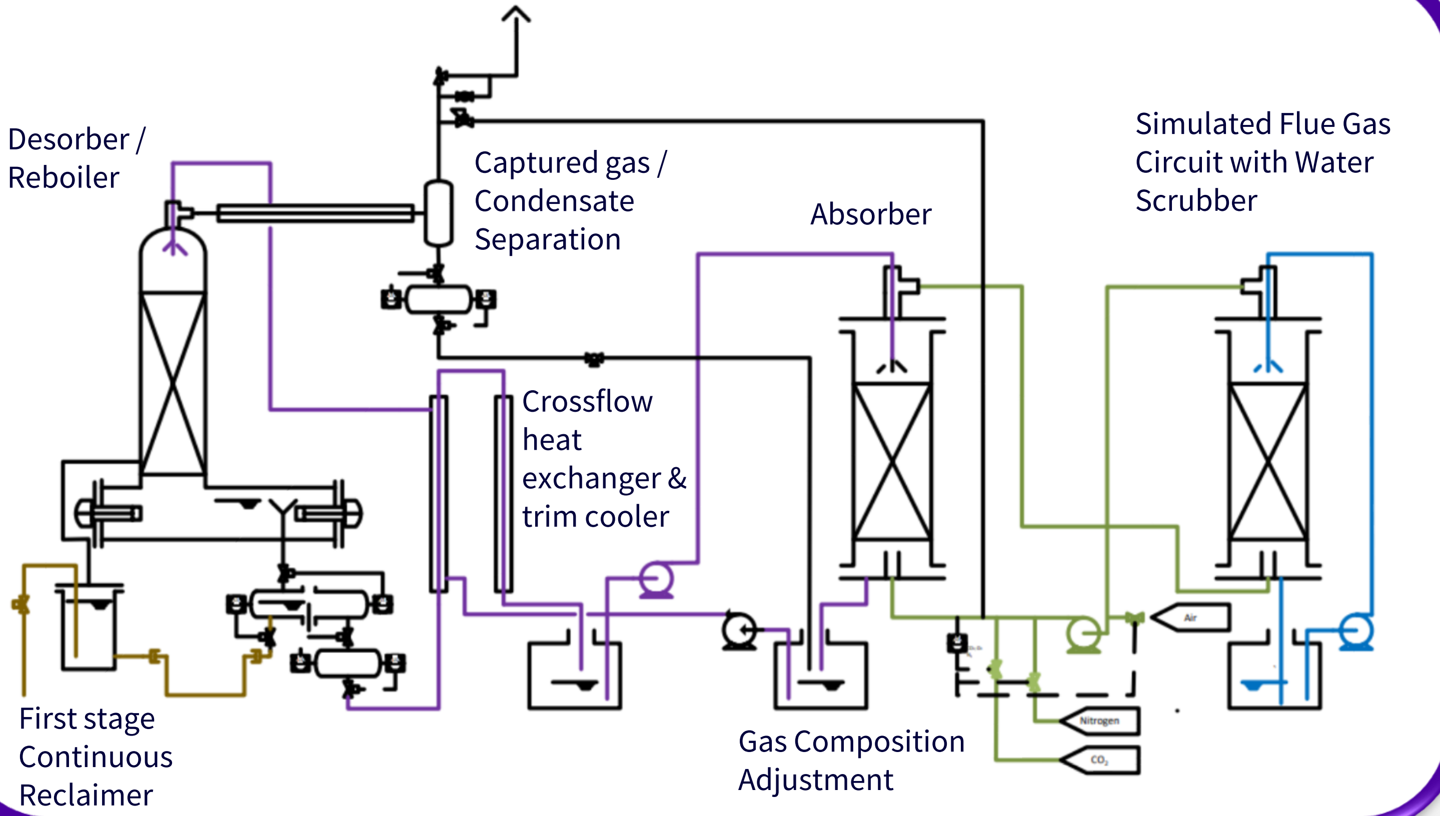
The types and approximate amounts of degradation products and flue gas related volatiles will be generated in the circulating solvent that would be encountered in a full-scale plant.



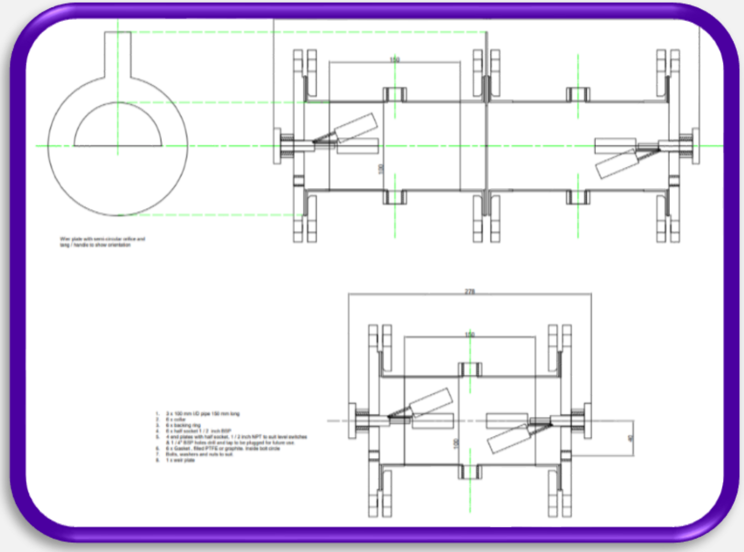
CAD Design of SMART Lab Rig
(Joel et al., 2024)

SMART Lab Rig at University of Sheffield
(Frame - W:1.7m; L:2.7m; H:2.5m)

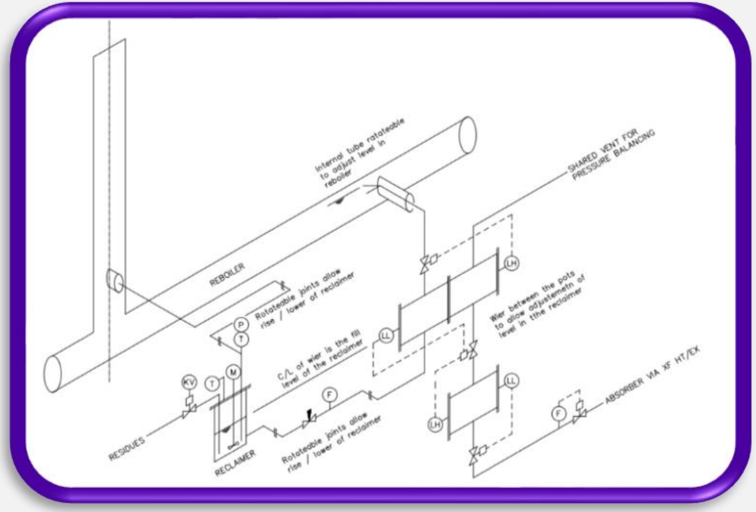
Simplified Diagram of the Laboratory Rig



Overflow Weir and Pressure Retention



Not All Details Shown



There are design problems to solve because of the small scale. Also, due to long term operation in industry where there won't necessarily be a researcher with it all the time.

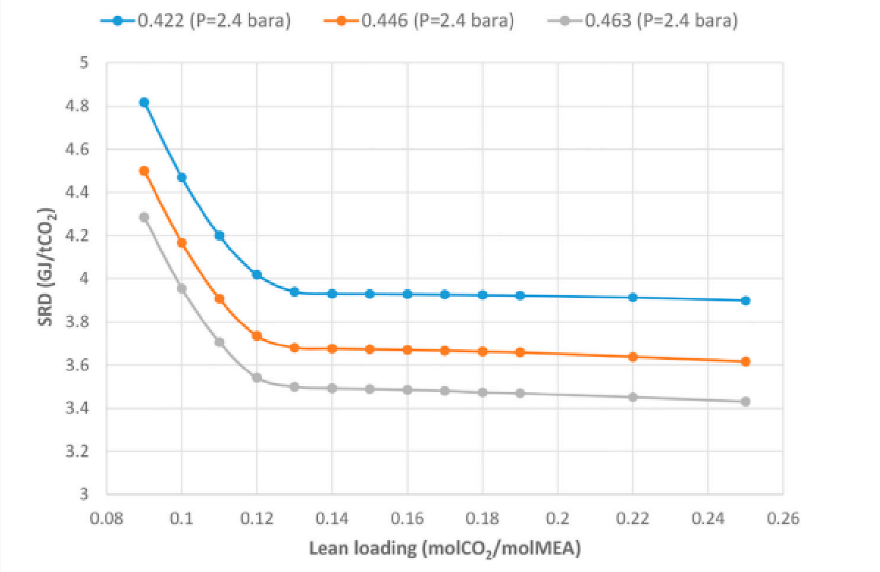
On a large scale, level control can be done by ultrasonic or radar level transmitters driving a level control valve. At small scale, an overflowing weir arrangement keeps the reclaimer full while directing most of the lean solvent to the lean storage tank

Level and residence time in the reclaimer are adjusted by lifting and lowering the reclaimer compared to the overflowing weir.

Outline Sizing of the Lab Rig

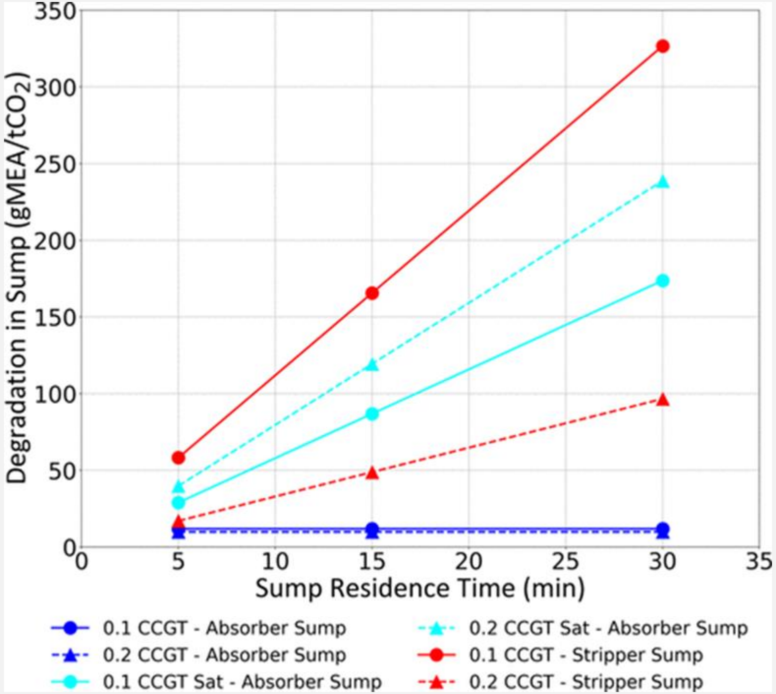
Design Features	
CO_2 Capture Rate	6 kg h^{-1}
Reboiler Power	6 kW [variable]
Desorber Packing	3/8” Pall Ring
Desorber Packing Height	1 m
Desorber Diameter	100 mm
Absorber Packing	Sulzer BX
Absorber Packing Height	1 m
Absorber Diameter	300 mm
Solvent Flowrate	1.3 – 5.5 l min^{-1}
Flue Flowrate	760 m^3 h^{-1}

(Joel et al., 2024)



Increased desorber pressure allows increased temperature, lower lean loading (reasonable SRD). In turn allows a higher capture rate than 95% CO_2 considered.
(Michailos and Gibbins, 2022)

Increased degradation due to elevated temperature in the desorber and reboiler.
(Mullen et al., 2024)



Other Features of Thermal Reclaiming

- Caustic dosing to displace amine from HSS
- Water dilution to control temperature
- Increased thermal degradation (so the need to control temperature!)
- Two stage reclaiming proposed by (Michailos et al., 2025)
- Breakdown product with similar boiling point also recovered. (HEEDA, HEIA, 2 OZD).
- SMART will incorporate 1st stage of reclaiming,
  Work on second stage, ongoing by Marcin Pokora. (Pokora et al., 2024)
- Work on instruments to monitor loading and degradation by Aisha Ibrahim(Ibrahim et al., 2024)

Hazard Study Findings

A Hazard Study has been carried out on the laboratory SMART rig.

Findings: -

1. Flammability of the solvent in the desorber and reclaimer. Potential for escape and ignition of heater surfaces.

2. Pressure envelope & release of mechanical pressure. 2.4 bar abs so not huge in the scheme of things but needs to be accounted for.

3. Contact with high temperature surfaces (≈ 150°C).

4. Acute toxicity from sampling or leak . Contact with hot alkali from leaks or while sampling.

5. Chronic toxicity. Some degradation products are carcinogens. Don’t know how much and how toxic until analysis available. Take precautions until proven un-necessary

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