The effect of increasing CO₂ concentration and flow rate on amine still performance in meeting gas sale specifications

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Abstract. The main purpose of this study is to examine the effect of increasing CO₂ removal and flow rate on performance of an amine still. The amine still is located in Field X in South East Sumatra at a new gas well producing gases with a rich CO₂ content. The still uses activated MDEA as the amine and has an IMTP 40-type packing column. Two film and desorption equilibrium curve theories were employed to analyse the amine still design conditions. Design equations were utilized to find the slope of the equilibrium curve. A slope of the equilibrium curve of 45° in the amine still is obtained in this study. The maximum liquid CO₂ composition of the amine still feedstock (xo) which can be separated to produce lean amine according to the specification design flow rate is 0.0307. The total flow rate of CO₂-rich amine at xo = 0.029 is 761,157.6 kg/hour; the total flow rate of CO₂-rich amine at xo = 0.0295 is 628,861.1 kg/hour; the total flow rate of CO₂-rich amine at xo = 0.03 is 513,962.6 kg/hour; and the total flow rate of CO₂-rich amine at xo = 0.0305 is 409,575.3 kg/hour.

1 Introduction

A significant drop in the flow rate of gas wells has led to the creation of new gas sources in the study area. The recently created gas well in Field X in South East Sumatra has a rich CO₂ composition. The sudden surge of CO₂ from the well will have an immediate effect on the amine unit used for CO₂ separation. Design barriers result in this increased CO₂ composition directly leading to a decrease in gas production.

The amine unit referred to in this study is a processing unit used to remove CO₂ from gases. This separation is required because of the absence of heating value of CO₂ and its corrosive effect when it reacts with water. The CO₂ composition of gas for commercial sale must therefore be below specified limits to conform to the specifications of the gas buyer. Increased CO₂ from gas wells leads to increased CO₂ concentrations in rich amine in the still.

Increasing the CO₂ content of rich amine will require optimized amine still performance, so that lean amine returns to the amine contactor to further separate CO₂ within the still as needed. Desorption performance in the optimized amine still requires low pressure and high temperature. Low pressure creates the low partial pressure required in the gas phase and high temperature creates the high vapour pressure required in the liquid phase. The pressure deviation between the partial gas phase and the larger liquid phase are required for better mass transfer between phases.

This research is valuable because of the importance of identifying and understanding the conditions for amine unit design, specifically amine stills used for the desorption process. Height transfer unit (HTU) and number transfer unit (NTU) design equations are used to determine the amine still design conditions.

The amine still is the location in which the desorption process between MDEA and CO₂ occurs. The amine still design used in Field X uses packing with IMTP type 40. The amine still design data and design equations enable us to obtain the equilibrium slope curves (myx) which are used to analyse the limits of CO₂ increase and flow rate that can be processed.

2 Research Methodology

2.1 HTU and NTU equations designs for the amine still

The HTU and NTU equations are required to calculate the slope of the equilibrium curve (myx). The data required for this design equation are drawn from material design data, dimensions and the amine still process. High packing (H) is the design data used to determine the myx value.

In order to achieve a high packing value (H), the myx guess value must be entered at the beginning of the process. The value of myx is compared to the convergence criteria. In the condition where the value of myx is smaller or equal to the convergence criterion, the myx value is assumed to be achieved. If the myx value is greater than the convergence value, re-guessing of the myx value is required.

Regardless of its current phase (gas or liquid), the HTU is a function of the mass transfer coefficient of both the liquid phase (kL) and the gas phase (kG). The NTU is a function of liquid load transfer and gas load transfer in both the bottom and overhead sections of the still towers.

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The slope of the equilibrium curve will be used to determine the amine still design conditions with variations of concentrations and flow rates.

2.2 Analysis of the impact of CO2 increase on amine still design capability

The analysis of the impact of CO2 increase on amine still design capability is executed by varying the value of $x_o$ (CO2 composition in the liquid phase of the amine feed) at a fixed flow rate. Subsequently, the value of $x_u$ (CO2 composition in liquid phase of the amine still) is solved by employing trial and error. As a result, the high value of the amine still remains in accordance with the design. The numerical analysis is performed using the slope value at equilibrium ($m_{xy}$) which was obtained from this calculation.

Variations are performed with the following assumptions:

1. An increase in $y_o$ with the assumption that all the increase in CO2 in the amine still ($x_o$) will flow to the top of the amine still.
2. $x_u$ is 0.01 mol/mol MDEA (assuming CO2 loading of lean amine) is 0.0013 mole fraction. This value is the maximum value of CO2 allowed in lean amine.
3. The increase in $y_u$ from the design value is proportional to the increase in the value of $x_u$.

2.3 Analysing the impact of increase in flow rate on amine still design capability

This step of the analysis focuses on the impact of the amine still design conditions on the variation of the flow rate for several CO2 compositions ($x_o$ and $y_o$). The equilibrium curve slope value ($m_{xy}$) was obtained from the previous calculation. The $x_o$ value uses numbers in-between the design value and the maximum value obtained from the previous $x_o$ variation. The value of $x_u$ is solved by employing trial and error to ensure that high amine value in the still is in accordance with the design specification.

Variations are performed with the following assumptions:

1. The liquid phase flow rate (L) and the gas phase flow rate ($V$) rise by the same ratio.
2. $x_u$ is 0.01 mol/mol MDEA and is 0.0013 mole fraction. This value is the maximum value of CO2 allowed in lean amine.
3. The increase in $y_u$ is equivalent to the increase in $x_u$ value.
4. $y_o$ increases with the assumption that all the addition of CO2 in the amine still feed ($x_o$) will flow to the top of the amine still.

3 Results And Analysis

3.1 Coefficient of gas CO2 diffusion and coefficient of liquid CO2 diffusion

The determination of the gas CO2 diffusion coefficient can be obtained using equation 1.

$$D_G = \frac{1.86 \cdot 10^{-362.59^3(1/M_1 + 1/M_2)^{1/2}}}{P \sigma_{12} \Omega}$$  (1)

The data obtained from the mechanical data sheet of the amine still for the above calculation is as follows:

$T = 193 °F = 362.594 °K$
$P = 7.1 psig = 0.486 barg = 1.5 bara$

The molecular weight for each component is:

$M_1 = 44.0097 \text{ g/mol}$
$M_2 = 18 \text{ g/mol}$

$$\sigma_{12} = \frac{1}{2}(\sigma_1 + \sigma_2)$$  (2)

then

$$\sigma_{12} = \frac{1}{2}(3,941 + 2,641) = 3,291$$

$$\varepsilon_{12} = \sqrt{\varepsilon_1 \varepsilon_2}$$  (3)

$\varepsilon/k_B$ value for each component is as follows:

$\varepsilon_1/k_B = 195.2 °K$
$\varepsilon_2/k_B = 809.1 °K$

Therefore,

$$\varepsilon_{12}/k_B = \sqrt{\varepsilon_1/k_B \times \varepsilon_2/k_B} = 397.4 °K$$

Dimensionless quantity ($\Omega$) is recognized as the function of $k_BT/\varepsilon_{12}$. $T$ is the operation temperature obtained from the mechanical data sheet of the amine still.

Thus, $k_BT/\varepsilon_{12} = 362.594/397.4 = 0.912$

By looking at the $\Omega$ value for $k_BT/\varepsilon_{12} = 0.912$, $\Omega = 1.52$

The CO2 diffusion coefficient obtained from equation 1 is as follows:

$$D_G = \frac{1.86 \cdot 10^{-362.59^3(1/44.0097 + 1/18)^{1/2}}}{1.5 \cdot 3.921^2 \cdot 1.52}$$

$$= 4.12 \times 10^{-6} \text{ m}^2/\text{s}$$

The diffusion value of the gas coefficient ranges from $10^{-5}$–$10^{-6}$ m$^2$/s (10$^{-4}$–$10^{-2}$ cm$^2$/s). This can be seen in the example of the diffusion coefficient value of the gas in other experimental results. The diffusion coefficient of the gas can be increased by raising the temperature or lowering the pressure. The underlying cause of this phenomenon is the faster movement of molecules at high temperatures or at lower pressure.

The determination of the liquid CO2 diffusion can be acquired from equation 4.
The CO₂ diffusion coefficient in water at temperature 293 °K (20 °C) is 3.2 Effective wetted packing area (aw)

The viscosity values of each component at the temperature and pressure of column operations obtained from Simulation are as follows:

\[
\begin{align*}
\mu_B &= 1.084 \text{ cp } = 0.001084 \text{ Pa.s} \\
\mu_W &= 0.3179 \text{ cp } = 0.0003179 \text{ Pa.s}
\end{align*}
\]

Therefore

\[
\frac{D_{N2O}}{D_{CO2,H2O}} = \frac{\mu_W}{\mu_B} = \frac{0.0003179^{0.8}}{0.001084^{0.8}} = 0.375
\]

\[
\frac{D_{L,CO2}}{D_{CO2,H2O}} = \frac{D_{N2O}}{D_{N2O,CO2}}
\]

From equation 6, the CO₂ diffusion coefficient value is as follows:

\[
D_{L,CO2} = D_{CO2,H2O} \frac{D_{N2O}}{D_{N2O,CO2}} = 6.792 \times 10^{-9} \times 0.375 = 2.5457 \times 10^{-9} \text{ m}^2/\text{s}.
\]

From the above calculation of the gas diffusion coefficient it is found that the obstacles faced by the liquid diffusion coefficient have resulted in its lower value in comparison to the gas diffusion coefficient.

The data obtained from the mechanical data sheet for the amine still is as follows:

\[
\begin{align*}
\sigma &= 75 \text{ mN/m} \\
\gamma &= 46.4 \text{ dyne/cm} = 0.0464 \text{ kg/s} \\
h &= 1.18 \text{ cp } = 0.00118 \text{ kg/m.s}
\end{align*}
\]

The Froude number (Fr₁) at the gravity value of 9.8 m/s is as follows:

\[
Fr₁ = 151 \times 0.01475²/9.8 = 0.00335
\]

The surface tension packing material (\(\sigma_c\)) value for packing metal is 75 mN/m:

\[
\sigma = 75 \text{ mN/m} = 0.075 \text{ kg/s}^2
\]

By employing equation 7, the effective wetted packing area is as follows:

\[
a_w = a_p \left\{ 1 - \exp \left[ -1.45 Re_\text{Fr}^{0.1} Fr^{-0.05} W e_{\text{Fr}}^{0.2} \left( \frac{\sigma}{\sigma_c} \right)^{-0.75} \right] \right\}
\]

The data obtained from the mechanical data sheet for the amine still is as follows:

\[
\rho_L = 64.4 \text{ lb/ft}^3 = 1.032.04 \text{ kg/m}^3 \\
\mu_L = 1.18 \text{ cp } = 0.00118 \text{ kg/m.s}
\]

The mechanical data sheet figures for the amine still used to determine the liquid speed are as follows:

\[
L = \text{fluid flow rate} = 740,745.6 \text{ lb/h} = 335,996.3 \text{ kg/h} \\
D = \text{diameter column} = 110 \text{ in} = 2.794 \text{ m}
\]

The fluid speed is as follows:

\[
u_L = \frac{L/\rho_L}{\frac{\pi d^2}{4}} = \frac{335996.3/1032.04}{\pi \times 2.794²/4} = 53.1 \text{ m/h} / 0.01475 \text{ m/s}
\]

The surface tension packing material (\(\sigma_c\)) value for packing metal is 75 mN/m:

\[
\sigma = 75 \text{ mN/m} = 0.075 \text{ kg/s}^2
\]

By employing equation 7, the effective wetted packing area is as follows:

\[
a_w = a_p \left\{ 1 - \exp \left[ -1.45 Re_\text{Fr}^{0.1} Fr^{-0.05} W e_{\text{Fr}}^{0.2} \left( \frac{\sigma}{\sigma_c} \right)^{-0.75} \right] \right\}
\]

The data obtained from the mechanical data sheet for the amine still is as follows:
3.3 Liquid mass transfer coefficient (kL) and gas mass transfer coefficient (kG)

Equation 11 can be used to determine the liquid mass diffusion coefficient:

$$k_L = \frac{\rho_L g \mu_L}{a_w \mu_L} \left( \frac{L}{a_w \mu_L} \right)^{2} \frac{1}{S_{c_L}^{0.5}} (a_p d_p)^{0.4}$$ (11)

The Schmidt number \(S_{c_L}\) of the liquid is determined using equation 12. The Schmidt number \(S_{c_L}\) of the liquid is 448.372.

$$S_{c_L} = \frac{\mu_L}{\rho_L D_L}$$ (12)

From the mechanical data sheet for the amine still and the calculation from the previous section, the following number is obtained:

- \(\mu_L = \text{liquid viscosity} = 1.18 \, \text{cp} = 0.00118 \, \text{kg/m.s}\)
- \(\rho_L = \text{fluid density} = 64.4 \, \text{lb/ft}^3 = 1,032.04 \, \text{kg/m}^3\)
- \(D_L = \text{fluid diffusion coefficient} = 2.546 \times 10^{-9} \, \text{m}^2/\text{s}\)

Then

$$S_{c_L} = \frac{0.00118}{1032.04 \times 2.546 \times 10^{-9}} = 448.37$$

Specification data for the IMTP 40 packing is:

- \(a_p = 151 \, \text{m}^2/\text{m}^3\)
- \(d_p = 40 \, \text{mm} = 0.04 \, \text{m}\)

The value of \(L\), which is the fluid flow rate per area, is calculated as follows:

$$L = \frac{V}{\pi d^2/4} = \frac{26459.7}{\pi \times 2.7942/4} = 4315.6 \, \text{kg/m}^2\text{h}$$

$$= 1.2 \, \text{kg/m}^2\text{s}$$

Data for Raschig rings and saddles of less than 15 mm were correlated by conducting an alteration of the Ks constant to 2. This change from kG data for packing smaller than 15 mm tended to decrease constantly with increasing \(a_p\). For IMTP 40, the Ks constant used is 5.23. Schmid number \(S_{c_G}\) is determined using equation 14. The value of the Schmidt number \(S_{c_G}\) of the gas is 2.2773.

$$S_{c_G} = \frac{\mu_G}{\rho_G D_G}$$ (14)

From the mechanical data sheet for the amine still and the calculation from the previous section, the following number is obtained:

- \(\mu_G = \text{gas viscosity} = 0.016 \, \text{cp} = 1.6 \times 10^{-5} \, \text{kg/m.s}\)
- \(\rho_G = \text{gas density} = 0.1 \, \text{lb/ft}^3 = 1.705 \, \text{kg/m}^3\)
- \(D_G = \text{gas diffusion coefficient} = 4.12 \times 10^{-6} \, \text{m}^2/\text{s}\)

Therefore,

$$S_{c_G} = \frac{1.6 \times 10^{-5}}{1.705 \times 4.12 \times 10^{-6}} = 2.277$$

The value of gas mass transfer coefficient \(k_G\) from equation 13 is as follows:

$$k_G = \frac{0.08314 \times 362.6 \times 151 \times 4.12 \times 10^{-6}}{(151 \times 1.6 \times 10^{-5})^{0.7} \times 2.277^{1/3} \times (151 \times 0.04)^{-2}} = 3 \times 10^{-4} \, \text{kmol/sm}^2\text{bar} = 1.08 \, \text{kmol/hm}^2\text{bar}$$

The diffusion coefficient of the gas affects the value of the mass transfer coefficient. The greater the gas diffusion coefficient, the greater the value of the gas mass transfer coefficient.

3.4 Height transfer unit (HTUL) liquid and height transfer unit (HTUG) gas

Equation 15 is used to calculate the height transfer unit (HTUL) for liquid. From the equation for height transfer unit (HTUL) the value for fluid is 5.37 x 10^{-1} m.

$$HTU_L = \frac{L}{k_L a_p C_t}$$ (15)

in which

- \(L = \text{molar fluid flow rate per area (kmol/m}^2\text{s)}\)
- \(C_t = \text{total concentration} = \rho_t/\text{molecular weight of the solution (kmol/m}^3)\)

\(HTU_L = 0.48 \times 0.3034/362.6 = 0.537 \, \text{m}\)

As depicted in equation 15, the liquid HTU is inversely proportional to the mass transfer coefficient of liquid. Thus, the higher (the more effective) the fluid mass transfer coefficient, the liquid HTU required will be smaller.
Equation 16 is used to calculate the gas height transfer unit (HTUG). From the equation, HTU\text{G} value of fluid is equal to $7.14 \times 10^{-1}$ m.

$$HTU_G = \frac{G}{k_G a_W P}$$

(16)

where \( G \) = gas molar flow rate per area (kmol/m$^2$s)
\( P \) = pressure of operation column (atm or bar)

$$HTU_G = \frac{0.0294}{3 \times 10^{-4} \times 91.5 \times 1.5} = 0.71 \text{ m}$$

Similar to liquid HTU, gas HTU is inversely proportional to the mass transfer coefficient of the gas. Thus, the higher (the more effective) the coefficient of mass transfer of gas the smaller the HTU of gas needed.

### 3.5 Calculation of equilibrium slope (myx)

The equilibrium curve for the linear desorption process for low-load component transfer in gas Y and in liquid X. In other words, the slope of $m_{yx}$ in relation to $Y = f(X)$ can be considered fixed. The equilibrium curve can be found using equation 17.

$$Y = m_{yx} X$$

(17)

The goal-seek value for high packing (H) is obtained in accordance with the design data for the HTU–NTU model to determine the height of bed packing. Overall height transfer unit (HTU\text{OL}) for the liquid phase (HTU\text{OL}) relates to the respective phases of HTU\text{V} and HTU\text{L} using stripping factor $\lambda$. High packing (H) is determined from the unit transfer in the liquid phase (NTU\text{OL}). NTU\text{OL} is a function of the load factor for liquid load components at both overhead ($X_o$) and bottom ($X_u$) levels and the load factor components of both the overhead ($Y_o$) and bottom ($Y_u$) levels.

From the flow diagram process the fraction of liquid mole data obtained are as follows:

\( x_o = 0.0287 \) (fraction at amine still operating pressure using HYSYS because the PFD data is still at high pressure).

\( x_u = 0.00085 \)

therefore,

\[
X_o = \frac{0.0287}{1 - 0.0287} = 0.0295 \\
X_u = \frac{0.00085}{1 - 0.00085} = 0.0008507 \\
Y = \frac{Y_o}{1 - Y_o} \\
Y = \frac{0.5347}{1 - 0.5347} = 1.15 \\
Y_u = \frac{0.00977}{1 - 0.00977} = 0.00987
\]

The value of $\Delta X_o$ and $\Delta X_u$ can be calculated by using the equation (19):

$$\Delta X_o = 0.0295 - \frac{1}{m_{yx}} 1,15$$

$$\Delta X_u = 0.0008507 - \frac{1}{m_{yx}} 0.00987$$

(19)

The value of NTU\text{OL} and HTU\text{OL} is as follows:

$$\text{NTU}_{OL} = \frac{0.0295 - 0.00085}{(0.0295 \frac{1}{m_{yx}} 1,15) - (0.0008507 \frac{1}{m_{yx}} 0.00987)}$$

\[
\text{ln} \frac{0.0295 - 0.00085}{0.0008507 \frac{1}{m_{yx}} 0.00987} \\
\gamma = m_{yx} \frac{33596.3}{26459.7} = 0.0787 m_{yx} \\
\text{HTU}_{OL} = 0.537 + \frac{1}{0.714} = 0.537 + 9.07 \frac{m_{yx}}{m_{yx}}
\]

A connection is apparent between the packing height values NTU\text{OL} and HTU\text{OL}. The height from the mechanical data sheet for the amine still is calculated as 12 m and the $m_{yx}$ value can be determined by performing a goal-seek analysis. The analysis generates an $m_{yx}$ value of 45. This value indicates that the gas phase transfer load component (Y) is higher than that of the liquid phase transfer load component (X) in both the overhead and bottom sides of the still. The transfer load component is a function of the mole fraction, which explains its greater magnitude in comparison to the liquid mole fraction. The amine still desorption process is the mass transfer of the CO$_2$ component from the liquid phase to the gas phase. Mass transfer occurs to achieve equilibrium both in the gas phase and liquid phase.

The slope value is a fixed variable used in high packing calculation design. Since the packing height serves as the design data, this slope will be used as a fixed variable of variation for the increase in concentration and the flow rate.

The following numbers are the value of NTU\text{OL} and HTU\text{OL} after determining the $m_{yx}$ value:

\[
\Delta X_o = 0.0042 \\
\Delta X_u = 0.00063 \\
\gamma = 2.786 \\
\text{NTU}_{OL} = 15.13 \\
\text{HTU}_{OL} = 0.79 \text{ m}
\]

Table 1. Results of equilibrium curve calculations
Table 2. Variation of xo towards xu

| xo  | yo  | xu  | yu  |
|-----|-----|-----|-----|
| 0.02870 | 0.5347 | 0.00085 | 0.0098 |
| 0.02899 | 0.5383 | 0.00090 | 0.0103 |
| 0.02927 | 0.5420 | 0.00095 | 0.0109 |
| 0.02956 | 0.5456 | 0.00101 | 0.0116 |
| 0.02985 | 0.5493 | 0.00107 | 0.0123 |
| 0.03014 | 0.5529 | 0.00114 | 0.0131 |
| 0.03042 | 0.5566 | 0.00121 | 0.0139 |
| 0.03071 | 0.5602 | 0.00129 | 0.0149 |
| 0.03100 | 0.5639 | 0.00138 | 0.0159 |

The xo towards xu graph obtained is presented in Figure 1. As depicted, an increase in xo will lead to an increase in xu. Mass transfer in the liquid phase uses concentration, which is not in an equilibrium state, as the driving force. Hence, a voltage gradient exists in the contact surface. This situation is also known as the Marangoni effect. Consequently, the voltage gradient increases the mass transfer rate.

3.6 Amine still design conditions for CO2 concentration in the amine still (xo)

We utilized the above design equations and results of equilibrium curve calculations to create differentiation for the liquid phase of CO2 composition in the amine still (xo) feed (rich amine). To ensure that the amine still fulfills the design conditions (12 m), a goal-seek analysis is performed for the liquid phase of CO2 composition out of the amine still (xu) (lean amine). The slope of the equilibrium curve in the desorption process can be considered constant at all concentrations from top to bottom of the amine still, hence the myx values can be used. The results of the xo to xu variations are as follows:

Table 3. Variation of flow rate to xu (xo = 0.029)

| L (kg/h) | V (kg/h) | Total flow rate (kg/h) | xu | yu |
|----------|----------|------------------------|----|----|
| 335,996.3 | 26,459.7 | 362,456.0 | 0.00090 | 0.0104 |
| 369,595.9 | 29,105.7 | 398,701.6 | 0.00094 | 0.0109 |
| 403,195.5 | 31,751.6 | 434,947.2 | 0.00099 | 0.0113 |
| 436,795.2 | 34,397.6 | 471,192.8 | 0.00103 | 0.0118 |
| 470,394.8 | 37,043.6 | 507,438.4 | 0.00106 | 0.0122 |
| 503,994.4 | 39,689.6 | 543,684.0 | 0.00110 | 0.0127 |
| 537,594.0 | 42,335.5 | 579,929.6 | 0.00114 | 0.0131 |
| 571,193.7 | 44,981.5 | 616,175.2 | 0.00117 | 0.0135 |
| 604,793.3 | 47,627.5 | 652,420.8 | 0.00121 | 0.0139 |
| 638,392.9 | 50,273.4 | 688,666.4 | 0.00124 | 0.0143 |
| 671,992.6 | 52,919.4 | 724,912.0 | 0.00128 | 0.0147 |
| 705,592.2 | 55,565.4 | 761,157.6 | 0.00131 | 0.0150 |
| 739,191.8 | 58,211.4 | 797,403.2 | 0.00134 | 0.0154 |
| 772,791.4 | 60,857.3 | 833,648.8 | 0.00137 | 0.0157 |
| 806,391.1 | 63,503.3 | 869,894.4 | 0.00140 | 0.0161 |

3.7 Amine still design condition towards flow rate

The variation of the amine still design to the flow rate serves as a way to obtain the xu value of 0.0013 mole fraction, which happens to be the maximum value of CO2 allowed in lean amine. The value of the CO2 composition in the liquid phase at the bottom of the packing (xo) with a maximum limit value of 0.0013 in each variation.
Table 4. Variation of flow rate to \(x_o = 0.0295\)

| L (kg/h) | V (kg/h) | Total flow rate (kg/h) | \(x_o\) | \(y_o\) |
|----------|----------|------------------------|--------|--------|
| 335,996.3 | 26,459.7 | 362,456.0 | 0.00110 | 0.0114 |
| 369,595.9 | 29,105.7 | 398,701.6 | 0.00104 | 0.0120 |
| 403,195.5 | 31,751.6 | 434,947.2 | 0.00109 | 0.0125 |
| 436,795.2 | 34,397.6 | 471,192.8 | 0.00113 | 0.0130 |
| 470,394.8 | 37,043.6 | 507,438.4 | 0.00117 | 0.0135 |
| 503,994.4 | 39,689.6 | 543,684.0 | 0.00121 | 0.0139 |
| 537,594.0 | 42,335.5 | 579,929.6 | 0.00125 | 0.0144 |
| 571,193.7 | 44,981.5 | 616,175.2 | 0.00129 | 0.0148 |
| 604,793.3 | 47,627.5 | 652,420.8 | 0.00130 | 0.0150 |
| 638,392.9 | 50,273.4 | 688,666.4 | 0.00136 | 0.0156 |
| 671,992.6 | 52,919.4 | 724,912.0 | 0.00139 | 0.0160 |

Table 5. Variation of flow rate to \(x_o = 0.03\)

| L (kg/h) | V (kg/h) | Total flow rate (kg/h) | \(x_o\) | \(y_o\) |
|----------|----------|------------------------|--------|--------|
| 335,996.3 | 26,459.7 | 362,456.0 | 0.00111 | 0.0127 |
| 369,595.9 | 29,105.7 | 398,701.6 | 0.00116 | 0.0133 |
| 403,195.5 | 31,751.6 | 434,947.2 | 0.00120 | 0.0138 |
| 436,795.2 | 34,397.6 | 471,192.8 | 0.00125 | 0.0144 |
| 470,394.8 | 37,043.6 | 507,438.4 | 0.00129 | 0.0149 |
| 476,442.7 | 37,519.9 | 513,962.6 | 0.00130 | 0.0150 |
| 503,994.4 | 39,689.6 | 543,684.0 | 0.00134 | 0.0154 |
| 537,594.0 | 42,335.5 | 579,929.6 | 0.00138 | 0.0158 |
| 571,193.7 | 44,981.5 | 616,175.2 | 0.00142 | 0.0163 |

Using the above equations and myx results, variations in flow rates (L and V) are performed for the amine still with different \(x_o\) values. The slope of the equilibrium curve in the desorption process can be considered constant at all concentrations from top to bottom of the amine still so that the max values of the calculations can be used.

The \(x_o\) value used is between the design value (0.0287) and the maximum value (0.0307). Table 3 shows the variation at \(x_o\) of 0.029. Table 4 shows the variation at \(x_o\) of 0.0295. Table 5 presents the variation at \(x_o\) of 0.03. Table 6 demonstrates the variation at \(x_o\) of 0.0305. A goal- seek analysis was then performed on the liquid phase CO2 composition out of the amine still (\(x_u\)) (lean amine) so that the high amine still remained in accordance with the design (12 m).

The total flow rates of \(x_u\) obtained are as presented in Figure 2. As demonstrated, the increase in flow rate will cause an increase in \(x_u\). This occurs because the increase in flow rate causes fluid turbulence inside the column to increase. In turbulent flow, the molecules in the fluid will move in any direction, increasing the rate of collision between them and these collisions form gaps where the gas will be trapped. This causes increased mass transfer from one phase to another.

Table 6. Variation of flow rate to \(x_u (x_o = 0.0305)\)

| L (kg/h) | V (kg/h) | Total flow rate (kg/h) | \(x_u\) | \(y_u\) |
|----------|----------|------------------------|--------|--------|
| 335,996.3 | 26,459.7 | 362,456.0 | 0.00123 | 0.0142 |
| 342,716.2 | 26,988.9 | 369,705.1 | 0.00124 | 0.0143 |
| 349,436.1 | 27,518.1 | 376,954.2 | 0.00126 | 0.0144 |
| 356,156.1 | 28,047.3 | 384,203.3 | 0.00127 | 0.0146 |
| 362,876.0 | 28,576.5 | 391,452.5 | 0.00128 | 0.0147 |
| 369,595.9 | 29,105.7 | 398,701.6 | 0.00129 | 0.0148 |
| 376,315.8 | 30,248.7 | 406,744.5 | 0.00130 | 0.0149 |
| 379,675.8 | 29,899.5 | 409,575.3 | 0.00130 | 0.0150 |
| 383,035.8 | 30,164.1 | 413,199.8 | 0.00131 | 0.0150 |
| 403,195.5 | 31,751.6 | 434,947.2 | 0.00134 | 0.0154 |
| 436,795.2 | 34,397.6 | 471,192.8 | 0.00139 | 0.0160 |

Fig. 2. Variation of flow rate of \(x_u\) for several \(x_o\) values

Table 7. Maximum total flow rate value based on the \(x_o\) value

| \(x_o\) | Maximum flow rate (kg/h) |
|--------|--------------------------|
| 0.0295 | 761,157.6                |
| 0.03   | 628,861.1                |
| 0.0305 | 409,575.3                |

At the value of CO2 of rich amine of \(x_o = 0.029\), the total flow rate value is 761.157.6 kg/hour. At the value of CO2 rich amine of \(x_o = 0.0295\), the total flow rate value is
628,861.1 kg/hour. At the value of CO₂ rich amine of \( x_o = 0.03 \), the total flow rate value is 513,962.6 kg/hour. At the value of CO₂ rich amine of \( x_o = 0.0305 \), the total flow rate value is 409,575.3 kg/hour.

4 Conclusion

This study attempts to analyze the correlation between amine still design in Field X and increase in CO₂. Utilizing HTU and NTU designs, the findings suggest that an equilibrium curve slope \( (\frac{d}{dx}) \) in the amine still desorption process of 45 is acquired from the data and design equation. The maximum liquid CO₂ composition of the amine still \( (x_o) \) feedstock which can be separated to produce lean amine according to the specification (maximum \( x_u 0.01 \) mol/mol MDEA of 0.0013 mole fraction) for the design flow rate is 0.0307. The total flow rate of CO₂ rich amine at \( x_o = 0.029 \) is 761,157.6 kg/hour. The total flow rate of CO₂ rich amine (\( x_o = 0.0295 \)) is 628,861.1 kg/hour. The total flow rate of CO₂ rich amine (\( x_o = 0.03 \)) is 513,962.6 kg/hour. The total flow rate of CO₂ rich amine (\( x_o = 0.0305 \)) is 409,575.3 kg/hour.

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