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A demonstration of the STRETCHER method for ultra-high capture rates with low energy requirements

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Abstract

The 'STRETCHER' – System Tuning for Regenerator Efficiency and Target Capture with High Exit Rich – method is expected to give the optimum solvent regeneration energy requirement for any combination of desorber pressure, absorber packing height and CO_2 capture rate. It appears to be capable of enabling capture rates of up to 100% of added CO_2 to be achieved without excessive capital or operating costs in amine post-combustion capture (PCC) systems using MEA and should also be applicable to most other amine systems, within the limits of their vapour liquid equilibrium properties and thermal stability. Originally developed as a theoretical concept based on modelling the approach has now been demonstrated successfully at 40 tCO_2/day scale and with a realistic pilot plant configuration using a once-through thermosyphon reboiler. The method, the new confirmatory test data and related important practical experience, plus potential enhancements, will be described and discussed.

The key features of the STRETCHER method can be summarised as follows:

a) Produce the lowest possible lean loading without wasted energy for a given desorber pressure

b) Control the lean flow to the absorber to give the highest possible rich loading for the target CO_2 capture rate

c) Use lean and rich solvent buffer storage to allow desorber and absorber performance to be optimised independently

The lowest possible lean loading without wasted energy at a given desorber pressure will be achieved when, as described in (Michailos, 2022), the desorber is operating at its 'inflection point', where as much as possible of the water vapour produced with the CO_2 in the reboiler is condensed by the time the CO_2/vapour reaches the rich solvent entry point in the desorber column.

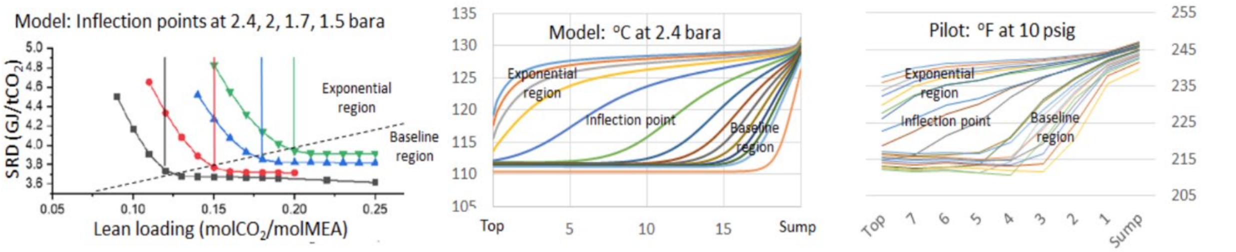

Figure 1: The 'inflection point' is where there is a rapid rise in the curve of specific reboiler duty (SRD – energy per unit mass of CO_2 desorbed) vs. lean loading, as shown in the diagram above left. Corresponding desorber column temperatures are on the right.

It has often been thought that the very low lean loadings (around 0.1 $molCO_2/molMEA$) required to achieve high capture rates would require excessive thermal energy input in the desorber reboiler but, as Figure 1 shows, the inflection point – and hence the lean loading that can be achieved without excessive SRD - can be shifted to lower lean loadings by increasing the desorber operating pressure, with a corresponding increase in reboiler temperature.

Through additional modelling work and personal discussions with the National Carbon Capture Center (NCCC) in Wilsonville, Alabama a practical way for operators to be able to reliably hit the inflection point 'sweet spot' on operating plants was developed. It was observed in modelling runs that the switch from as much water vapour as possible being condensed in the desorber packing to more than necessary leaving with the CO_2, i.e. the inflection point, could be seen as a marked change in the modelled desorber column temperature profiles, as shown in the central diagram in Figure 1. And, subsequently, qualitatively very similar measured desorber column temperature profiles were obtained from a data for a series of MEA baseline tests at NCCC, shown on the right in Figure 1, confirming that the temperature profiles in the solvent/vapour counterflow section of the desorber packing could indeed be used to verify that a desorber is operating at the inflection point.

At lean loadings higher than the inflection value the gas and liquid temperatures in the packing drop rapidly going up the column from the reboiler (the 'Baseline region' curves). At lean loadings lower than the inflection point value (the 'Exponential region' curves) desorber packing internal temperatures stay high, falling only to an extent at the top and never reaching the rich solvent inlet temperature (after any flashing). In the 'Inflection point' region, however, the temperatures in the desorber packing fall approximately linearly from bottom to top, with the differences from the other profiles most striking around the mid-height.

A practically-relevant feature therefore is that, with such large changes in mid-height temperature, the mid-point thermocouple accuracy, or whether it is measuring gas or liquid phase temperature, should not be a concern - the flip in temperature profile around the inflection point will always be far too big to miss.

Operators also need to maintain the lean solvent flow to the absorber at the minimum value required to achieve the targeted exit CO_2 concentration; this will maximise the rich loading and hence give the minimum specific reboiler duty (SRD). Capture rate will vary with lean solvent flow as shown in the 'absorber corner' diagram in Figure 2. But, while a low lean solvent flow can readily be identified from a reduced CO_2 capture rate (higher exit CO_2 concentration), excess lean solvent flow may not be so readily determined by this measurement because the exit CO_2 concentration will be relatively insensitive to further increases in lean solvent flow beyond the 'absorber corner'. The absorber column temperature distribution may give some additional indication but expected changes are also small.

A supplementary real-time measurement of the rich loading at the absorber exit is therefore expected to be of significant value in implementing the STRETCHER method. A suitable method will be described in another presentation at PCCC8 (Ibrahim, 2025) but this was not available to use in the tests described in this paper.

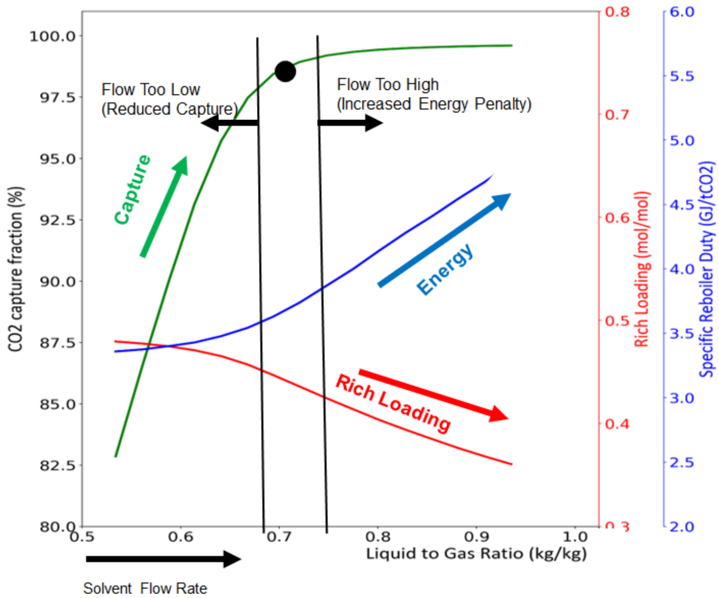

Figure 2: Optimising absorber operation for ultra-high capture rates (Mullen, 2024)

A practical test of the STRETCHER principles was undertaken, with the assistance of the Guandong CCUS Centre and funded by the UK FCDO and DESNZ, at around 40 tCO_2/day scale using the Haifeng amine PCC pilot plant at the Guangdong Carbon

Capture Test Platform. A detailed description of the plant is given by Ren (2018). The pilot plant is attached to Unit 1 of the Haifeng Power Plant and receives flue gas, steam and other services from the power plant – this is an important consideration since flue gas CO_2 content, and also steam and cooling water temperatures to some extent, are unavoidably affected by the operating patterns of the power plant. It does, however, have the benefit of mimicking some of the challenges of most real-world PCC applications, where similar, uncontrolled input fluctuations will occur.

A key feature of the Haifeng pilot plant is the chimney tray at the bottom of the packing in the desorber feeding a once-through thermosyphon reboiler. This tray/reboiler arrangement is not common in PCC pilot plants but is used in all full-scale commercial units. This type of reboiler takes all of the solvent coming down through the packing, heats it and then vents the mixture below the tray to flash into the regenerated lean solvent and a CO_2/water vapour mixture that passes up through the 'chimneys' in the tray and into the desorber packing. The result is a very close link between conditions in the reboiler and temperatures in the desorber packing, where the necessary thermocouples are available in the sump and between and above the two beds of packing (ID:1m, 2 beds: each 4.26m, packing: Sulzer Mellapak CC).

The absorber (ID: 1.8m, 3 beds: each 5.3m, packing: Sulzer Mellapak CC) incorporates solvent intercooling above the lowest of the three beds. At the flue gas CO_2 concentrations being used, approximately 12-16% v/v dry, and especially at the low lean loadings used to achieve high capture rates, the heat of reaction when the CO_2 is absorbed is greater than the heat capacity of the solvent and flue gas alone can take up without temperatures becoming too high for effective operation.

Tests were undertaken in October/November 2024. A typical STRETCHER test is shown overleaf in Figure 3. In line with STRETCHER principles the main operator targets for this test were:

1. The steam supply to the reboiler should be adjusted to keep the desorber midpoint temperature (DT3) between the values in the sump (DT1) and top (DT4) of the packing – the conditions expected to operate the desorber at the inflection point.
2. The absorber exit CO_2 should be controlled to be around 0.3% v/v by varying the lean solvent flow.

This exit CO_2 measurement was made using a FTIR analyser with limited resolution at very low CO_2 concentrations and it was found by experience that below an exit CO_2 of around 0.2%v/v the relationship between lean solvent flow and exit CO_2 was lost. i.e. below this CO_2 level it appeared that lean solvent flow could increase, and hence rich loading decrease, without a clear reduction in exit CO_2 level. Adding an operating margin to give the 0.3%v/v target then inherently restricted the maximum capture rate in controlled operation to around 98%, although higher capture rates appeared to be feasible.

Another factor affecting operational settings was achieving effective intercooling, The limiting factor here appears to be the mass of CO_2 being captured per unit time from this flue gas, and hence the reaction heat generated in the absorber, with a satisfactory maximum value in these tests of around 40 tCO_2/day. This translates into a superficial flue gas flow velocity of around 7.5 m/s, a somewhat lower value than in typical commercial practice, but this also compensates for the relatively low absorber packing height (15.9m) compared to what might be included in a high-capture-rate design (perhaps 20-25m). The desorber was also found to exhibit foaming if left to operate unattended and at non-optimised conditions overnight.

Multiple periods of ~98% capture (based on flue gas CO_2 concentrations in and out of the absorber) at moderate SRD values (based on reboiler heat inputs and desorber CO_2 output) of around 3.6/3.7 GJ/tCO_2 were achieved after gaining experience of the plant characteristics when applying STRETCHER operating principles, with one example shown Figure 3. It should be noted that this data is from 'real' operation of an amine post-combustion capture plant, with the operators having to adjust the flows to respond to changing external conditions, principally the varying flue gas CO_2 concentration and also steam temperature and pressure etc.. This means the plant is rarely in a fully-stable condition. A lean buffer storage tank was in place but not a rich storage buffer, which would have been helpful. Note, though, that the absorber itself is exhibiting greater internal buffering than might be expected – the exit CO_2 concentration varies much less than the inlet CO_2 concentration. Further practical features of the tests that may be relevant for full-scale commercial implementation will be presented and discussed at the conference.

References

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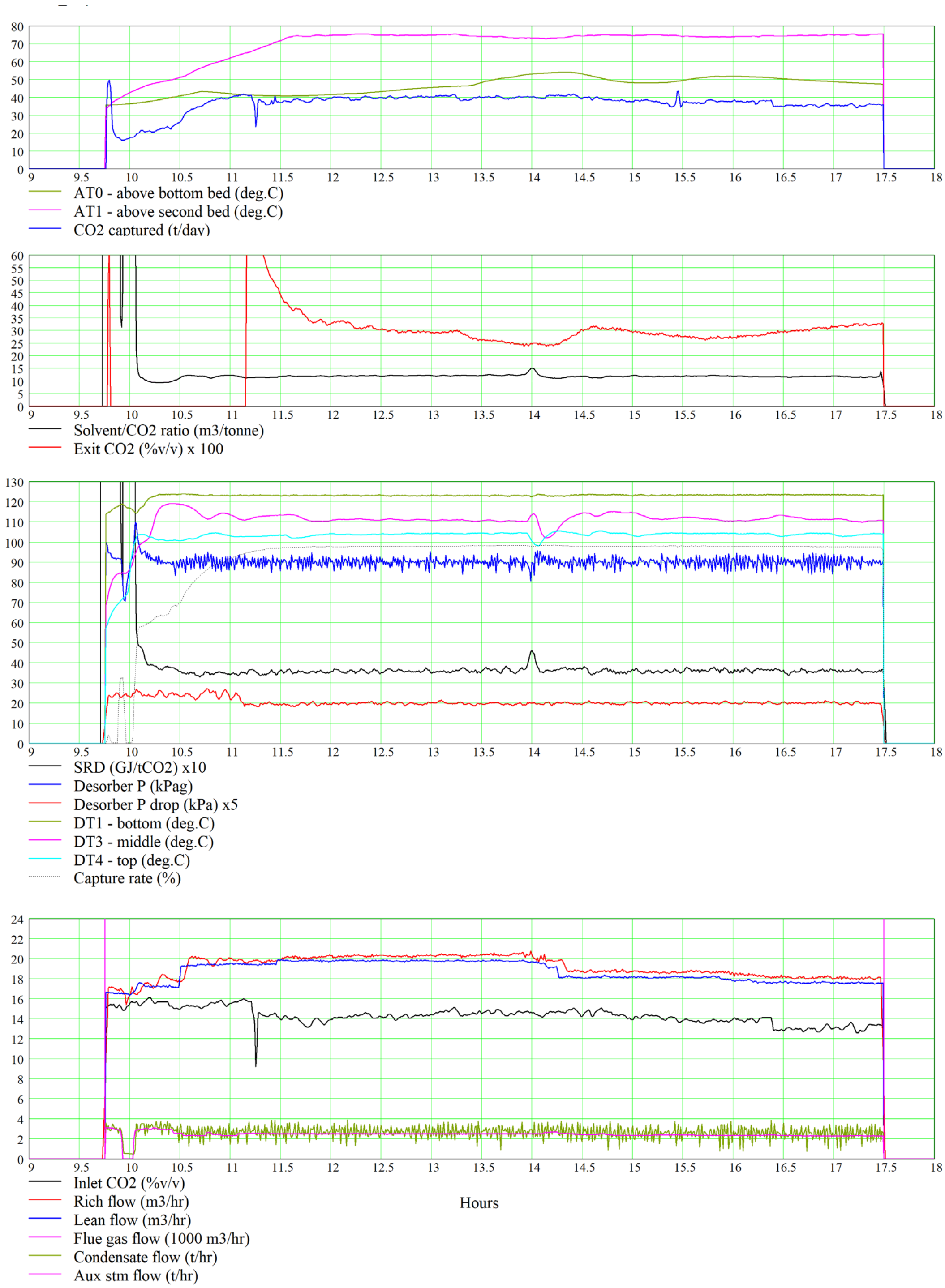

Figure 3: Test data from the Haifeng pilot plant over one operating day showing an extended period of operation (11:30-17:30) at an average desorber pressure of 90 kPa with high capture (average 97.9%) operation at moderate SRD (average 3.61 GJ/tCO_2).

Keywords: Amine post-combustion capture; optimisation; SRD; capture rate