Sensitivity Analysis of Post Combustion Carbon Capture Using Monoethanolamine (MEA) as a Solvent. A Simulation Study

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Abstract. *Carbon capturing and storage (CCS) is new technology to remove CO_2 from the processes that involve elimination of CO_2 as its effect on the environment and incessant increase in temperature of the Earth, makes it interesting as well as most dangerous issue that should be dealt timely to reduce the greenhouse gas emissions. In the present research, the data obtained from the experimental study of CO_2 capture pilot plant at the Laboratory of Engineering Thermodynamic in TU Kaiserslautern, Germany, is used for the rate based model validation for different cases using monoethenolamine (MEA) as a solvent. Process simulation sensitivity analysis performed includes a wide range of CO_2 concentrations for flue gas of different sources i.e. natural gas fired power plant, exhaust gas recycle and coal based power plant. Results obtained from sensitivity analysis point out the effects of lean loading, stripper pressure, MEA concentration and CO_2 concentration in flue gas on energy requirement of reboiler and degree of regeneration using MEA as a solvent for a pilot-scale study. It was found that the specific reboiler duty is least for coal-fired power plant in comparison to the natural gas –fired and exhaust gas recycled power plant, keeping the flow rate of the flue gas constant.*

Keywords: Carbon capture, sensitivity analysis, monoethanolamine

1.Introduction

Carbon capture in industry is widely practiced and dates to decades ago. There are several industrial processes which require carbon capture for the refinement or the quality of the finished product. In natural gas processing, CO_2 is removed to reduce the compression and transportation cost. CO_2 is removed from H_2 as it affects the catalyst which is used for the reaction of H_2 and N_2 in ammonia process. Above all, CO_2 is posing a serious threat to the environment due to its greenhouse gas ability, resulting in climate change and global warming. So, carbon capturing and further storing it is relatively new technology to remove CO_2 from the processes that involve elimination of CO_2 as its effect the environment and result in incessant increase in temperature of the Earth, making it an interesting as well as most dangerous issue that should be dealt timely to reduce the greenhouse emissions [1].

Prior to industrialization, CO_2 concentrations into the atmosphere have been recorded 280 parts per million by volume (ppmv) in 1860 and it has been incessantly growing from now on and reached to a level of 316 ppmv in 1958. Today, it is estimated to a hilarious level of 420 ppmv. Without taking eminent measures to stop CO_2 concentration into the atmosphere, it is predicted to escalate as high as 750 ppmv by 2100. Unfortunately, third world countries even great proportion of developed countries are fulfilling their power generation demands from fossil fuel-fired power plants (e.g. coal and natural gas) [2].

Three different routes of technology are available to capture CO_2, including pre-combustion CO_2 capture, post-combustion CO_2 capture (PCC), and oxy-fuel combustion CO_2 capture. Oxy-fuel combustion is a general term used for technologies where nitrogen (N_2) is excluded from the combustion process. In case of pre-combustion CO_2, the CO_2 is captured prior to combustion. It is well suited for gas fired combined cycle power plants.

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The fuel is reacted with steam or steam/oxygen mixture to produce a mixture rich in H_2 and CO_2 and then CO_2 is removed before combustion [3]. In case of PCC, the tail end recovery of the CO_2 from the flue gas of the power plant is exploited. The most mature technology from the number of the PCC involves the use of the liquid solvent to capture CO_2 from the flue gas. However, PCC is most viable and promising technology as diversity of solvents are exploited to minimize energy requirements of the process [3].

In power generation sector, generally the most trusted and commercially utilized technology to capture CO_2 is PCC technology as it involves the capturing of CO_2 after the conversion of fuel into energy. The flue gas of natural gas fired power plant typically contain 3-5 % CO_2 and 5-13 % in exhaust gas recycle (EGR), while 13-15 % CO_2 is present in the coal fired power plant [4].

The challenges which are underway in implementation of PCC are: how to mitigate high capital and operating cost and how the process can be scaled up for industrial use. Stripping is energy intensive process as reboiler duty requirements are higher. As a consequence, a lot of work is done to reduce the specific reboiler duty and the operating cost [5]. Aspen Plus software has been used to simulate the absorption/desorption mechanism, highlighting the process and design parameters to validate the base case [6]. Pointing out that the reduction in reboiler can be achieved if absorber height is increased by 20 %. The rate based model examination in terms of film discretization ratio and flow models along with packing type resulting in excellent predictability to scale up the process [7].

Due to the ever-increasing demand of energy, the dependence on fossil fuels based energy generation will remain higher. So, there is a need to make CO_2 capture process more economical and less energy intensive. The process improvements regarding absorption enhancement, heat integration and heat pumps in order to optimize the energy demands has been proposed in the literature [8]. In addition, the process schematics with tentative changes are recomposed [8]. The sensitivity study of all input parameters related to the thermodynamic properties of the process are performed in the literature [9, 10] and concluded that the high sensitivities are related for the Henry's law constant, the interfacial area and the enthalpy of absorption as well as for the factors which describe the equilibrium in order to develop the rate based model which need improved interfacial area correlation factors. Thus, the thermodynamic parameters and equations are widely agreed in the literature to predict the optimum or near to optimum results.

A rate based model is presented using 2-amino-2-methyl-1-propanol (AMP) as a solvent and validated by providing sensitivity analysis [11]. The blend of MDEA and MEA is studied with the appropriate ratio for CO_2 capture and a significant reduction is found in energy consumption that is required for CO_2 regeneration [9]. The new solvents are also being discussed to reduce the specific reboiler duty such as two new solvents CASTOR1 and CASTOR2 with MEA were reported [12]. These new solvents showed excellent performance in absorption and reducing energy penalties. CASTOR 2 showed lower required flow rate and for higher columns these solvents need less reboiler duty to strip out CO_2. However, still in the literature MEA is being discussed as a bench-scale solvent to show fundamental findings. Therefore, this study mainly focuses on the absorption of CO_2 using MEA as solvent which is widely studied for this purpose due to its high loading capacity.

Different process alterations are also being discussed in the literature, such as natural gas exhaust gas recycles (EGR) to increase CO_2 concentration in flue gas and calculated optimum liquid to gas ratio which could result in lower energy consumption forfeits [13]. More the concentration of CO_2 is absorbed, the lower will be specific reboiler duty [13]. The process is further improved by reducing the required MEA recycle stream [5]. Important perceptions have been attained on the functioning of washing sections on the top of both absorber and desorption columns by analyzing the factors that limit the flowrates of recycle water and make-up water around the absorber washing section. The desorption model is validated through literature [9]. The heat loss is not dependent on flow rates and reboiler duty, however, it depend truly on level of insulation [4, 14]. Notz et al. [14]. executed a detailed experimental study of absorption/desorption at pilot-scale level. MEA was used as a solvent and influence of all important parameters, such as CO_2 partial pressure, lean loading, desorber pressure, dynamic loading,

CO_2 removal rate and MEA weight percentage checked. Further, the trends were presented by varying operational parameters which give a deep insight how energy requirement can be reduced.

In the nutshell, it is agreed that the main environmental concern is CO_2 emissions by the combustion of fossil-fuel fired power plants to fulfill the increasing energy requirements worldwide. However, the massive emissions of CO_2 are attracting the researcher's attentions to reduce it by using different existing or innovative technologies to make them practically feasible. Sensitivity analysis is one type of study by which the performance of the post combustion CO_2 capture unit using liquid as a reactive solvent can be assessed by changing the number of parameters for an operable region to be assessed.

Therefore, in the present study, the pilot-scale plant model is developed and simulated using Aspen Plus® (v.10). Rate based distillation model (RDFRAC) simulate the packed as well as tray column keeping into account the mass and energy balance with carefully observing the flooding limit into the absorption/desorption column, hence it is selected for the present analysis. Appropriate kinetic expressions are included for the reaction that don't reach equilibrium [15]. The rate based model developed in Aspen Plus uses the dimensions from the literature [14]. Further, validation of the developed model is done by comparing the experimental results with simulated results. Finally, the sensitivity analysis is performed to check the effects of process variables on performance of the CO_2 capture process.

2.Materials and methods
2.1. Model development

The rate-based model of CO_2 absorption/desorption model was established within the Aspen Plus® RADFRAC modelling framework. Figure 1 shows the developed Aspen plus flowsheet of the presented model. The model was developed by properly applying a thermodynamic framework that represent the CO_2-H_2O-MEA system, including kinetics of CO_2 reaction with the MEA solution, and appropriate transport properties which affect mass and the heat transfer [3]. Two packed columns acting as absorber and stripper are used for absorption and desorption reaction for MEA+H_2O+CO_2, respectively. The internal specification and dimensions of columns along with process variables are shown in Table 1.
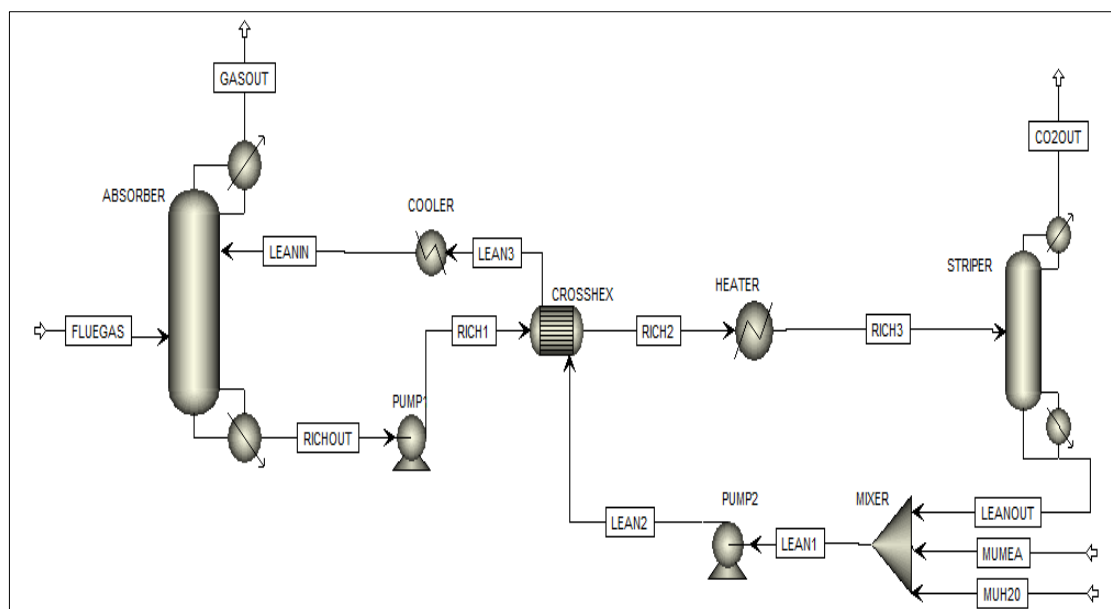
Figure 1. Process flow model developed in ASPEN PLUS

The flue gas containing CO_2 enters the bottom of the absorber while the lean solvent with a 0.1-0.3 CO_2 loading comes in contact counter-currently as flue gas rises the column and solvent falls down under the effect of the gravity. The CO_2 is absorbed in the solvent and absorption increases the temperature

inside the column and reaches up-to 60ºC and the scrubbed gas from the absorber is vented to the atmosphere. The rich solvent exists the absorber with higher CO_2 loading in range of 0.3-0.5. The rich stream is further needed to escalate its temperature before entering the stripper so a cross-heat exchanger exchanges the heat from the regenerated stream coming out of the stripper. Finally, the rich solvent enters the stripper at a temperature range of 100-120ºC and is operated at higher pressure (1.5-2 bar) than atmospheric pressure. The stripped CO_2 is collected from the top of the stripper and is further transported to storage. Reboiler at the bottom of the stripper provides the heat and is the only energy intensive part which needs reduction. The solvent which is free of CO_2 is pumped to cross-heat exchanger where it enters the absorber after reduction in temperature. Before entering the absorber makeup water and makeup MEA solution is added to fulfil the deficiency of the flow rate after stripping of the CO_2 from top of the stripper.

Table 1. Survey of data characterizing the pilot plant Notz et al. [14]

Parameters	Characteristics
Flue gas source	Natural gas power plant/Coal power plant/ Exhaust gas recycle
CO_2 partial pressure in the flue gas	3-16 mbar
Diameter of columns (absorber and desorber)	0.125 m
Height of absorber	4.2 m
Height of desorber	2.52 m
Column internals in absorber, desorber	Structured packing Sulzer Mellapak 250Y^{TM}
Pressure in the absorber	Atmospheric Pressure
Pressure in the desorber	1-3 bar
Temperature of flue gas	40 ºC

Furthermore, a variety of simulations were performed using different conditions of solvent flow rate, CO_2 loading, solvent strength and stripper pressure. The diversity of results allowed a broad understanding of the absorption/desorption process especially at the pilot-scale level. For the number of research work presented in the literature, the liquid flow rate was kept constant [16, 17]. However, Notz et al. [14] and Tobiesen et al [4] studies showed the maximum liquid flow was up to 4.5 times higher than the smallest value. Hence, the data reported by Notz et al. [14] is used for the model validation and subsequent sensitivity analysis in the present work due to diversity of the reported experimental results.

2.2. Chemical reactions

Chemical reactions happen only in liquid phase where ionic species of H_2O, MEA and CO_2 are involved. As amines and acid gases are weak electrolytes and the partially dissociates in water, resulting in a complex mixture of non-volatiles (H_2O plus amines) [18]. A variety of equilibrium constant that depends on temperature are derived from the literature [19]. The number of chemical reactions involved in the reactive absorption and desorption of CO_2 with MEA are given as:

Hydrolysis reactions:
$$MEACOO^- + H_2O \leftrightarrow MEA + HCO_3^- \tag{1}$$

Dissociation of dissolved carbon dioxide:
$$CO_2 + 2H_2O \leftrightarrow HCO_3^- + H_3O^+ \tag{2}$$

Dissociation of bicarbonate:
$$HCO_3^- + H_2O \leftrightarrow H_3O^+ + CO_3^{2-} \tag{3}$$

Dissociation of protonated MEA:
$$MEAH^+ + H_2O \leftrightarrow MEA + H_3O^+ \tag{4}$$

Ionization of water:
$$2H_2O \leftrightarrow OH^- + H_3O^+ \tag{5}$$

2.2.1. Equilibrium data

The equilibrium constants for the above given reactions are calculated by using Table 2 that represents the data imported from Arachchige and Melaaen [19] to develop model mathematically using the equation (6).

$$\ln K_j = A_j + \frac{B_j}{T} + C_j \ln T + D_j T \tag{6}$$

2.2.2. Rate kinetic data

To understand the reacting system, it is compulsory to have a strong knowledge about rate kinetic data involving the following chemical reactions.

$$CO_2 + OH^- \leftrightarrow HCO_3^- \tag{7}$$
$$MEA + CO_2 + H_2O \leftrightarrow MEACOO^- + H_3O^+ \tag{8}$$
$$HCO_3^- \leftrightarrow CO_2 + OH^- \tag{9}$$
$$MEACOO^- \, H_3O^+ \leftrightarrow MEA + CO_{2\,+} H_2O \tag{10}$$

The mathematical equation utilized in Aspen Plus to calculate kinetic equations for the above chemical reactions is given below with constants in Table 3.

$$r_j = k_j \left(\frac{T}{T_0}\right)^{nj} exp\left[-\frac{E_j}{R}\left(\frac{1}{T} - \frac{1}{T_0}\right)\right] \tag{11}$$

Table 2. Equilibrium constants

Parameter	Reaction 1	Reaction 2	Reaction 3	Reaction 4	Reaction 5
A_j	-0.52	231.46	216.05	-3.038	132.89
B_j	-2545.53	-12092.1	-12431.7	-7008.3	-12445.9
C_j	0	-36.78	-35.48	0	-22.47
D_j	0	0	0	-0.00313	0

Table 3. Rate kinetic data

| Parameter	Reaction 7	Reaction 8	Reaction 9	Reaction 10
K_j	4.32×10^{13}	9.77×10^{10}	2.38×10^{17}	2.7963×10^{20}
n_j	0	0	0	0
E_j (cal/mol)	13249	9855.80	29450.89	17229.79
T_0(K)	298	298	298	298

a)

b)

c)
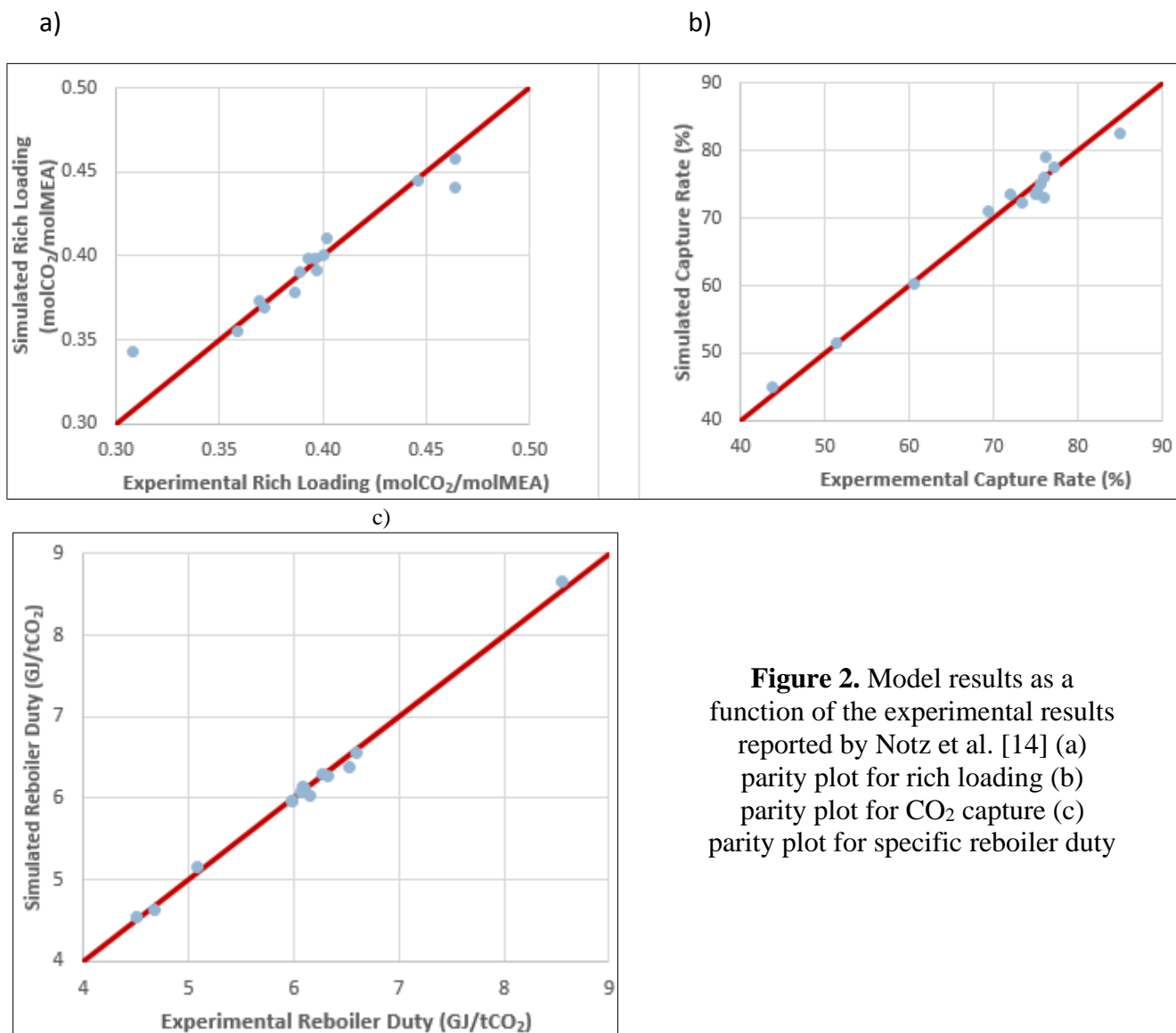
Figure 2. Model results as a function of the experimental results reported by Notz et al. [14] (a) parity plot for rich loading (b) parity plot for CO_2 capture (c) parity plot for specific reboiler duty
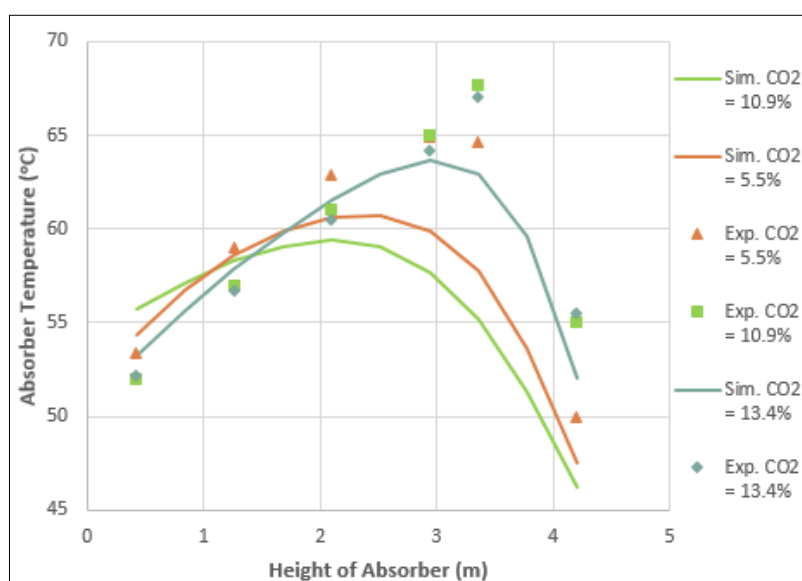
Figure 3. Model results as a function of the experimental results for the absorber temperature profiles reported by Notz et al. [14]
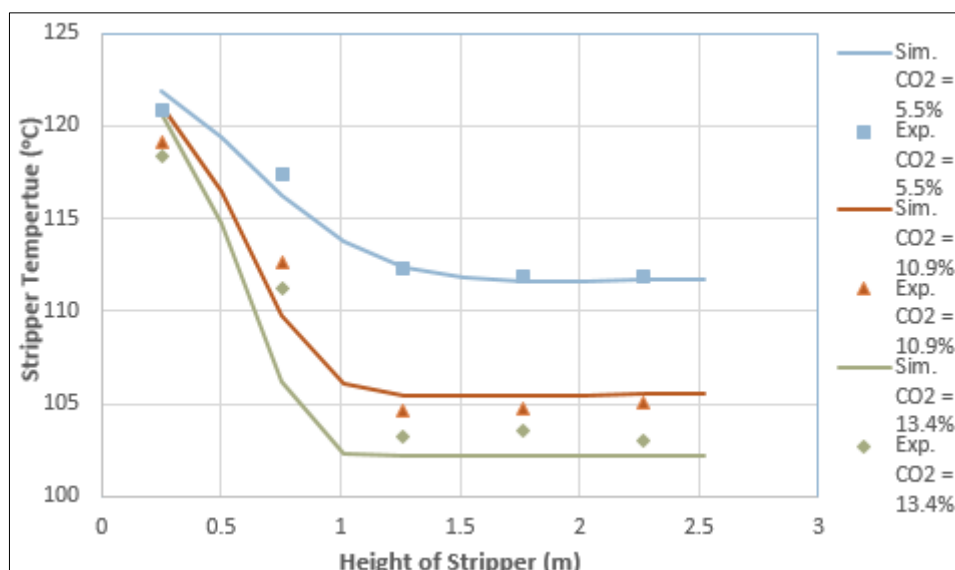
Figure 4. Model results as a function of the experimental results for
the stripper temperature profiles reported by Notz et al. [14]

2.3. Model validation

The obtained data from experimental study of CO_2 capture pilot plant at the Laboratory of Engineering Thermodynamic in TU Kaiserslautern, Germany, is used for rate based model validation for different cases as reported in the literature [14] using MEA as a solvent. Comprehensive and detailed set of experiments were performed and were categorized according to key performance parameters. The experiments regarding variation of CO_2 partial pressure in flue gas, stripper pressure and dynamic load were simulated to validate rate based model. The detailed process flow diagrams with process parameters for the experimental setup can be found in reference [14]. All the errors regarding i.e. capture rate, solvent flow rate, lean/rich loadings, reboiler duty and specific reboiler duty are kept under 5 %.

The results shown in Figure 2 are in good agreement with the experimental results. Temperature profiles express clearly how absorption/desorption is occurring along the length of absorber and stripper. In Figure 3 and Figure 4, the temperature profiles of absorber and stripper is shown, respectively.

3.Results and discussions
Sensitivity analysis

To perform sensitivity analysis, four operational parameters i.e. stripper pressure, lean loading, MEA weight percentage in the solution and CO_2 concentration in the flue gas are varied. For each of the operational parameter, all other parameters are fixed and only prescribed parameter is varied to check the impact of the varied parameter on the performance parameters which are specific reboiler duty and degree of regeneration.

3.1. Stripper pressure

The desorber pressure is varied from 1-3 bar (absolute) keeping all other parameters constant as shown in Table 4. Changes in pressure results in the variance for the required energy of regeneration as provided in the literature [14]. Increase in stripper pressure is effective as the reboiler temperature and pressure are directly related to each other. As the flow rate and the CO_2 loading of the solvent is constant so a specified amount of the CO_2 is absorbed in the absorber, before entering in the stripper. Hence, L/G ratio and CO_2 loading of the rich solvent is unchanged no matter what ever the pressure is used. By increasing the pressure in the stripper, the temperature rises and provides an increase gradient to strip out more CO_2. Therefore, the reboiler duty decreases as lower amount of water is to be evaporated which means the regeneration task is getting easier as lesser amount of water is present with CO_2 to strip it out.

Hence, the reboiler at bottom of the stripper requires less energy due to the elevated pressure. As a consequence, the specific reboiler duty is decreased as also found in the literature [20].

Table 4. Process variables for varying stripper pressure

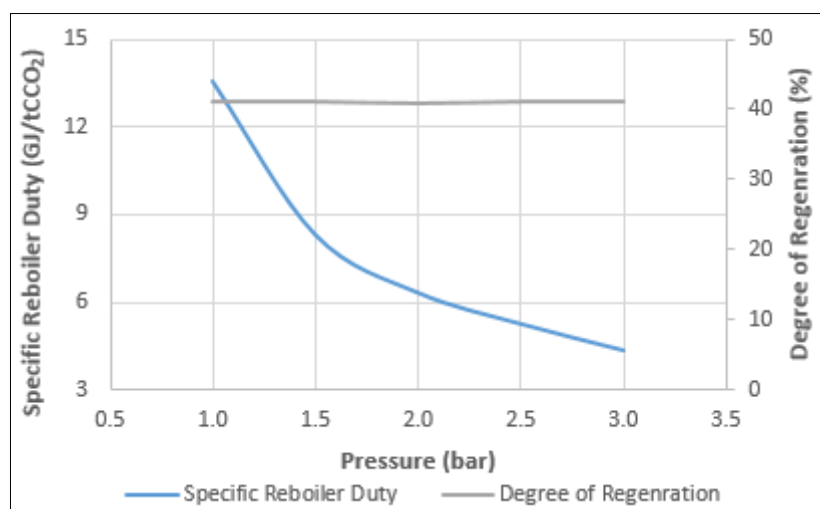| Process variables	Ranges
Desorber pressure (bar)	1-3
Flue gas mass flow rate (kg/h)	72
CO_2 composition (mol%)	9.7
Solvent mass flow rate (kg/h)	321
Reboiler duty (kW)	37-11.946
CO_2 removal rate (%)	85
Lean Loading (mol CO_2/mol MEA)	0.209
MEA weight % (g/g)	30

However, increasing the pressure causes elevated temperature throughout the stripper resulting in the degradation of the MEA. MEA degradation is minor around 110°C, however, it accelerates as temperature is approached to 130°C [21]. So, the temperature should be limited around 120-124°C in order to avoid any degradation. It is found with increase in pressure from 2 to 3 bar the reduction in the specific reboiler duty is 31 %. It is obvious from the Figure 5 where the pressure is increased from 1 to 1.5 bar the reduction in the specific reboiler duty brings abrupt change. However, as it moves further, the curve shows less gradient and reduction is relatively slower than previous one. As pilot plant is designed for 2 bar stripper pressure, hence it should be limited as MEA degradation starts at higher pressure due to the restrictions of stripper design limitation.

3.1.1. Degree of regeneration

Degree of regeneration is defined as how much percentage of CO_2 is captured from rich solvent when it exits the stripper. It is percentage difference of rich and lean loading with respect to rich loading.
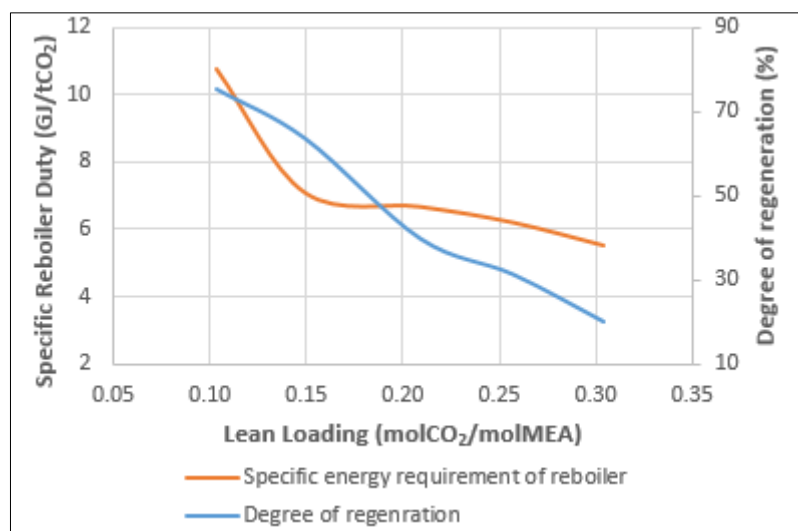
$$Degree\ of\ Regeneration\ (\%) = \frac{Rich\ Loading - Lean\ Loading}{Rich\ Loading} \times 100$$

As in case of varying stripper pressure the solvent which has absorbed CO_2 in the absorber remains unaffected after how much change in stripper pressure is brought. So, the striper pressure has no effect on the degree of regeneration as can be seen in Figure 5-2.

Figure 5. Effect of varying pressure on specific reboiler duty and degree of regeneration

Figure 6. Effect varying lean loading on specific reboiler
duty and degree of regeneration

Table 5. Process variables for varying lean loading

Process variables	Ranges
CO_2 partial pressure (mol%)	9.7
Flue gas mass flow (kg/h)	72
Desorber pressure (bar)	2
CO_2 removal rate (%)	85
MEA weight % (g/g)	30
Lean Loadings (mol CO_2/mol MEA)	0.10-0.30

3.2. Lean loading

For each simulation the lean loading is varied and all other process parameters are kept constant as given in Table 5. When solvent lean loading is increased and the MEA weight percentage is fixed then the water content in the solvent stream is reduced. Increased CO_2 concentration and less water content in rich solvent results in lower specific reboiler duty [20]. Increase in the CO_2 concentration require higher flow rate of the solvent to absorb the CO_2 from the flue gas. So, reboiler duty is increased with increase in the higher solvent flow rate. However, captured CO_2 flow rate is increased further and as a result the specific reboiler duty is reduced. Furthermore, the specific reboiler duty becomes almost constant after some specific value of the lean loading. Hence, the lean loading can be considered as a parameter of optimization to find the best value for the operating condition. For the present case, the specific reboiler duty is considered as optimum at a value of 0.15 mol CO_2/mol MEA of lean loading.

3.2.1. Degree of regeneration

Degree of regeneration and specific reboiler duty are dependent on each other. As its obvious in Figure 6 that with increase in lean loading the reboiler duty as well as degree of regeneration decreases. With increase in lean loading, the solvent capacity to absorb CO_2 is limited as CO_2 concentration in solvent itself is increasing. So, the concentration of CO_2 in the rich stream is reduced along with the reduced rich loading resulting in less solvent regeneration.

3.3. MEA Weight percentage

In this set of simulations, MEA weight percentage is varied and all other parameters are kept constant as can be seen in Table 6. To absorb one molecule of CO_2, stoichiometricaly two molecules of MEA are required for one molecule of CO_2, hence maximum CO_2 loading can be 0.5 mol CO_2/mol MEA. As CO_2 loading of lean solvent is kept constant and MEA composition in the solvent is increased, it means there is higher potential for solvent to attach more numbers of CO_2 molecules. So, the flow rate of solvent

which is required to absorb CO_2 in the absorber is decreased, resulting in lower L/G ratio. More and more CO_2 is absorbed as MEA weight percentage increases resulting in the higher rich loading. Higher rich loading ensures higher CO_2 partial pressure in the stripper. In industrial plants, rich loading can reach upto 0.4-0.47 mol CO_2/mol MEA [20]. However, in the pilot plant, it rises to a maximum of 0.425 due to the length of the stripper which is limited and it becomes difficult to achieve a value of 0.47 mol CO_2/mol MEA. The decreased load of solvent flowrate and higher rich loading results in the deduction of the reboiler duty. Consequently, the specific reboiler duty is reduced from 7.90 to 5.5 GJ/TCO$_2$ as MEA weight percentage is increased from 20 to 40 %, respectively. MEA content was limited to 20 % only because of corrosivity, so corrosion inhibitors are added to make it 30 % or higher. If the MEA contents are increased to 40% then the corrosion effect is drastic [14].

**Table 6.** Process variables for varying MEA strength

Process variables	Ranges
Desorber pressure (bar)	2
Flue gas mass flow rate (kg/h)	72
CO_2 composition (mol%)	9.7
L/G ratio	8.8-2.1
Reboiler duty (kW)	21-14.17
CO_2 removal rate (%)	85
Rich Loading (mol CO_2/mol MEA)	0.318-0.425
Lean Loading (mol CO_2/mol MEA)	0.208
MEA weight % (g/g)	20-40
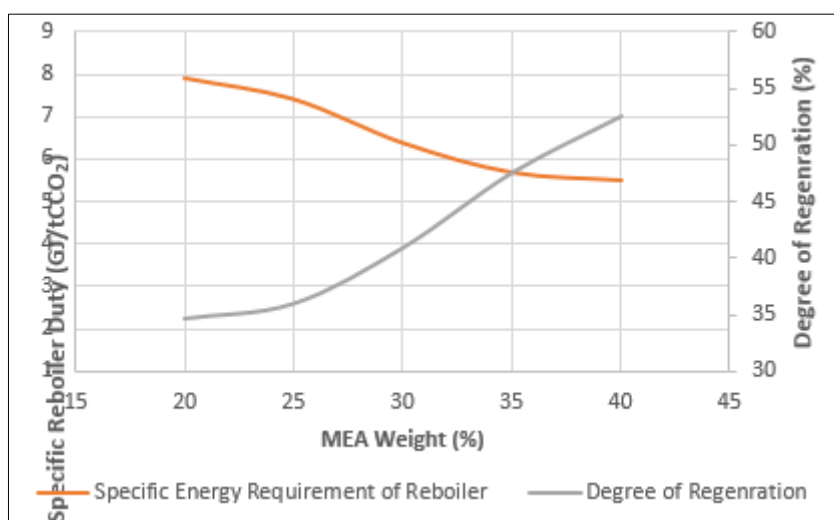
Figure 7. Effect varying MEA weight % on specific reboiler
duty and degree of regeneration

3.3.1. Degree of regeneration

There is inverse relation of specific reboiler duty and degree of regeneration when strength of MEA solvent is varied. As MEA concentration in the solvent is increased, the absorption capacity of solvent is increased with increase in molecules of MEA which results in more absorption of CO_2 from flue gas as shown in Figure 7. Increased concentration of MEA in solvent ensures higher rich loading and which results in increased difference of rich and lean loading and hence degree of regeneration increases. The percentage of captured CO_2 in the stripper is increased making the stripping easier and as a consequence the reboiler duty of the stripper is reduced.
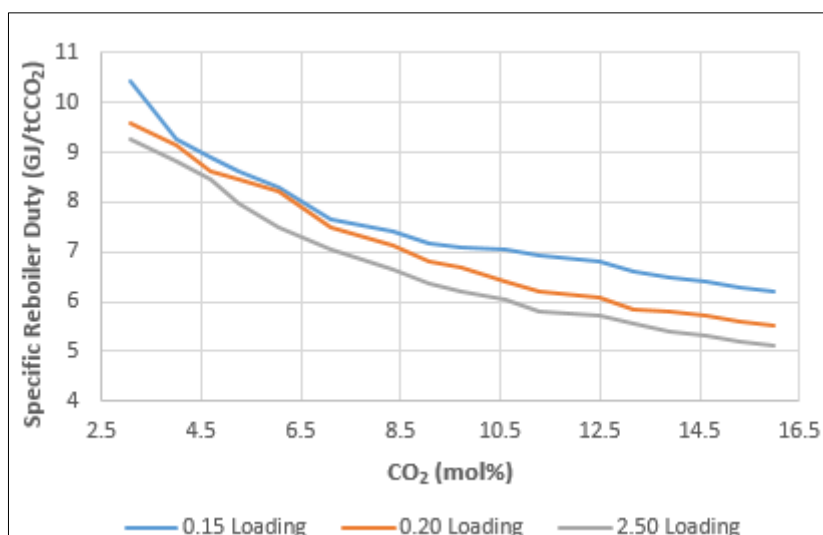
Figure 8. Effect concentration of CO_2 on specific reboiler duty

3.4. CO_2 Composition in flue gas

Specific reboiler duty decreases with increase in CO_2 partial pressure in the flue gas as given in Figure 8. The CO_2 contents in flue gas is varied in range of 3 - 16 mol %. Figure 8 shows three curves that are classified as variance in solvent loadings. For each loading, CO_2 partial pressure is varied and other process parameter are kept constant as given in Table 7.

3.4.1. Impact of CO_2 concentration on L/G ratio

Increase in CO_2 content increases the partial pressure of CO_2 in flue gas, resulting in the higher flow rate of the solvent. Hence, the increase in the CO_2 concentration requires more solvent molecules to absorb them. For the case of 0.15mol CO_2/mol MEA loading the solvent flow rate is in range of 85-210 kg/hr as CO_2 concentration in flue gas is varied from 3 mol% to 16 mol%. An increase of 60 % is noted for the loading of 0.15 mol CO_2/mol MEA. As solvent loading is further increased to 0.20 molCO_2/mol MEA, the required flow rate is varied further from 160 kg/h for 3 mol% to 406 kg/h for 16 mol% CO_2 for the flue gas. Again, the increase in flow rate of solvent is around 60 %. Hence, the increase in the solvent CO_2 loadings due to increase in the CO_2 concentration in the flue gas results in increased flow rate of the solvent.

Table 7. Process variables for varying CO_2 concentration in flue gas

Process variables	Rages
CO_2 partial pressure (mol%)	3-16
Flue gas mass flow (kg/h)	72
Desorber pressure (bar)	2
CO_2 removal rate (%)	85
MEA weight % (g/g)	30
Lean Loadings (mol CO_2/mol MEA)	0.15-025

3.4.2. Impact of CO_2 concentration on specific reboiler duty

CO_2 concentration in flue gas is plotted against specific reboiler duty in Figure 8. The drop in the specific reboiler duty is mainly due to the increased concentration of CO_2. As CO_2 concentration is increased, the partial pressure of CO_2 is also increased which act as a driving force for the absorption reaction with MEA solution. More CO_2 is absorbed in the solvent making it easier to strip it out [10]. Akram et al. [20] performed experiments of CO_2 concentration starting with 4.5 mol % CO_2 keeping the flow rate of solvent fixed and the CO_2 capture rate was varied. However, in current study the CO_2 capture rate is fixed at 85 %, so solvent flow rate is varied to capture the required amount of the CO_2, therefore

in both cases the reboiler duty shows same trends as CO_2 concentration is increased from 3 mol % to 16 mol %.

When solvent lean loading is increased and the MEA weight percentage is fixed then the water content in the solvent streams is reduced. Increased CO_2 concentration and less water content in rich solvent results in lower specific reboiler duty [20]. Increase in CO_2 concentration require higher flow rate of solvent to absorb the CO_2 from flue gas. So, the reboiler duty is increased with increase in the solvent flow rate. However, the captured CO_2 flow rate is increased further and as a result the specific reboiler duty is reduced.

For 3 mol % CO_2 in flue gas the specific reboiler duty is 10.44 GJ/tCO_2 using the solvent of 0.15 mol CO_2/mol MEA lean loading while it is decreased to 9.66 GJ/tCO_2 using 0.209 mol CO_2/mol MEA lean loading. Reduction of 7.47 % in specific reboiler duty is observed when solvent loading is increased from 0.15 to 0.209 mol CO_2/mol MEA. So, 0.25mol CO_2/mol MEA offers further reduction in specific reboiler duty.

3.4.3. Impact of CO_2 concentration on degree of regeneration

Degree of regeneration is related with ease of separation that ensures less reboiler duty. As more molecules of CO_2 are available to absorb in given the quantity of MEA solvent, the rich loading tends to increase. Increase in rich loading offers higher difference between rich and lean loading which results in escalated degree of regeneration. With increase in the lean loading of the solvent the capacity to absorb CO_2 from the flue gas is decreased and as a result the rich loading does not have the same potential to go as high as in previous scenario of lower lean loading. In Figure 9, it is clear as the lean loading 0.15-0.25 mol CO_2/mol MEA changes, the amount of the CO_2 captured and degree of regeneration is reduced. The degree of regeneration at 0.15 mol CO_2/mol MEA is 54 % at 3 mol % CO_2 in flue gas, however, in the case of 0.25 mol CO_2/mol MEA, it is only at 18 % while CO_2 concentration in flue gas is kept as above.

4.Conclusions

The process simulation model is successfully developed in ASPEN PLUS and clearly replicate the experimental results of post combustion CO_2 capture process at pilot scale level. The error between simulated and experimental values is under 5 % overall for lean loading, capture rate, rich loading and reboiler duty. Work performed in the present research includes a wide range of CO_2 emissions from different sources i.e. natural gas fired power plant, exhaust gas recycle and coal fired power plants. Process simulation performed clearly point out the effects of lean loading, stripper pressure, MEA concentration and CO_2 concentration in the flue gas on energy requirement of reboiler and degree of regeneration using MEA as a solvent. The conclusions from the present research can be summarized as below:

-Reduction of 7.47 % in specific reboiler duty is observed when solvent loading is increased from 0.15 to 0.209 mol CO_2 /mol MEA.

-The specific reboiler duty is reduced 30% as MEA weight percentage is increased from 20 to 40 (g/g).

-The specific reboiler duty is reduced 60 % as stripper pressure is increased from 1-3 (bar).

-With increase in lean loading and CO_2 concentration results in the decrease of the specific reboiler duty. Therefore, the specific reboiler duty will be less for the coal-fired power plant in comparison to the natural-gas fired and exhaust gas recycled power plants, keeping the flowrate of the flu e gas constant.

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