HEAT DUTY EVALUATION OF A NOVEL SOLVENT BLEND IN A CATALYST- AIDED CO_2 POST COMBUSTION CAPTURE PROCESS.

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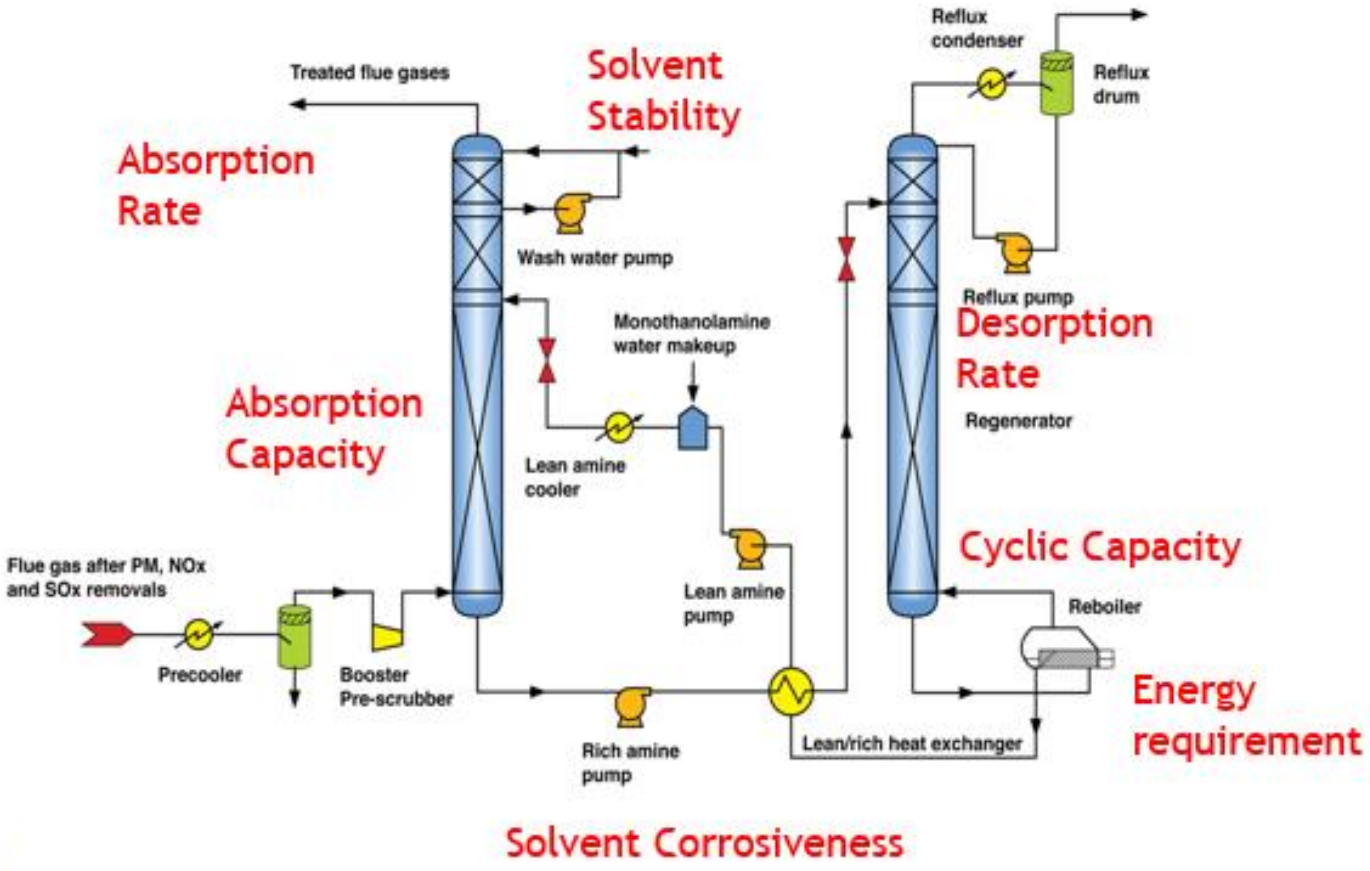
Presentation outline

- Introduction
- Background review & Solvent selection
- Process optimization & Objectives
- Experimental section
- Results and Discussion
- Conclusions
- References

Introduction

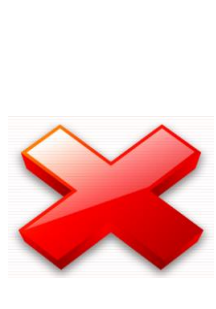


- **Slow Reaction Kinetics**
- **Degradation**
- **Corrosion**
- **High energy requirement**
- **Low absorption Capacity**
- **Low cyclic capacity**

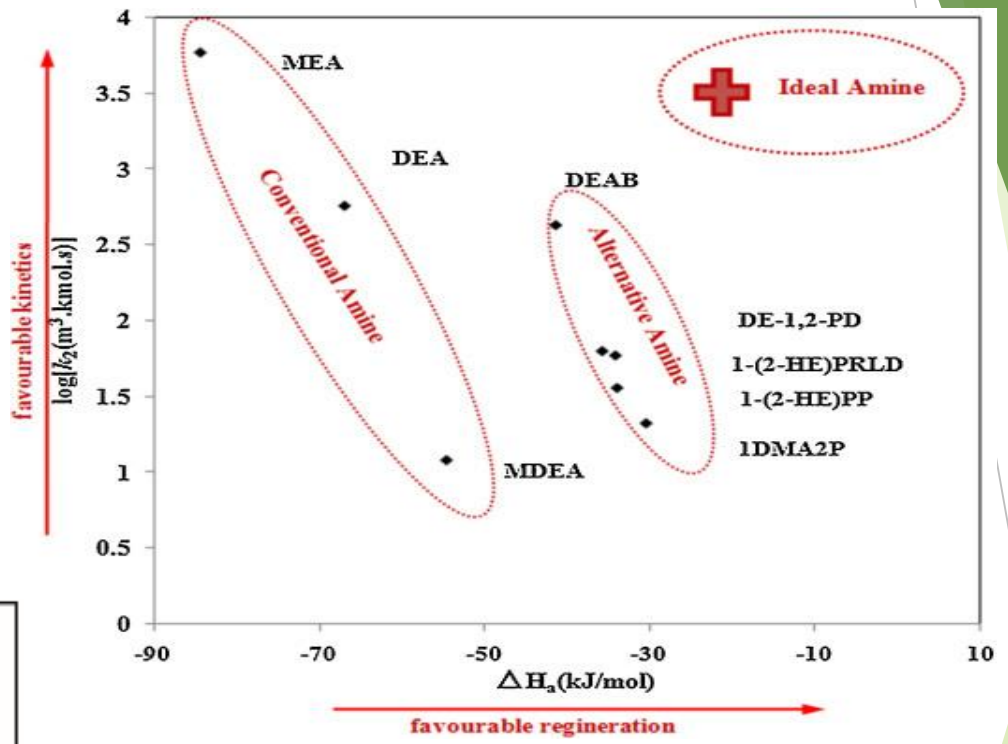
✓ Solvent improvement technology
✓ Process optimization

Background review

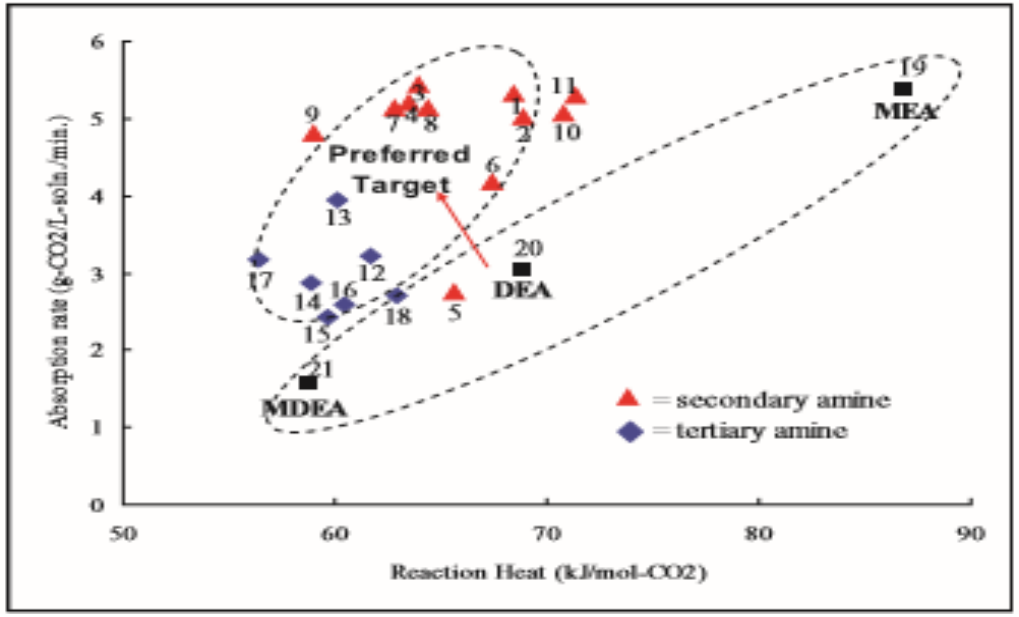
- Amine Selection



Structure & Activity Relationship Studies (Singh et al., 2007, 2008, 2009)

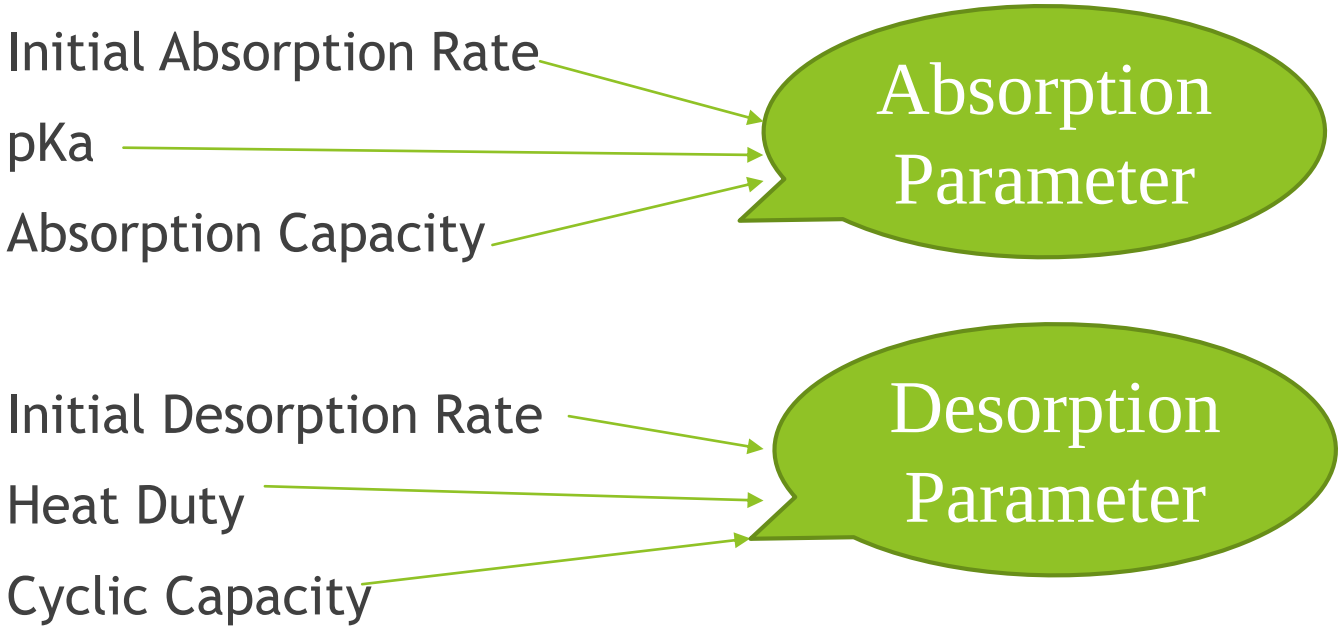


Liu et al., 2016



(Chowdhury et al., 2013)

Solvent Selection Criteria

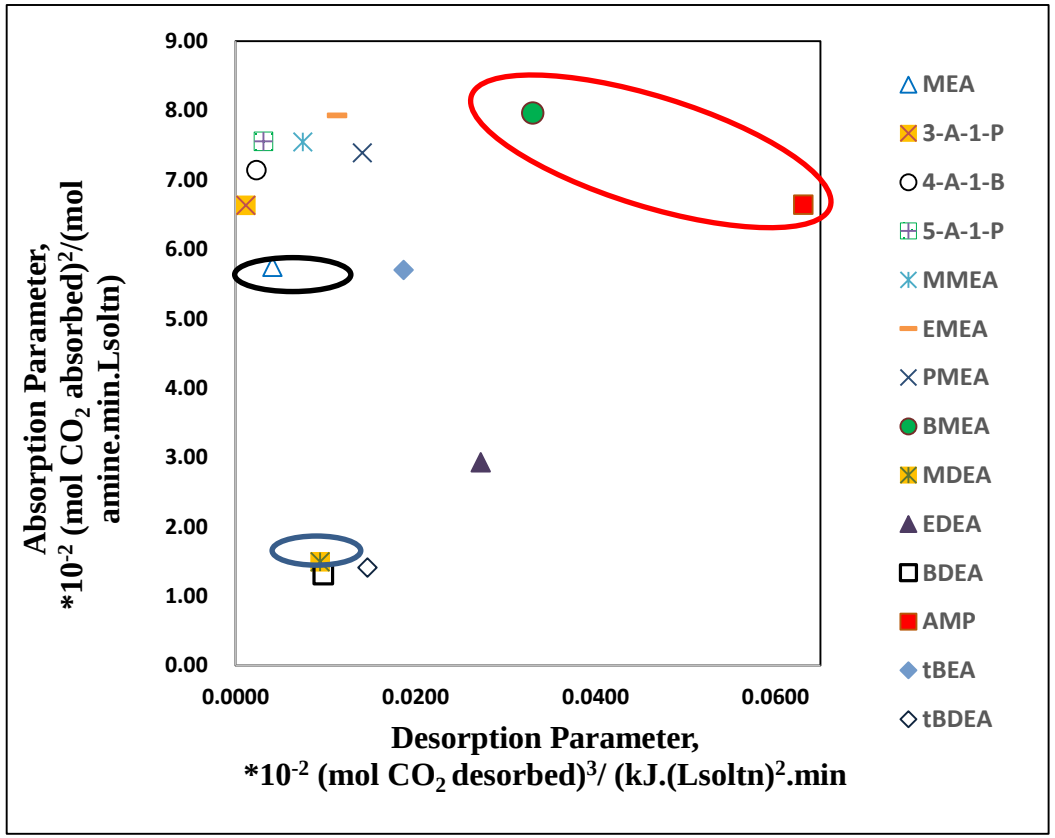


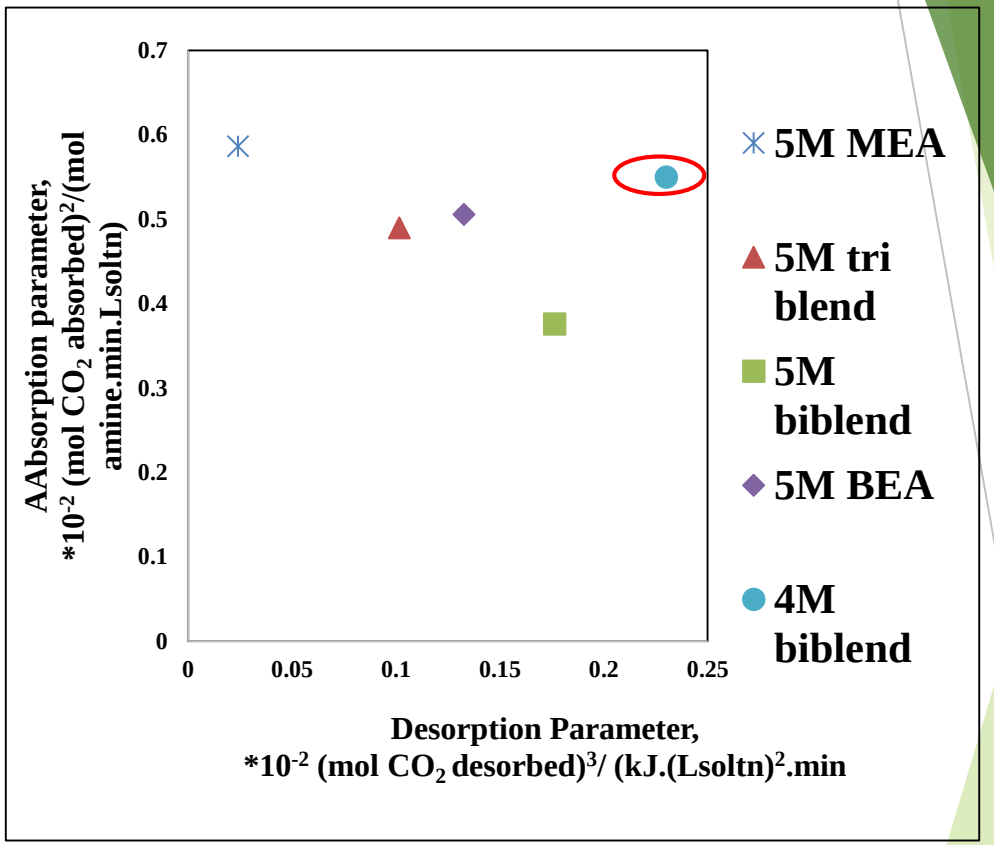
Absorption Parameter=Initial Absorption rate *pKa *Absorption capacity

$$\textbf{Desorption Parameter} = \frac{\textbf{Initial Desorption rate} * \textbf{Cyclic Capacity}}{\textbf{Heat Duty}}$$

(Narku-Tetteh et al., 2017)

Selection Chart





Selection Chart for single amines

Selection Chart for blended amines

BMEA: Butylmonoethanolamine
AMP: 2-Amino-2-methyl-1-propanol

5M triblend : 2M BEA:2M AMP:1M MEA
5M bi blend: 2.5 BEA:2.5AMP
4M biblend : 2M BEA:2M AMP

Process Optimisation

- The use of solid acid catalyst (HZSM-5) in reducing the heat of amine regeneration was first patented by Idem et al., 2017
- Srisang et al., 2017 and Decardi-Nelson et al. 2017 implemented the process for the first time in a pilot plant.
- The results showed a significant reduction in the heat duty and an overall improvement in the absorber efficiency and cyclic capacity.

Objectives

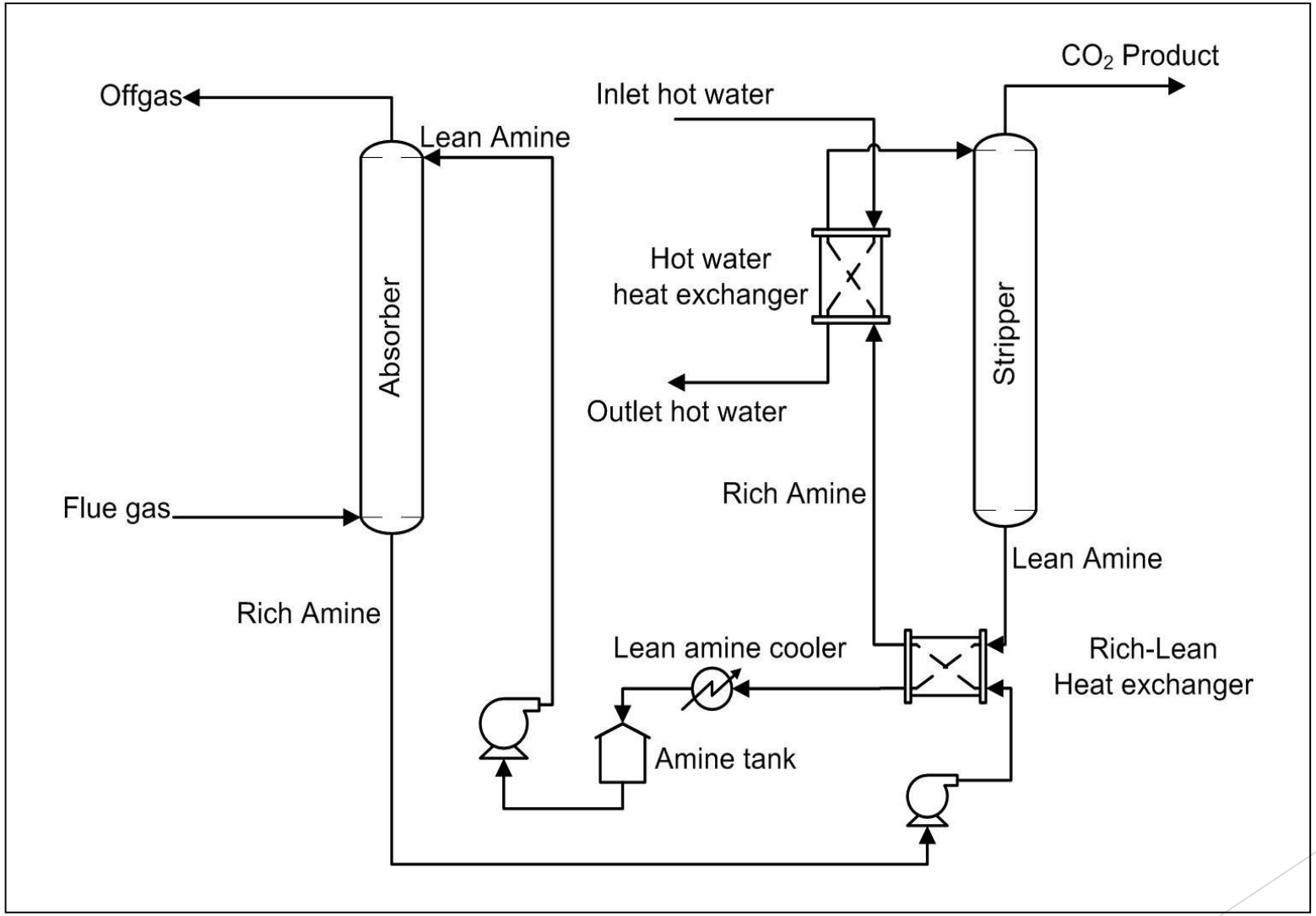
- Validate the criteria for selection of single and blended novel amine solvents developed from a batch process in an earlier work using a bench scale post combustion CO_2 capture plant.

- Evaluate any benefits provided by the improved new amine solvent blend using a bench scale post combustion CO_2 capture plant in terms of absorber efficiency, cyclic capacity and heat duty.

- Evaluate the contribution of a solid acid catalyst in lowering the heat duty after introducing into the desorption column of a bench scale post combustion CO_2 capture plant.

Experimental Section

Schematic representation of the bench scale experimental set-up for CO_2 capture



(Srisang et al., 2017)

Experimental Conditions

- 4M Bi blend (2:2 BEA:AMP)
- 7M MEA-MDEA (Base case)
- Base case better than 5M MEA (Decardi-Nelson et al., 2017)
- Operating conditions used in the pilot plant experiments

Condition	Value
Solvent used	7M MEA/MDEA, 4M BEA/AMP
Solvent flowrate	60 mL/min
Feed Gas flow rate	15 SLPM
CO_2 in feed gas	15%
Desorber amine inlet Temperature	87°C
Desorber Catalyst	HZSM-5 (Si/Al =19)
Desorber Catalyst weight	0g, 150 g
Absorber inlet Temperature	28°C

Absorber efficiency

$$= \frac{G_{in} * X_{CO_2 in} - G_{out} * X_{CO_2 out}}{G_{in} * X_{CO_2 in}} * 100\%$$

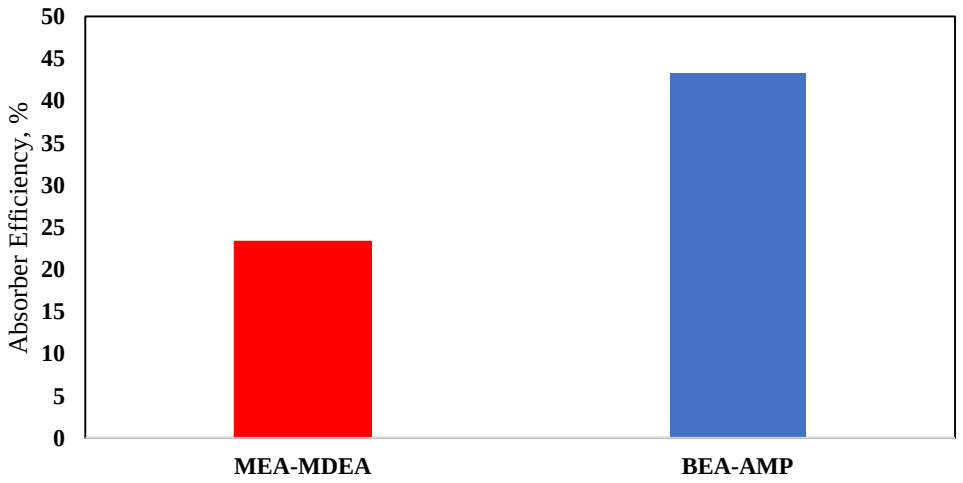
$$q = \frac{m_{hw} * Cp_{hw} * (T_{hw,in} - T_{hw,out})}{m_{CO_2}}$$

- ❖Absorber Efficiency
- ❖Heat duty
- ❖Cyclic capacity

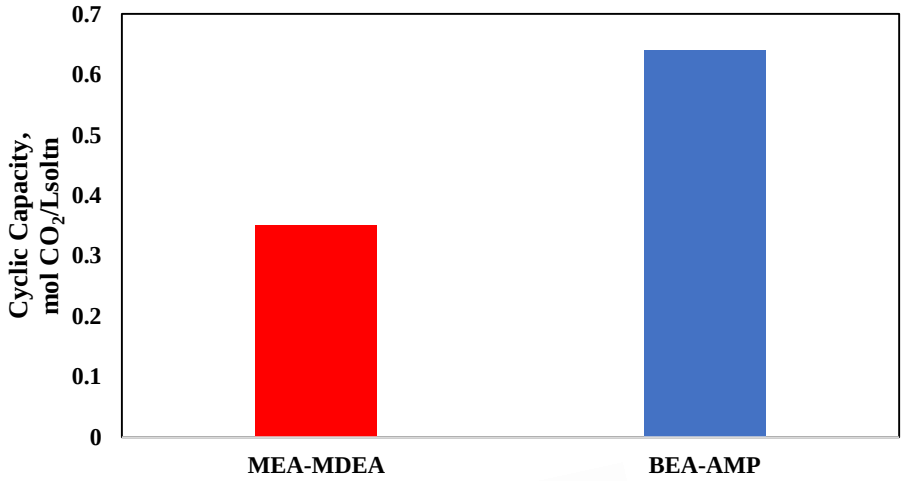
Results and Discussion

Comparison of novel blend with base case

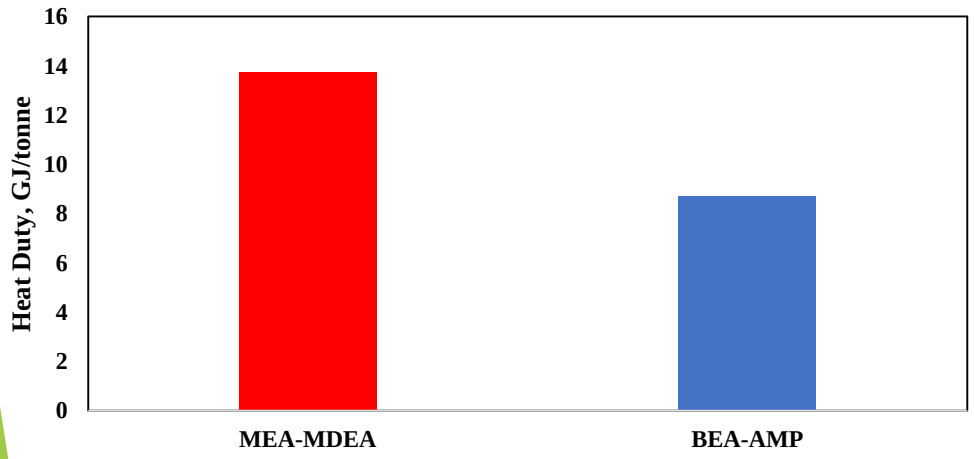
Absorber Efficiency



Cyclic Capacity



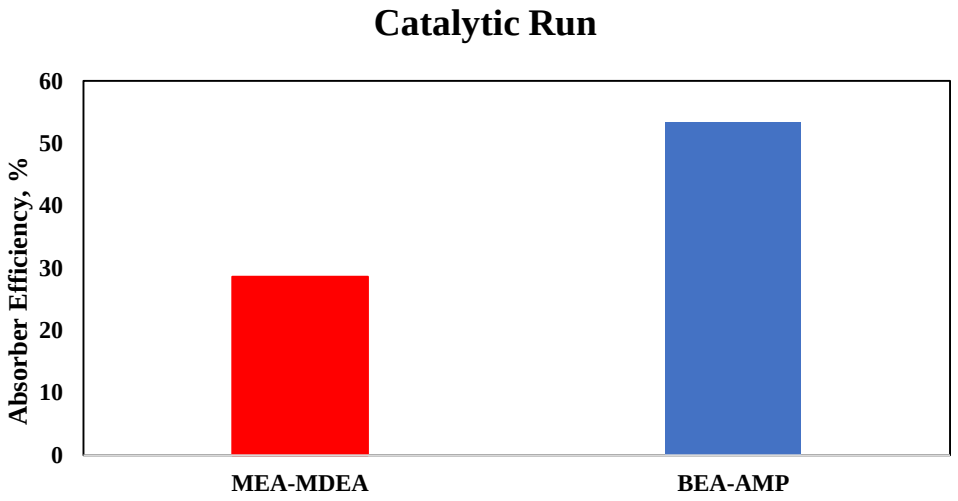
Heat Duty



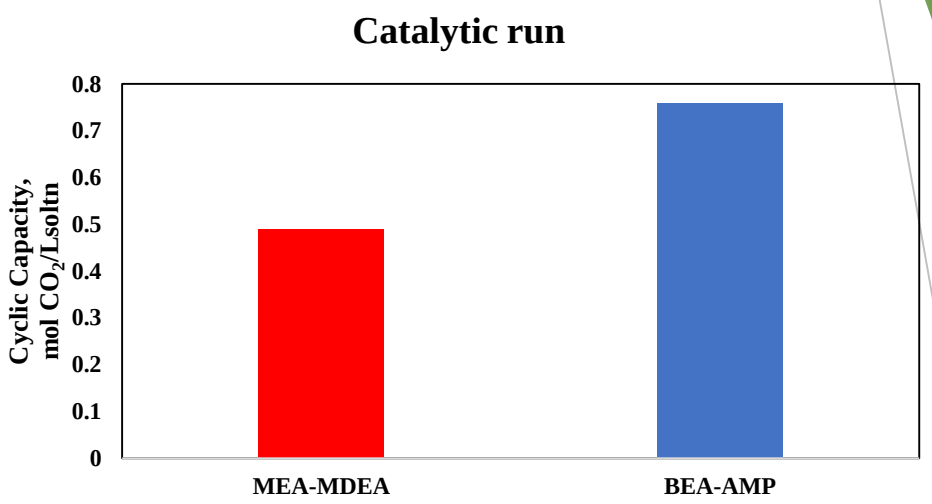
Results and Discussion (Cont'd)

Process Improvement (Catalytic Runs)

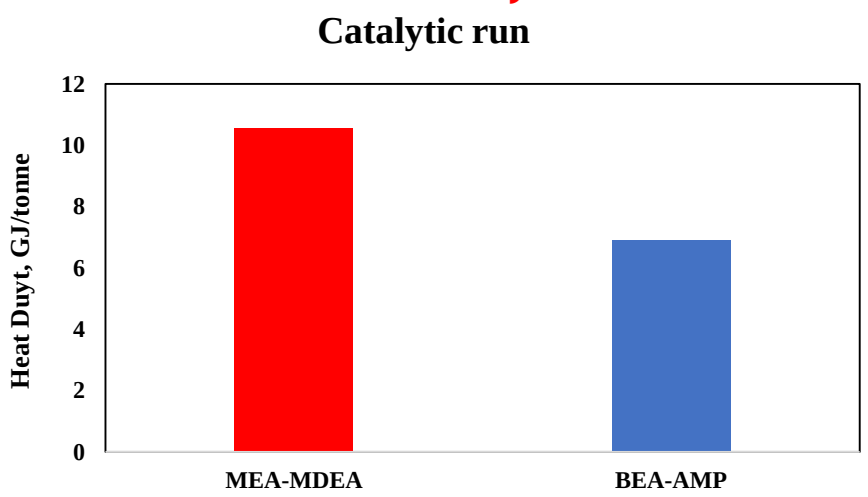
Absorber Efficiency



Cyclic Capacity



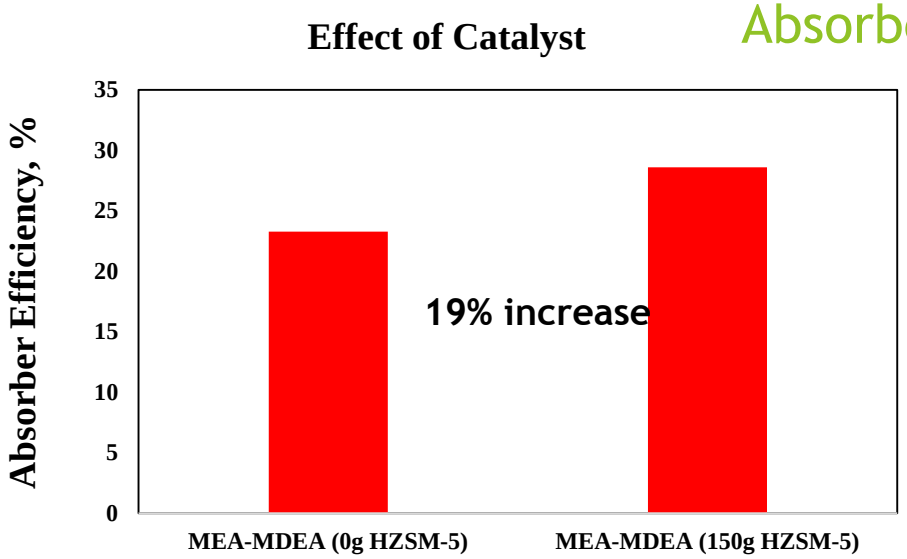
Heat Duty

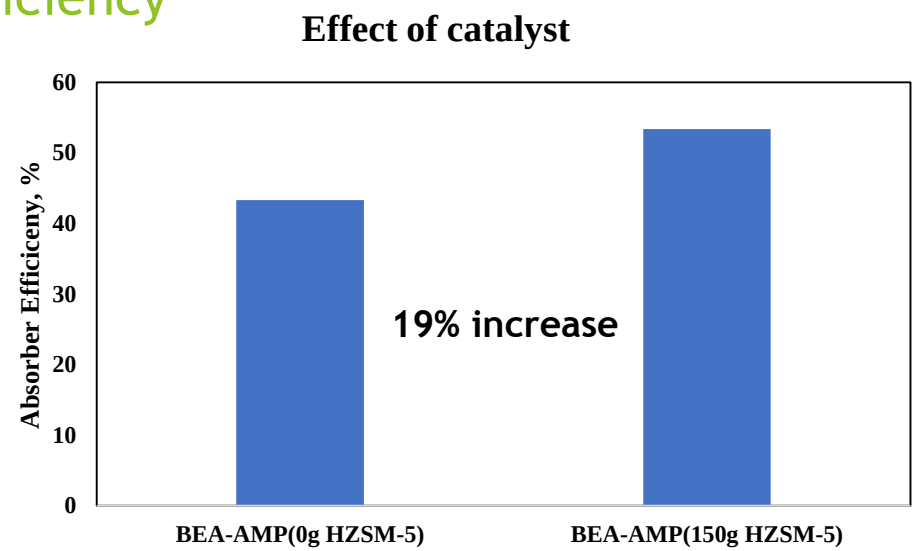


Results and Discussion (Cont'd)

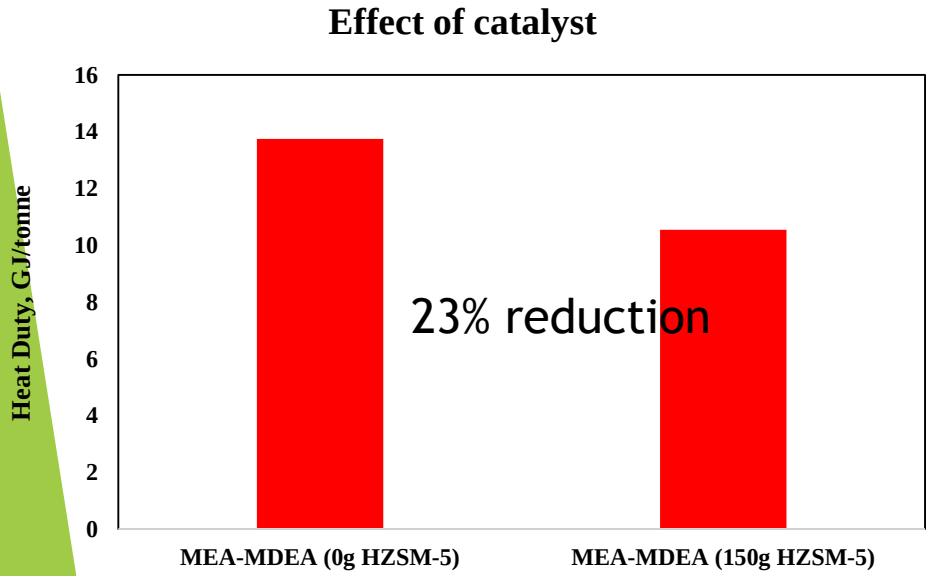
Catalytic Effect

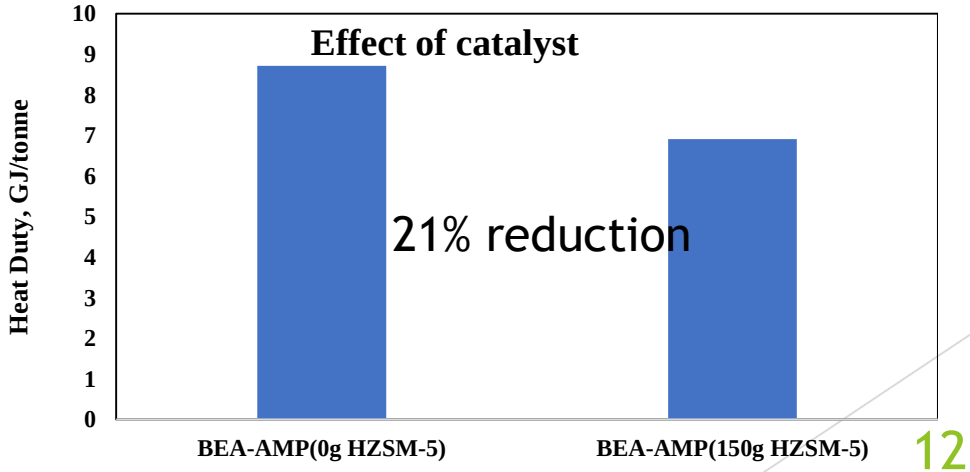
Absorber Efficiency





Heat Duty





Role of Catalyst

Without catalyst, For carbamate forming amines like MEA and BEA, desorption reactions are shown:

Step 1: Carbamate breakdown

$$MEA/BEACOO^- + H_3O^+ \leftrightarrow MEA/BEA + CO_2 + H_2O \quad (1)$$

Step 2: Amine Deprotonation

$$MEA/BEAH^+ + H_2O \leftrightarrow MEA/BEA + H_3O^+ \quad (2)$$

For sterically hindered amine like AMP the reaction mechanism is as shown below.

Step 1: Carbamate hydrolysis

$$AMPCOO^- + H_2O \leftrightarrow AMP + HCO_3^- \quad (3)$$

Step 2: bicarbonate breakdown

$$AMPH^+ + H_2O \leftrightarrow AMP + H_3O^+ \quad (4)$$

$$HCO_3^- + H_3O^+ \leftrightarrow CO_2 + 2H_2O \quad (5)$$

For bicarbonate forming amines like MDEA, the reaction is as follows:

$$MDEA + CO_2 + H_2O \leftrightarrow MDEAH^+ + HCO_3^- \quad (6)$$

$$MDEAH^+ + H_2O \leftrightarrow MDEA + H_3O^+ \quad (7)$$

$$HCO_3^- + H_3O^+ \leftrightarrow CO_2 + 2H_2O \quad (8)$$

Heat Duty Terms

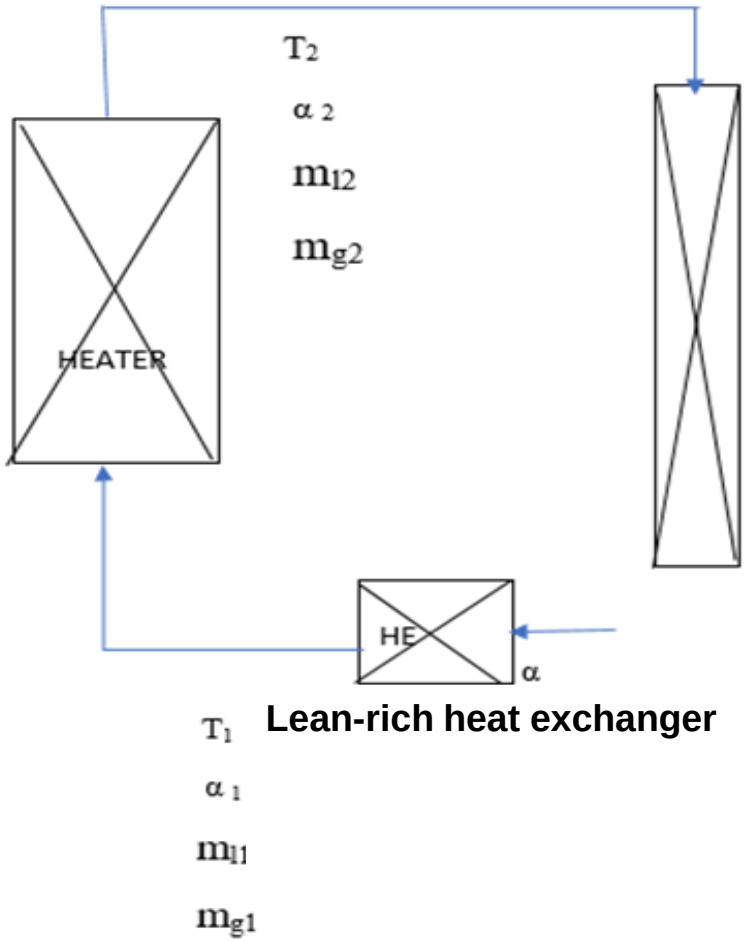
- Heat Duty- $(H_{sens} + H_{vap}) = H_{des}$

Heat duty, $q = \frac{m_{hw} * Cp_{hw} * (T_{hw,in} - T_{hw,out})}{m_{CO_2}}$

- Heat of vaporisation, H_{vap} obtained from steam tables at the average operating temperature

- Sensible heat, H_{sens} obtained using energy balance of both liquid and gas phases.

Schematic Illustration for Calculation of Sensible Heat

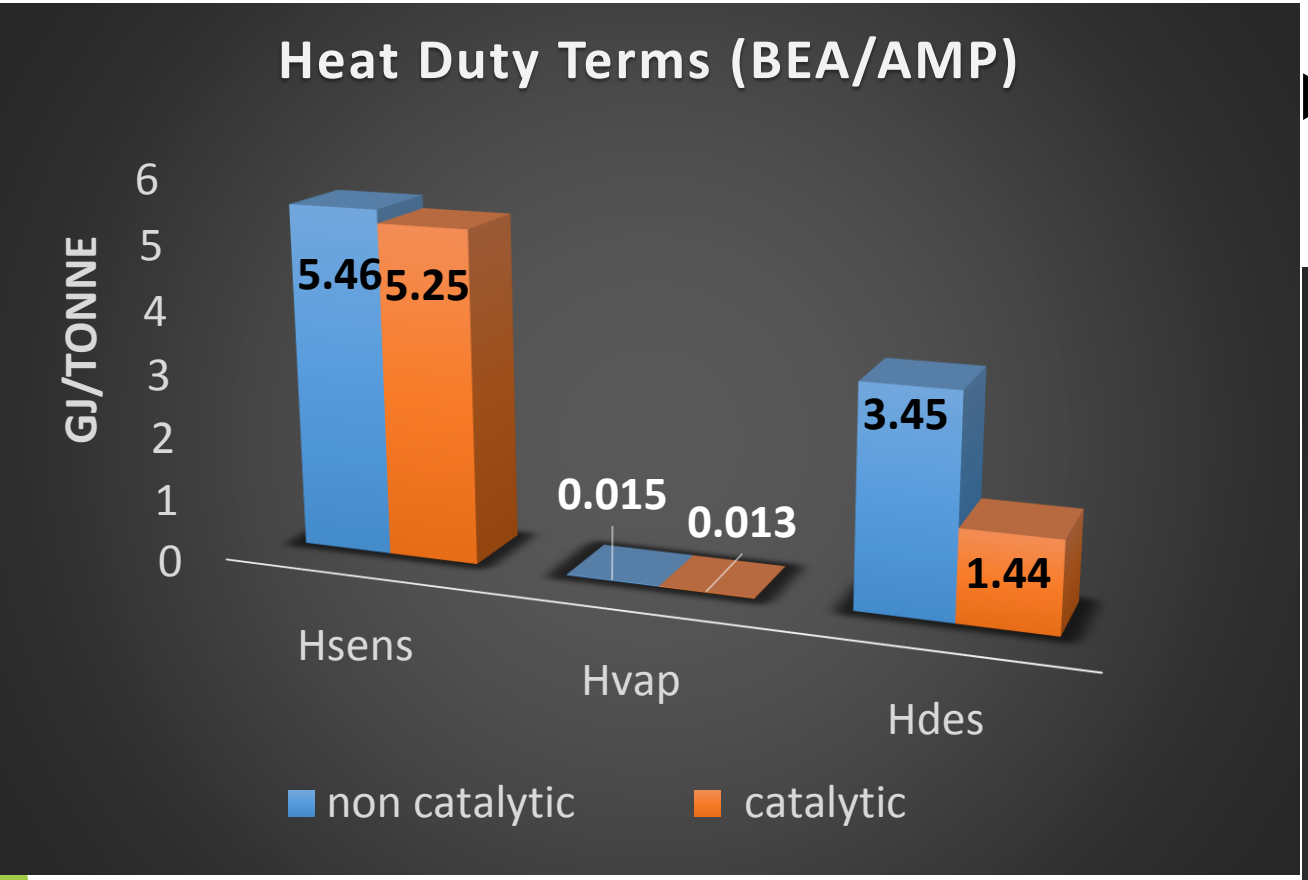


Lean-rich heat exchanger

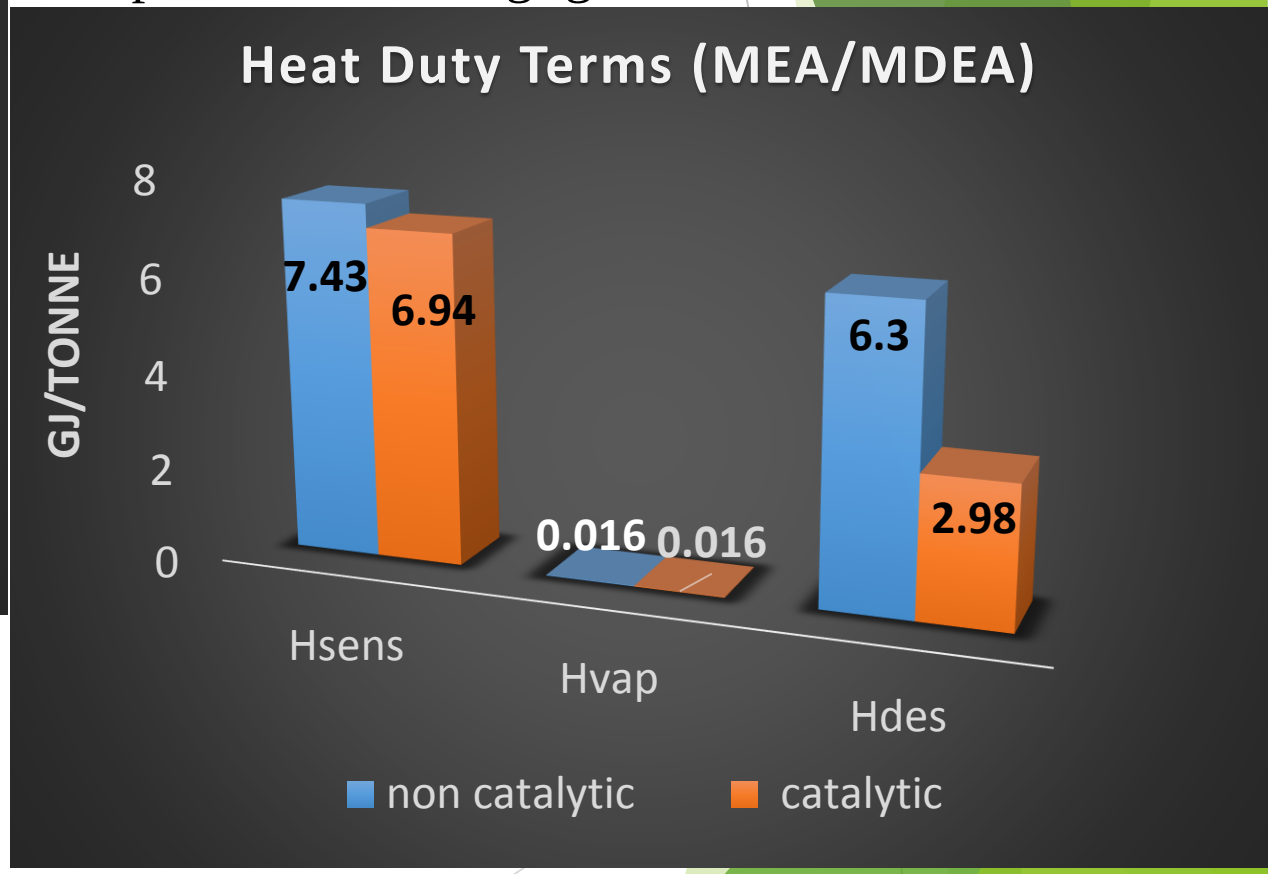
Desorber

m_{g1}	CO_2 in gas phase in stream entering heater (kg/l.soltn)
m_{g2}	CO_2 in gas phase in stream leaving heater (kg/l.soltn)
m_{l1}	mass of liquid solution entering heater (kg/l.soltn)
m_{l2}	mass of liquid solution leaving heater (kg/l.soltn)
T_1	amine solution temperature at heater inlet
T_2	amine solution temperature at heater outlet
α	loading of amine solution entering lean-rich heat exchanger
α_1	loading of amine solution entering heater
α_2	loading of amine solution exiting the heater

Summary of Heat duty terms for the blends



- The catalytic effect on both the sensible heat and heat of vaporisation are negligible.



- Thus, the role of catalyst is clearly manifested in the H_{des} for both systems.
- However, the values of H_{des} are apparent (a factor of amine cyclic capacity)

Conclusions

- The pilot plant test validated the selection as well as the selection criterion of BEA and AMP as the components for formulation of a good solvent blend.
- The novel 4M BEA-AMP bi-blend showed very attractive CO_2 capture performance, and as such is a good potential solvent for post combustion CO_2 capture.
- Employing the use of a catalyst resulted in a tremendous improvement in the absorber efficiency, cyclic capacity and a significant reduction in the heat duty.
- The results show that part of the energy needed for CO_2 desorption is contributed by the catalyst in proton donation thereby reducing the external energy required for CO_2 desorption from the amine solvent.
- The heat duty for the novel blend with and without the desorption catalyst (HZSM-5) were 6.91 GJ/tonne CO_2 and 8.71 GJ/tonne CO_2 respectively.

Acknowledgements

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References

- Narku-Tetteh J, Muchan P, Saiwan C, Supap T, Idem R. Selection of components for formulation of amine blends for post combustion CO2 capture based on the side chain structure of primary, secondary and tertiary amines. Chemical Engineering Science 170 (2017) 542-560
- Narku-Tetteh J, Muchan P, Idem R. Effect of alkanol chain length of primary alkanolamines and alkyl chain length of secondary and tertiary alkanolamines on their CO2 capture activities. Separation and Purification Technology 187 (2017) 453-467
- Muchan P, Saiwan C, Narku-Tetteh J, Idem R, Supap T, Tontiwachwuthikul P. Screening tests of aqueous alkanolamine solutions based on primary, secondary, and tertiary structure for blended aqueous amine solution selection in post combustion CO_2 capture. Chemical Engineering Science 170 (2017) 574-582
- Decardi-Nelson B, Akachuku A, Osei P, Srisang W, Pouryousefi F, Idem R. Catalyst performance and experimental validation of a rigorous desorber model for low temperature catalyst-aided desorption of CO2 in single and blended amine solutions Journal of Environmental Chemical Engineering 5 (2017) 3865–3872
- Osei PA, Akachuku A, Decardi-Nelson B, Srisang W, Pouryousefi F, Tontiwachwuthikul P, Idem R. Mass transfer studies on catalyst-aided CO2 desorption from CO2-loaded amine solution in a post-combustion CO2 capture plant. Chemical Engineering Science 170 (2017) 508-517
- Srisang W, Pouryousefi F, Osei PA, Decardi-Nelson B, Akachuku A, Tontiwachwuthikul P, Idem R. Evaluation of the heat duty of catalyst-aided amine-based post combustion CO2 capture. Chemical Engineering Science. 2017. http://dx.doi.org/10.1016/j.ces.2017.01.049
- Idem R, Shi H, Gelowitz D, Tontiwachwuthikul P, inventors; University Of Regina, assignee. Catalytic method and apparatus for separating a gaseous component from an incoming gas stream. United States patent US 9,586,175. 2017.

Thank You

Questions?