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An experimental investigation of optimum conditions for continuous two-stage reclaiming of MEA solvent inventories from commercial plants

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Abstract

This paper describes a series of tests to investigate the optimum conditions for continuous two-stage reclaiming of used monoethanolamine (MEA) solvent from an operating commercial plant, plus process modelling to assess the impact of fully integrated reclaimer operation on the overall energy requirements of a complete capture system. While modelling the reclaiming process itself can give useful semi-quantitative insights, the extreme complexity of the range of impurities present in real processes means that representative small-scale testing is required to confirm trends with the reliability needed to inform commercial equipment configurations and operating procedures. Although a generic solvent, MEA, is being used, which allows full disclosure of all results, much of the information and insights are expected to apply to any amine solvent formulation where thermal reclaiming achieves good separation between solvent components and impurities.

The key performance requirement for any reclaiming system is to remove all added or formed impurities from an operating amine capture system and indefinitely maintain the circulating solvent at an acceptable purity level. The two-stage system proposed for this purpose is shown in Figure 1. The first stage is operated by venting into the stripper to return heat to the system as water vapour as well as reclaimed MEA and therefore would operate either at stripper pressure or at a lower pressure with mechanical vapour compression. The second stage would vent into the absorber and operate at either atmospheric pressure or at reduced pressure using a vacuum pump. For both stages, the use of added equipment to achieve reduced operating pressures represents a trade-off between amine recovery, energy requirements and capital and maintenance costs, which the test data and process modelling will help to inform.

The objective for the first reclaiming stage is to recover as much of the reclaiming thermal energy input as possible to help regenerate further solvent, while also giving satisfactory amine recovery and impurity rejection overall. It will run continuously with the unwanted residue leaving in a relatively dilute, and hence free flowing, ‘blowdown’ stream, mixed with some of the incoming MEA and water. The impact of variable real impurity levels (based on used solvent from a commercial capture plant), the ratio between the ‘blowdown’ to the second stage and water addition on operating temperature, MEA recovery and volatile impurity returns will be reported for a maximum stripper pressure

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of 2.4 bara (20 psig) and lower pressures requiring vapour recompression.

The second reclaiming stage is intended to maximise amine recovery while also not using excessive energy and not returning an excessively high proportion of the more volatile impurities. Caustic is also added in this stage to release heat-stable salts, with the amount based on sample testing. Operation is in batch mode, involving three stages:

a) A filling/concentration stage where the inflowing first-stage blowdown (plus added water and any caustic) is heated, and vapour is collected until a characteristic temperature (The value of which is a key finding from the test programme) is reached where thermal degradation and unwanted volatile carryover become excessive.

b) An MEA recovery stage where first-stage blowdown input is stopped (two second-stage reclaimers may be used to allow continuous first-stage operation) and only water is added; the temperature will fall in this stage eventually reaching a plateau, indicating the MEA recovery stage completion, although the trade-offs between maximising MEA recovery and unwanted volatile residue recycling must be considered.

c) A concentration stage where (mainly) water is removed to the point where a flowing residue can still be obtained, in order to minimise the volume of waste while maintaining residue handleability; again, unwanted component evaporation must also be evaluated.

MEA recovery is measured using gas chromatography. In the test system used the vapour is condensed and collected, allowing a complete MEA balance to be made. The heterogeneous and complex residues and evaporates are characterised using thermogravimetric analysis (TGA), which can assess the entirety of the sample, plus mass spectrometry. TGA is a method that may be suitable for routine industrial use.

Data from tests on both reclaimer stages are included in the overall system modelling to estimate impacts on energy requirements as a function, mainly, of impurity levels and water addition. Modelling has been carried out using the CCSI toolkit Aspen Plus V12.1.

This work is expected to inform the operation of existing reclaimers and be the basis for the design of future commercial fully integrated MEA reclaiming systems.

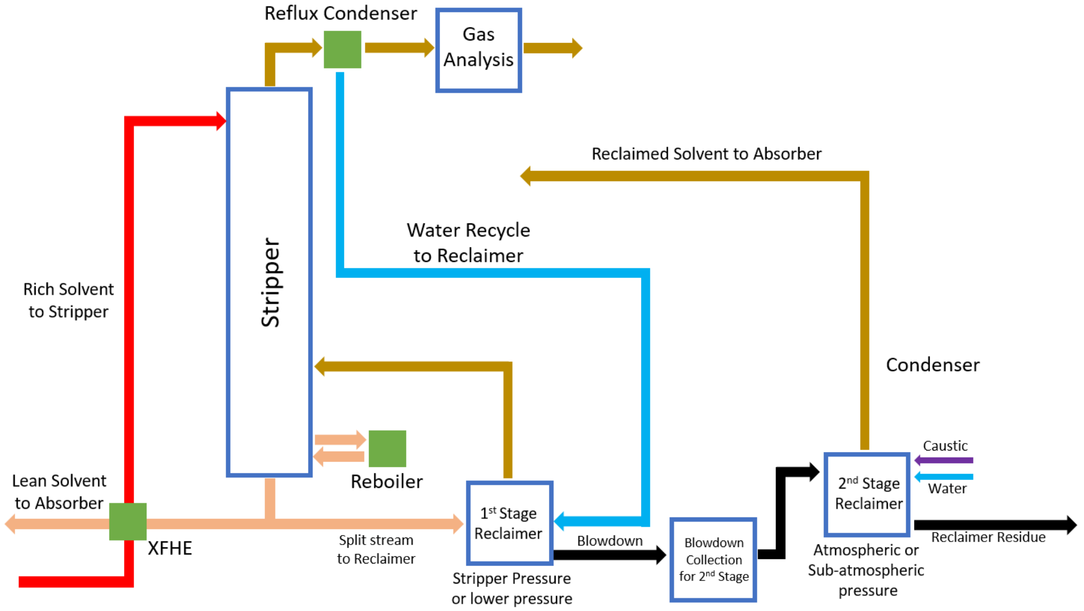

Figure 1. Proposed two-stage thermal reclaiming system.

Keywords: Amine post-combustion capture; Solvent management; Reclaiming; Thermal reclaiming; Carbon capture; MEA; Monoethanolamine

1. Introduction

Carbon capture using amine solvents in post-combustion processes is one of the essential technologies needed to combat dangerous climate change. This technology has been utilised since the 1930’s for CO_2 scrubbing [1] and has remained a continuously evolving field. However, with the increasing demand for CO_2 removal, the role of this technology has become more critical than ever.

One major drawback of this technology is the degradation of amine solvents over time. This degradation leads to several adverse effects, including solvent loss, corrosion, and foaming. These issues reduce CO_2 capture efficiency, elevate maintenance costs [2], and, in extreme cases, may contribute to the failure of capture plants. To prevent such outcomes, solvent management must be prioritised for any capture facilities using amine solvents. This is crucial to ensure these plants can operate effectively for an extended period between solvent replacement and plant cleaning intervals, matching the major service interval for other components. It is often assumed that an amine solvent that degrades slowly will have reduced solvent management costs, but the formation of degradation products is only one factor; the difficultly of their removal at a rate that balances formation and to costs of solvent makeup are also critically important.

Monoethanolamine (MEA) is one commonly used amine in post-combustion carbon capture systems. MEA is susceptible to both thermal and oxidative degradation. Thermal degradation occurs at elevated temperatures, where MEA carbamates react with other species in the solution, forming degradation products such as OZD (2-oxazolidinone), HEEDA (N-(2-hydroxyethyl) ethylenediamine), and HEIA (N-(2-hydroxyethyl) imidazolidinone) [3]. In parallel, oxidative degradation arises in the presence of oxygen, resulting in formation of acetaldehyde, formaldehyde, and carboxylic acids such as acetic acid, formic acid, glycolic acid, oxalic acid, which lead to the formation of heat-stable salts (HSSs) [4,5].

While small quantities of these degradation products may not immediately impact system performance, their catalytic properties may accelerate the overall degradation rate. Over time, their accumulation becomes critical to the health of the capture system, requiring the implementation of solvent management strategies to control degradation product buildup and ensure long-term plant performance.

Among the various solvent management strategies, thermal reclaiming stands out as a highly effective method for removing both uncharged and charged degradation products. This involves a process of separating valuable solvent from degradation products by the manipulation of different volatilities of the species involved. By using thermal energy, the solvent is boiled off from the mixture, leaving degradation products behind in the reclaimer bottoms.

Thermal reclaiming is performed on a split stream (e.g., 1 wt.%) of solvent from the desorber, using either a batch or semi-continuous process. For MEA-based systems, thermal reclaiming has demonstrated high impurity rejection rates, indicating its strong reclaimability [6]. Other commonly used non-proprietary solvents, such as CESAR-1, are also reported to have been thermally reclaimed. However, there is limited published data on the reclaimability of CESAR-1[7,8], and blended solvents like CESAR-1 may pose additional complexity compared to single-component solvents like MEA. For this reason, MEA was chosen as the solvent for this study. It is, however, important to note that the approaches in this research are generally expected to be transferable to any solvent if it is thermally reclaimable.

A significant issue evident from pilot-scale campaigns to date is that they are not sufficiently long to quantify long-term degradation rates. Long-term pilot testing (>8000 hours) [9] should therefore be undertaken to fully assess the effectiveness of thermal reclaiming. Since the accumulation of degradation products over time poses substantial challenges to the longevity of capture plants, two key performance requirements for any reclaiming system must be met: the removal of all degradation products at the same rate as they are formed (and also the removal of any added substances from the flue gas or plant corrosion), giving the ability to maintain the circulating solvent at an acceptable purity level indefinitely.

To achieve these requirements, the continuous removal of degradation products from the circulating solvent at the same rate as they are formed is essential. This may be accomplished by employing a two-stage thermal reclaiming strategy, consisting of a continuous first stage followed by a semi-continuous/batch second stage.

The first stage of reclaiming in this study will be continuous and tested either in a standalone stainless-steel SMART reclaimer or on-line using the SMART rig. The SMART rig is a lab-scale capture unit designed and operated to achieve low lean CO_2 loadings after the regeneration step and high CO_2 loadings during the absorption step, as demonstrated in a study, which utilised an Aspen Plus CCSI MEA steady-state model [10] to achieve high capture rates. Details of the rig's design and operation can be found elsewhere [11]

The continuous first stage of reclaiming must be energy efficient to be a viable strategy. To achieve this, it is designed to recover as much thermal energy input as possible to support further solvent regeneration. This is accomplished by integrating the reclaimer with the desorber, enabling all recovered vapour to be fed directly into the desorber. To allow this, the reclaimer operates at essentially the same pressure as the desorber, which, for the purpose of achieving high capture rates, is set at 2.4 bara.

This pressure is higher than typical for reclaimer operation and will result in higher boiling points for the species involved. Nevertheless, the reclaimer will operate within a temperature range of 130–150°C to limit the thermal degradation of the amine solvent. However, this temperature range will reduce the recovery of the amine solvent in the first stage due to the increased pressure and boiling points of all species.

The reclaimer will operate continuously, with the unwanted residue discharged in a relatively dilute, free-flowing ‘blowdown’ stream. This stream will be mixed with a portion of the incoming MEA and water from a split stream from the desorber. The purpose of this ‘blowdown’ stream is to remove degradation products that would otherwise accumulate within the reclaimer bottoms. Overall, this first stage of the reclaimer operation aims to minimise the accumulation of degradation products within the capture system and the reclaimer vessel, thereby maintaining its efficiency and longevity.

The ‘blowdown’ stream will be collected in a storage compartment for further processing in a second reclaiming stage. This second stage will be conducted off-line and is designed to maximise amine recovery while minimising energy consumption and avoiding the return of an excessively high proportion of highly volatile impurities. Conducting this reclaiming off-line provides additional control over the process, which is essential as this stage handles solvent with higher impurity levels, making it more challenging to process.

Off-line operation of the second stage allows reclaiming to be performed under atmospheric or sub-atmospheric conditions, enabling species separation at lower temperatures. This approach minimises further thermal degradation of the solvent and may also enhance separation based on different species volatilities. Additionally, the use of transparent laboratory apparatus in off-line operation enhances the ability to monitor and control liquid levels and temperatures with greater precision.

The second stage will also include the neutralisation of HSSs through the addition of caustic solution. This step ensures that the first reclaiming system contains minimal amounts of added impurities. Conducting neutralisation off-line allows for optimisation of this process. The reclaimed solvent inventory can be analysed for HSS concentrations, enabling precise determination of the optimal amount of caustic to be added. This prevents both incomplete neutralisation and the presence of excess caustic in the solution.

2. Apparatus Design, Methods and Results

2.1. First Stage Reclaimer

The first-stage reclaimer, shown in Figure 2, is constructed using stainless steel fittings to minimise the solvent's contact with transition metals [11]. It has been documented that transition metals, such as iron, copper, and chromium, exhibit catalytic effects on oxidative degradation when present in solution [12,13,14].

Figure 2. Prototype First Stage Continuous Reclaimer (Standalone, without heating tape)

The continuous reclaimer can be operated either as part of the integrated SMART system or as a standalone unit, allowing off-line testing of reclaiming operations and conditions. The main reclaimer vessel is heated using a stirrer hotplate, which stirs the vessel's contents, along with heating tape wrapped around the reclaimer's outer walls. The solvent volume within the reclaimer is maintained at approximately 2 litres, controlled by a weir and a blowdown outlet that pumps solvent from the reclaimer bottoms at a set rate. The blowdown flow from the first-stage reclaimer is extracted, cooled, and sent to a secondary reclaiming stage, which helps prevent the accumulation of degradation products in the main reclaiming vessel. The standalone unit has now been built and has commenced preliminary testing.

2.2. Second Stage Reclaimer

The second stage reclaimer, shown in Figure 3, is designed for control and is constructed using QuickFit glassware apparatus ensuring an adequate seal and allowing for easy visual monitoring of reclaimer solvent levels.

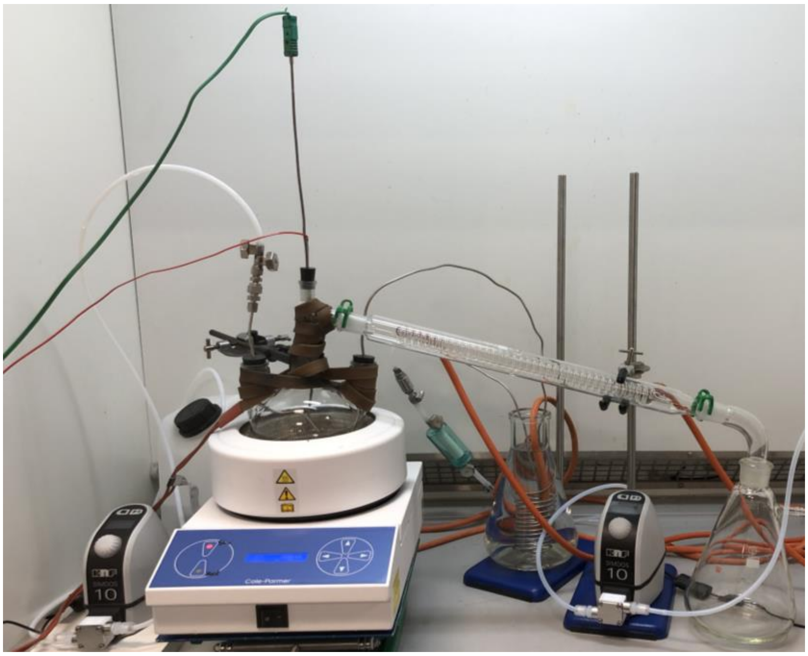

Figure 3. Second Stage Batch Glassware Reclaimer

The main reclaimer vessel, a 1L round-bottom flask, is heated and stirred using a magnetic stirrer bar and a Cole-Parmer 1L round-bottom flask heating mantle. The necks of the flask and the still head are heated with BriskHeat silicone heating tape to minimise condensation of vapour before it reaches the condenser. This is particularly important for MEA, which has a higher boiling point than water and tends to condense more readily. If the vapour encounters cooler areas before reaching the condenser, it will reflux back into the reclaimer vessel instead of condensing and being collected after at the condenser.

Reclaiming with the secondary-stage glass reclaimer can be carried out at both atmospheric and sub-atmospheric pressures by attaching a water jet pump to the arm of the collection flask. The ability to operate this reclaimer under vacuum is particularly beneficial for the two-stage reclaiming approach, as the second stage handles solvent with higher concentrations of degradation products. This results in higher boiling temperatures for the overall solution. Elevated temperatures can accelerate thermal degradation rates, leading to increased MEA losses.

Sodium hydroxide is added to the solvent being reclaimed to neutralise HSSs. The reaction between the caustic and HSSs is stoichiometric, as shown in Equation 1, the neutralisation reaction of HSSs with NaOH to liberate trapped amine. Therefore, knowing the concentration of HSSs allows for the optimum amount of caustic to be added for complete neutralisation. The concentration of HSSs is determined using conductometric titration of a solvent sample with caustic, a method documented by Cummings et al. [15]. Titrating the MEA solution with NaOH will allow for the calculation of the concentration of bound amine in the solution.

$$NaOH + AmineH^{+} + RCOO^{-} \rightarrow Amine + H_2O + Na^{+} + RCOO^{-} \qquad \text{[Eqn.1]}$$

The titration with a base (NaOH) produces a characteristic conductance trace with a nearly flat, zero-gradient slope. The point at which all the amine trapped within the HSSs has been replaced by OH^- from NaOH is marked by a sharply rising slope, as illustrated in Figure 4. Table 1 presents the reactions occurring during this process and the expected gradients of the slopes.

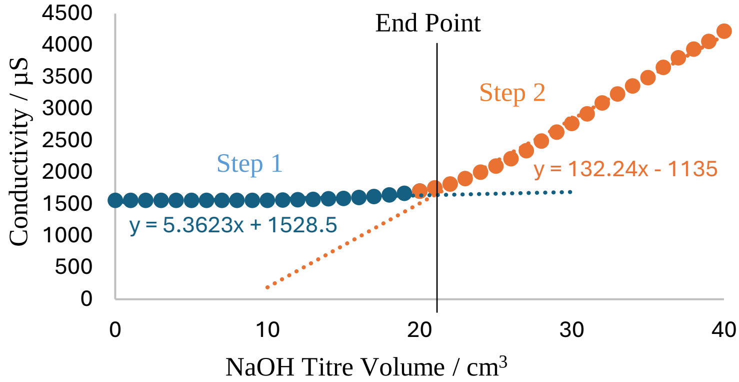

Figure 4. Graph of Conductometric titration of industrially degraded MEA solvent with NaOH

Table 1. Graph showing reactions during the conductometric titration of MEA solvent sample with NaOH

Step	**Reaction**	**Conductance Slope**
1	$AmineH^+ + NaOH \dashrightarrow Amine + H_2O + Na^+$	~ 0
2	$NaOH \dashrightarrow Na^+ + OH^-$	>>0

The apparatus and reagents required for this experiment are:

- Conductance meter and probe
- Burette
- Balance
- Beakers
- Stirrer
- NaOH solution
- Water, conductance grade

The implemented procedure is:

1) Weigh out 2 grams of amine solution and transfer to the titration beaker.
2) Add conductance water to bring solution level to top of vent holes in conductance probe. Begin continuous stirring without visible vortex.
3) Titrate with NaOH to at least 3 mL beyond the beginning of the increased slope evidencing excess OH^-
4) Determine the equivalence point from a graph of the titration curve (conductance vs. mL of titrant). That will be the point where the extrapolation of the small gradient meets the large gradient value.

The endpoint is found, as shown in Figure 4, at the intersection of extrapolations of the linear portions of the titration curve. To calculate the concentration of bound amine the following equation was used [15].

$$[B] = \frac{V \times N}{W} \qquad \text{[Eqn.2]}$$

$[B] = Bound\ Amine\ concentration\ (HSS's)\ in\ meq/g$ (milliequivalents per gram)
$V = Volume\ of\ NaOH\ added\ to\ reach\ the\ end\ point\ in\ mL$
$N = Normality\ of\ NaOH\ added\ in\ meq/mL$
$W = Weight\ of\ amine\ sample, g$

$Conversion\ of\ the\ concentration\ of\ bound\ amine\ from\ meq/g\ to\ wt\%\ using\ equation\ below:$

$$wt\% = \frac{(meq/g) \times Mr}{10} \qquad \text{[Eqn.3]}$$

$Mr = Molecular\ weight\ of\ the\ amine\ (MEA = 61\ g/mol)$

For the sample tested in Figure 4, the equivalence point was reached at 20.99 ml of NaOH, which corresponds to 6.16 wt.% HSS for the 2 g of solvent. This method of determining HSS content allows for optimised caustic dosing in the secondary reclaimer to maximise MEA recovery. It is important to note that, although caustic addition is currently applied to the solvent sent to the secondary-stage reclaimer, its application within the first-stage reclaimer will also be investigated.

The operation of the second stage reclaimer is in batch mode and it involves three stages, all under level control:

1) **The Filling/MEA Concentration Stage:** Initially, the boiling flask is filled halfway with the solvent awaiting secondary-stage reclaiming, along with any required water and caustic, using a diaphragm pump connected to one of the necks of the round-bottom flask. The liquid level is marked on the flask, and all stirring and heating systems are switched on. As the temperature of the solvent begins to rise, it is monitored using a long thermocouple inserted from the top of the still head through an EPDM plug. This plug not only ensures a tight seal but also serves as a safety measure in the event of unexpected pressure buildup in the system. The thermocouple extends down to the bottom of the round-bottom flask. Once the solvent starts to boil, a low-flow feed of solvent (blowdown) into the reclaiming vessel is turned on. This feed is continuously monitored and adjusted to maintain a constant liquid level within the reclaimer as the solution boils. This process increases the concentration of degradation products in the reclaimer, allowing the solution temperature to rise. Distillate is collected until a target temperature is reached, beyond which thermal degradation and unwanted volatile carryover become excessive.
2) **The MEA Recovery Stage**: Once the desired temperature from the concentration stage is reached, the solvent feed (blowdown) is stopped, and the pump is switched to feed water into the reclaimer vessel. This water flow is continuously monitored and adjusted to maintain a constant liquid level within the reclaimer. The addition of water strips any remaining MEA from the reclaimer, and as water is added, the solution temperature gradually falls. A plateau in temperature indicates the completion of the MEA recovery stage, at which point the water feed is stopped. However, trade-offs between maximising MEA recovery and the risk of recycling unwanted volatile residues must be carefully considered.
3) **The Residue Concentration stage**: Once the water feed is stopped, heating continues, and the temperature of the reclaimer vessel rises. At this point, primarily water is removed from the boiling solution, reducing the residue volume in the reclaimer while maintaining it in a flowing state. This stage ensures the minimisation of waste volume while preserving the handleability of the residue. However, the evaporation of unwanted components must also be carefully evaluated.

The temperature profiles for these three stages under atmospheric conditions are shown in Figure 5, highlighting the precise control achievable during this stage of reclaiming, as evidenced by the minimal temperature spikes throughout the process. Furthermore, visual representation of reclaiming (industrially degraded solvent) using this method is shown in Figure 6, where upon visual examination the reclaiming, was able to separate the MEA and water from impurities which cause the browning of the solvent overtime through degradation processes.

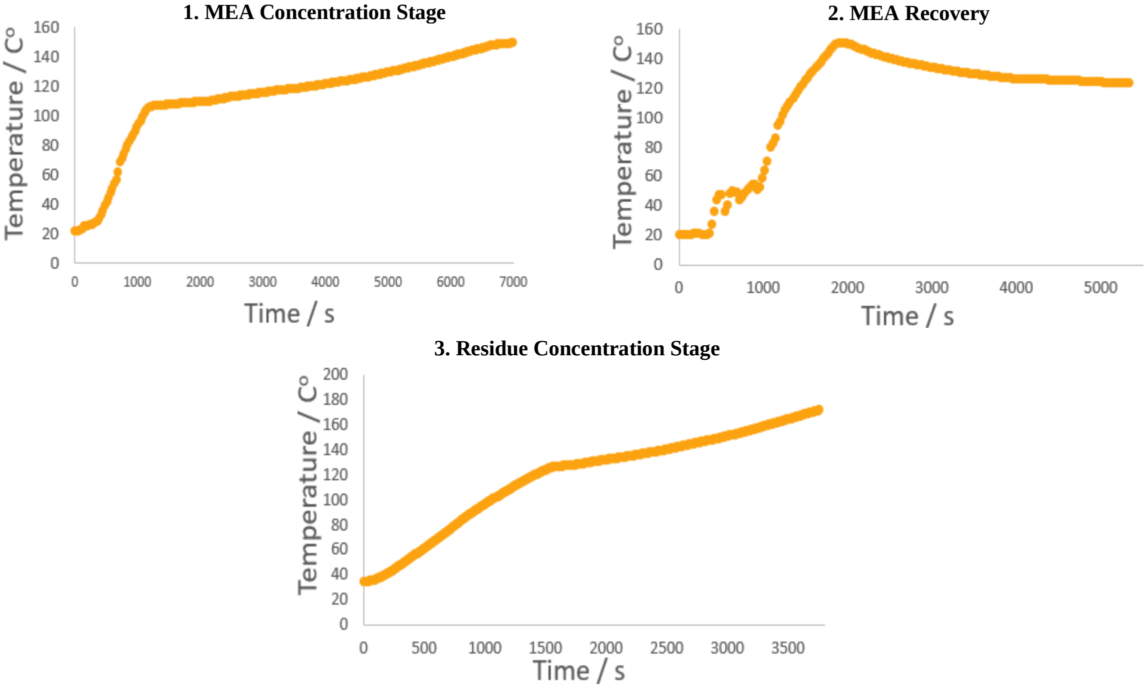

Figure 6. Temperature profile graphs of a reclaiming run using the second stage reclaimer.

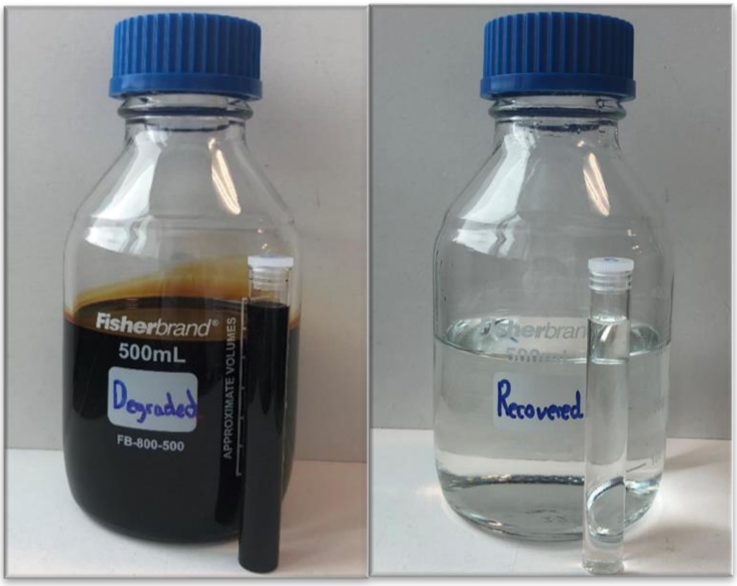

*Figure 6. Visual representation of degraded end of life industrial MEA solvent before (left) and after (right) reclaiming. *Volumes of reclaimed solvent not to scale*

2.3. Analytical Methods

Various analytical techniques have been explored and developed to assess reclaiming efficiency through amine concentration determination and the identification of degradation compounds. These techniques include gas chromatography, total inorganic carbon analysis, titrations, thermogravimetric analysis, boiling tests, and density measurements.

Gas chromatography is widely documented in the literature, employing various methods and gas chromatography columns [16,17,18,19,20]. Based on the literature, the nonpolar CPSIL8-CB-for Amines (Agilent) column has been selected, with its dimensions and GC-FID parameters listed in Table 2. Although this method is currently being used, it is still under development to ensure accuracy and precision. Other columns, such as the RTX-35 Amine (Length: 30m, ID: 0.53mm, Film Thickness: 3 µm), will also be examined in the future.

Table 2. Table showing gas chromatography parameters used, the column and its dimensions.

	GC - FID
Column	CPSIL8-CB for Amines
Column phase	5% phenyl/95% dimethylsiloxane
Length	30 m
Internal diameter	320 µm
Film thickness	1.0 µm
	Parameters
Initial temp	70°C
initial hold time	1 min
Oven ramp (1)	10 °C· min^{-1}
Intermediate temp	100 °C
Oven ramp (2)	20 °C· min^{-1}
Final temp	320 °C
Final hold time	3
Flow rate (constant)	1.6 mL·min^{-1}
Injector temp	260 °C
Injection Volume	0.5 µL
Sample Dilution	15 (water)
Split ratio	1 to 10
Detector temp	335°C

TGA is another method being developed for MEA solvent analysis, with the aim of determining the solvent's degradation status. TGA was performed on three different industrially aged solvents: a) fresh 35% w/w MEA solvent, b) MEA solvent after 180 operational hours, and c) solvent that has reached its end of life. The data from this analysis is shown in Figure 7, where the three solvents were subjected to a temperature ramp of 10°C per minute, with a nitrogen purge to prevent oxidative degradation, up to a temperature of 700°C. The purge was then switched to oxygen until a temperature of 800°C was reached.

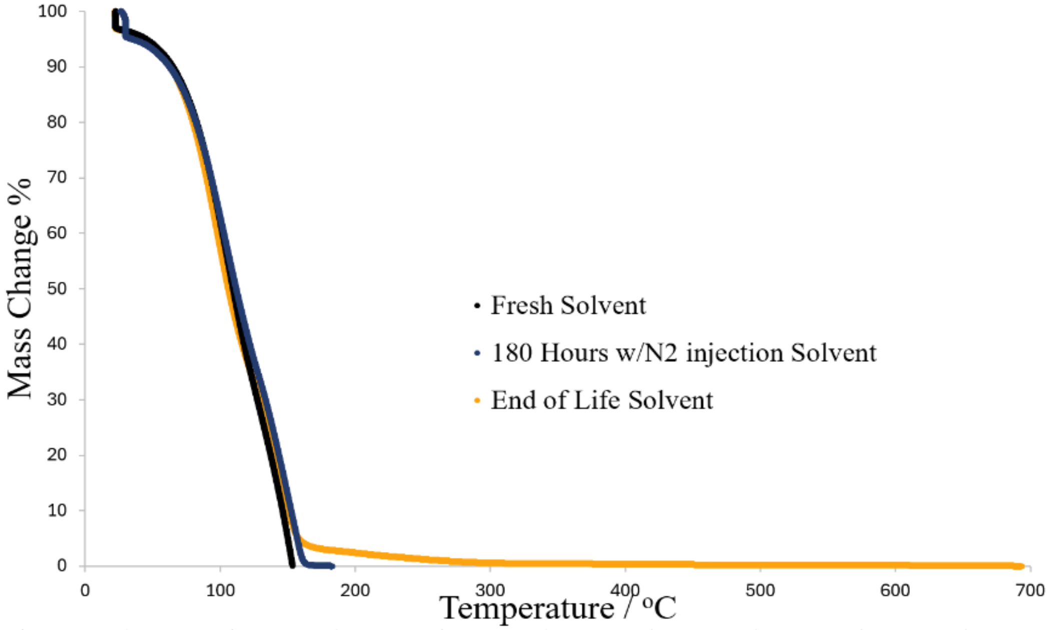

Figure 8. Thermogravimetric Analysis of MEA solvents

From this data, it was observed that the time and temperature at which the sample's mass is depleted can serve as good indicators of the degree of degradation of the MEA solvent. The results align with expectations, as the more degraded the MEA solvent, the higher the likelihood of it containing high boiling point compounds. However, further tests are required to fully evaluate the effectiveness of this analytical strategy.

Another developed analytical method to determine solvent amine concentration is a specialised boiling-off approach, which uses modified laboratory equipment to measure mass loss during boiling. Three different fresh MEA solvents were tested using this method, and the mass loss graphs are shown in Figure 8.

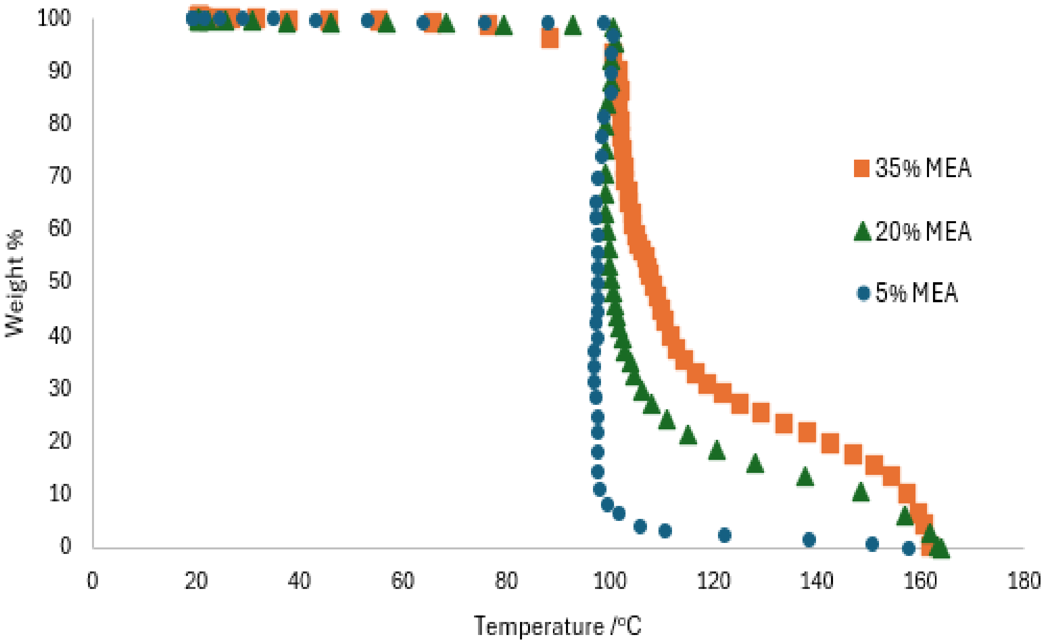

Figure 9. Graph showing data from boiling MEA solvents of varying concentrations.

This data demonstrates that the simple boiling of solvent produces different graphs depending on the concentration of MEA being boiled. This could potentially become an easy test for any industry to use, provided further development of this method is conducted to test how degradation products affect this approach.

3. Reclaimer Process Modelling

Given the lack of literature on reclaimer modelling, work has been undertaken to model continuous thermal reclaiming in order to deepen our understanding of reclaimer conditions and efficiency. This modelling has been carried out using MathCAD and has been validated with data from ASPEN Plus (further validation will be conducted with real experimental data). All findings will be made available through an accessible Excel model file for simple operator use. This model will enable thermal reclaimer operators to predict how different operational conditions affect the reclaiming efficiency. While the model is still a work in progress, good agreement between MathCAD and the simplified Excel model can be observed in Figure 9.

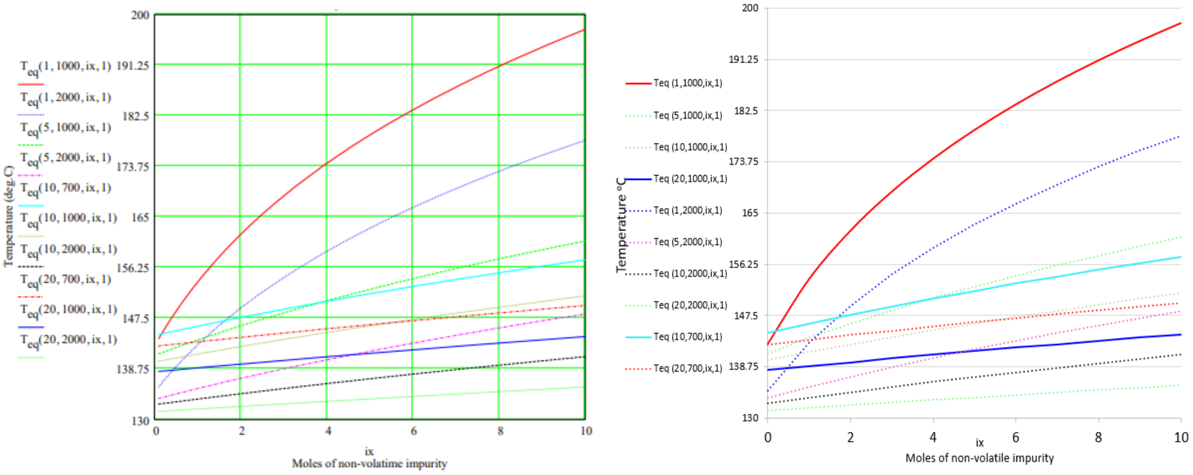

Figure 10. Comparison of MathCAD model and the Excel model. Where for Teq (A, B, C, D), A is the MEA in the blowdown [mol h-1], B is the H2O in the reclaimer feed [mol h-1] C is the non-volatile impurity in the reclaimer feed [mol h-1] and D is the moles of HEEDA in the reclaimer feed [mol h-1] at 2 bar(a).

From Figure 9, several observations can be made. For instance, an increase in the water flow rate to the reclaimer lowers the temperature of the solution, while an increase in the amount of non-volatile impurities within the reclaimer results in a temperature rise. Additionally, increasing the blowdown flow (i.e., the amount of MEA in the blowdown) reduces the temperature of the solution within the reclaimer. Consequently, the temperature rise associated with the accumulation of non-volatile impurities will have a less significant impact on the solution temperature, according to the model. Having a model that predicts these trends is crucial, as it helps balance reclaimer performance with minimising costs and solvent degradation.

Since modelling software such as ASPEN Plus and MathCAD can be complex, this model has been translated into an accessible Excel file for ease of use by all operatives. Figure 9 clearly shows that the trends from both software tools overlap well. The model is still awaiting experimental validation and the incorporation of energy expenditures under different operational conditions. It is also important to note that vapour pressure data for degradation compounds is not readily available. As a result, HEEDA was chosen as a volatile impurity due to the availability of its data. However, if more data becomes available, this could be used to further expand the model.

4. Conclusion

In conclusion, the utilisation of amine solvents in post-combustion carbon capture processes remains a vital technology in the fight against climate change, despite challenges such as solvent degradation. The degradation of solvents like monoethanolamine (MEA) over time significantly impacts CO_2 capture efficiency and increases operational costs. Two-stage thermal reclaiming presents a promising solution to address these issues by efficiently removing degradation products and maintaining solvent purity, thus enhancing the long-term performance of capture plants.

Through a two-stage thermal reclaiming approach, this study has demonstrated the potential to optimise MEA recovery while minimizing energy consumption and solvent degradation. However, further tests to examine the overall function of this two-stage reclaiming are needed. The first stage focuses on continuous operation, effectively preventing the accumulation of degradation products, while the second stage, carried out off-line, facilitates further purification and neutralization of heat-stable salts (HSS) aiming to maximise solvent recovery.

The first stage still awaits testing however, the second stage reclaiming done on the industrially degraded solvent showed promise in its efficiency but analysis of its true recovery still needs investigation.

The development and optimisation of analytical methods, including gas chromatography, thermogravimetric analysis and boiling analysis all seem promising in precise monitoring of solvent degradation and recovery efficiency. Boiling tests seem a promising simple and easy tool for industrial determination of solvent concentration. But further work is still required to ensure accuracy and precision of these techniques.

Furthermore, the development of a predictive model for reclaimer performance, once fully validated with experimental data and incorporating energy expenditures, will enable better management of operational conditions, balancing the efficiency of reclaiming processes with the minimisation of costs and solvent degradation.

5. Future Work

Future work will consist of operating the first-stage standalone reclaimer continuously to obtain real blowdown from the reclaimer bottoms, which will then be subjected to secondary-stage reclaiming. The primary focus of future work will be on solvent analysis, as this will enable validation of the two-stage reclaiming strategy. Furthermore, analytical methods, such as boiling the solvent for concentration determination, will be studied using degraded MEA samples to evaluate the effects of degradation products on this analytical approach. Work on expanding the reclaimer process modelling will continue and expand to incorporate the energy expenditures of running the reclaimer at different conditions.

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