Pilot plant study of novel AMP–based amine solvent blend for CO₂ capture: Rich amine loading, absorption rate, absorber overall volumetric mass transfer coefficient and amine cost

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Abstract
This pilot plant study covers the CO₂ absorption and amine cost potentials of novel AMP–based amine blend solvent for CO₂ capture. The activators for AMP are 1,5–diamino–2–methylpentane (DA2MP) and MEA. Results showed that 2M AMP–2M DA2MP bi–amine solvent blend and 2M AMP–2M DA2MP–2M MEA tri–amine solvent blend outperformed 5M MEA in rich amine loading, absorption rate, absorber overall mass transfer coefficient. However, the initial amine costs of the blended amine solvents are higher than that of 5M MEA. This observation shows that the novel AMP–based blended amine solvent blend is a viable and cost effective alternative for CO₂ capture.

Keywords: AMP; DA2MP; MEA; Overall volumetric mass transfer coefficient; Absorption rate; Amine cost

1 Introduction
Table 1 shows the skeletal structure of the amine solvents. The choice of applying only primary amine solvents is because primary amine solvents produces the least nitrosamines when compared to secondary and tertiary amines (3).

Table 1 Skeletal structure of the amine solvents

<table>
<thead>
<tr>
<th>Amine Solvents</th>
<th>Skeletal Structure</th>
</tr>
</thead>
<tbody>
<tr>
<td>AMP</td>
<td>HO-(\text{NH}_2)</td>
</tr>
<tr>
<td>DA2MP</td>
<td>(\text{H}<em>2\text{N}-\text{CH}</em>{2}\text{CH}<em>{2}\text{CH}</em>{2}\text{CH}<em>{2}\text{CH}</em>{2}\text{NH}_2)</td>
</tr>
<tr>
<td>MEA</td>
<td>HO-(\text{NH}_2)</td>
</tr>
</tbody>
</table>
2 Experimental sections

2.1 Chemicals

MEA (≥ 98%), AMP (≥ 95%) and DA2MP (> 99%) were obtained from Sigma Aldrich, USA. Standard 1N hydrochloric acid purity (for titration) was purchased from Fisher Chemical, United States.

2.2 Experimental procedure

Figure 1 displays the bench–scale absorber pilot plant used for the experimental study. The insulated absorber dimension is 0.05 m by 1 m and is made of 316 stainless steel. The laboratory structured packing (LDX Sulzer by Sulzer Chemtech Ltd., Switzerland) provided adequate contact for the simulated flue gas (15 % CO₂ and 85 % N₂ dry basis) and amine solution. Thermocouples located at 5 different points along the absorber provide the temperature profile and it is monitored and recorded real time by Labview data acquisition (National Instruments, Product of Hungary). The dry gas flow rate is 14 SLPM while the amine solution flow rate is 50 mL/min. Steady state is confirmed in different ways, firstly when the CO₂ concentration leaving the top of the absorber is constant, secondly when the temperature profile in the absorber does not change significantly within 5 minutes. The maximum time to reach steady state in all experiments was 30 minutes.

Figure 1 Process configuration of the bench–scale absorber pilot plant

The recorded experimental data is used to determine the rich amine loading (RAL, mol CO₂/mol amine), absorption rates (g–CO₂/min), average overall volumetric mass transfer coefficient (K_G(ave), kmol/m².min.kPa) and initial cost of amine solvent (US$ amine/min and US$ amine/g–CO₂) (Eqs. (1) to (5)).

Absorption Rate = (\(\alpha_{rich} - \alpha_{lean}\))\(C_{amine} F_{Amine}\)\(MW_{CO2}\)  \(\text{Eq. (1)}\)
\[\text{Amine}_{\text{ini-cost}} = \left(\left(\frac{C_{\text{amine}} \cdot MW_{\text{amine}}}{F_{\text{CO2}}}\right)_{i[h]} \cdot \text{Cost}_{\text{amine}}\right)\] (2)

\[\text{Amine}_{\text{ini-cost}} = \left(\left(\frac{C_{\text{amine}} \cdot MW_{\text{amine}}}{F_{\text{CO2}}}\right)_{i[h]} \cdot \text{Cost}_{\text{amine}}\right)\] (3)

Where; Cost_{amine} is the actual cost of the amine solvent(s) in the aqueous amine solution (US$/g – amine). The Cost_{amine} is gotten from the amine supplier website.

\[K_Ga_{\text{ave}}(a) = \frac{G_i}{P(y_{\text{CO2}} - y_{\text{CO2}}^*)_{\text{lm}}} \left(\frac{y_{\text{CO2in}} - y_{\text{CO2out}}}{Z}\right)\] (4)

\[(y_{\text{CO2}} - y_{\text{CO2}}^*)_{\text{lm}} = \frac{(y_{\text{CO2in}} - y_{\text{CO2in}}^*) - (y_{\text{CO2out}} - y_{\text{CO2out}}^*)}{\ln \left(\frac{y_{\text{CO2in}} - y_{\text{CO2in}}^*}{y_{\text{CO2out}} - y_{\text{CO2out}}^*}\right)}\] (5)

Where; \(K_Ga_{\text{ave}}(a)\) is the average overall volumetric mass transfer coefficient (kmol/m$^3$.hr.kPa), \(G_i\) is the inert gas flux (kmol/m$^2$.hr), \(P\) is the total pressure of the system (kPa), \((y_{\text{CO2}} - y_{\text{CO2}}^*)_{\text{lm}}\) is the log–mean driving force, \(y_{\text{CO2}}\) is the mole fraction of CO$_2$ in the gas bulk, \(y_{\text{CO2}}^*\) is the mole fraction of CO$_2$ in the gas–liquid interface, \(Z\) is the height of the absorber (m), \(Y_{CO2in}\) is the mole ratio of CO$_2$ in the absorber inlet and \(Y_{CO2out}\) is the CO$_2$ mole ratio in the absorber outlet.

The average overall volumetric mass transfer coefficient (Eqs. (4) and (5)) has been previously used (4).

3 Results and discussions
3.1 Rich amine loading (RAL)

The contribution of amine concentration towards rich amine loading is shown in Figure 2, and they follow the order 2M AMP–2M DA2MP > 2M AMP–2M DA2MP–2M > 5M MEA.
3.2 Absorption rate
The absorption rate as shown in Figure 3 reveals that the tri–amine solvent blend has the highest absorption rate while 5M MEA has the least.

![Figure 3. Absorption rates of 5M MEA and AMP–based amine solvent blends.](image)

The trend of the absorption rate is also reflected in the CO₂ concentration profiles along the absorber height (Figure 4).

![Figure 4. Relationship between amine concentration and CO₂ concentration profile.](image)
3.3 Absorber average overall volumetric mass transfer coefficient ($K_{Gav(ave)}$)

The temperature profile along the absorber height is depicted in Figure 5.

![Figure 5. Impact of amine concentration on absorber temperature profile.](image)

From Figure 6 the $K_{Gav(ave)}$ of the AMP–based amine solvent blends were higher than the single solvent 5M MEA.
Figure 6. Comparison between $K_{G\alpha v(ave)}$ of 5M MEA and the AMP–based amine solvent blends.

### 3.4 Initial amine cost

The initial amine cost and amine cost per CO$_2$ absorbed is shown in Figure 7. The amine cost per CO$_2$ absorbed showed that the AMP blends are competitive to 5M MEA.

![Graph showing amine cost comparison](image)

Figure 7. Amine cost of the studied amine solvents.

### Conclusion

The rich amine loading of the AMP blends were higher than MEA but the bi–amine solvent blend has the highest. For absorption rates and $K_{G\alpha v(ave)}$, the tri–amine solvent blend was more superior followed by the bi–amine solvent blend. The amine cost per CO$_2$ absorbed of the AMP–based amine blends is comparable to 5M MEA. The high amine cost will be offset by the high $K_{G\alpha v(ave)}$, which translates to reduced absorber height.
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