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Optimization of an Existing 130 Tonne per Day CO_2 Capture Plant from a Flue Gas Slipstream of a Coal Power Plant

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Abstract

An optimization study has been conducted on an existing 130 tonne per day carbon dioxide capture plant. A rate-based modelling approach is used to simulate the performance of the CO_2 capture plant using actual plant process flow-sheet and operating parameters. The average absolute deviation of the predicted parameters from the measured parameters is within 8%. The developed rate-based model is then used to plan the operating conditions for optimum utilization of the resources. Based on the results obtained from the process optimization, it is possible to minimize the operating cost and enhance the production capacity of the CO_2 capture plant at minimum additional investment.

keywords: CO_2 capture plant, rate based modelling, optimization, coal power plant, food grade CO_2

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1. Introduction

An optimization study has been carried out on an existing 130 TPD CO_2 capture plant. The CO_2 technology implemented in this plant is based on a conventional process configuration using 16-17 wt% MEA) solvent. A slipstream of 5-6% of the flue gas is being taken from the coal power plant and sent to CO_2 capture plant through two blowers operating at 60% capacity. The flue gas enters the CO_2 recovery facility at the flue gas scrubber in order to reduce the sulfur dioxide (SO_2) concentration to less than 10 ppmv. The flue gas is further cooled to 40 ºC before entering the amine absorber column. The major equipment in the plant include SO_2 scrubber, flue gas cooler, CO_2 absorption column, solvent stripper column, solvent reclaimer, and filtration system. The captured CO_2 is then sent to the purification and liquefaction package for food grade applications. Table 1 provides a brief description of the

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absorber/stripper dimensions and internals. The primary objective of this work is to build a rate based model that has the capability to predict the actual behaviour and performance of the CO_2 capture plant. Subsequent to this simulation, the model is used to plan the operating conditions for optimum utilization of the available resources; material, utilities, and unit capacities. The first phase is to increase the capacity and/or minimize the operating cost of the plant at no additional expenditures. In the second phase, the rate based model is used to explore the feasibility of altering the solvent concentration and/or the existing equipment to enhance further the production capacity and/or further minimizing the operating cost.

Table 1 Absorber/stripper dimensions and internals.

Process equipment	**Absorber**		**Stripper**	
Number of Unit	1		1	
Unit operator	**Absorber**	**Wash section**	**Stripper**	**Reflux Section**
Packing Type	Polypropylene Ring	Polypropylene Ring	Valve Type	Valve Type
# of Trays	-	-	22	4
Tray Spacing, m	-	-	0.762	0.762
Packing Size, mm	50.8	25.4	-	-
Column Diameter, m	2.90	2.90	2.60	2.60
Packing Height, m	6.85	3.00	-	-
# of packed bed section	2	1	-	-
Weir Height, mm	-	-	50.8	50.8
Number of pass	-	-	1	1

2. Model validation

For the purpose of this study, a rate based modeling approach is used to simulate the performance of the CO_2 capture plant using actual plant data collected during the plant visit. The non-equilibrium stage approach or, what could be called rate based approach, for absorption/stripping process simulation is recommended for complex and non-ideal systems such as amine treatment plants [1–3].The plant data collected are shown in Table 2, which are the main operating conditions used to simulate the actual behavior of the plant. The simplified process flow diagram of the plant, which has been used to setup the rate based model is shown in Figure 1. Using the rate based model, the material balances for the major streams of the CO_2 plant are produced and presented in Table 3.

Table 4 shows a comparison between actual plant data and modelling results. The average absolute deviation of the main predicted parameters from the measured parameters is within 8%. Large deviation can be noticed between the measured and predicted data of the off-gas composition and reflux water volumetric flow rate. The deviations in the off gas composition could be attributed to the gas analysis for different runs at different operating conditions. The cause of the large deviation between the predicted and measured reflux water flow rate is not known for the time being.

Table 2 CO_2 Capture Plant Data

Input Data	Unit	
Solvent Type	-	MEA
Lean amine Concentration	wt%	16-17
Lean amine Temperature	^{o}C	40.60
HSS Content	wt%	0.30
Solvent Circulation Rate	m^3/hr	153
Wash Section Circulation Rate	m^3/hr	123
Wash Section Make up	m^3/hr	1.59
Inlet flue gas composition		
CO_2	vol%	12.50
O_2	vol%	7.04
N_2	vol%	74.37
H_2O	vol%	5.98
H_2	vol%	0.009
CO	vol%	0.019
He	vol%	0.085
Inlet flue gas Temperature	^{o}C	38.10
Inlet flue gas pressure	bar	1.12
Steam flow rate to reboiler	kg/hr	17,460
Steam conditions at reboiler	bar	3.77

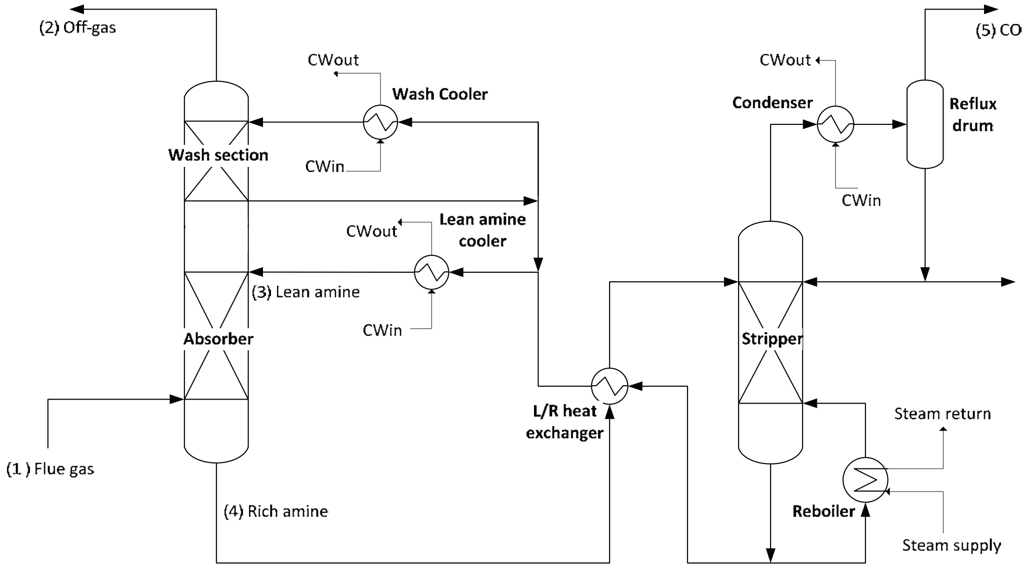

Figure 1: Simplified Process Flow Diagram of the CO_2 Capture Plant

Table 3 Material Balances of the CO_2 Capture Plant

Stream	**Unit**	**1**	**2**	**3**	**4**	**5**
Stream name		**Flue gas**	**Off-Gas**	**Lean amine**	**Rich Amine**	**CO_2 Product**
Water	mol %	5.97	6.43	94.09	92.61	3.76
CO_2	mol %	12.50	0.40	0.53	2.10	96.20
MEA	mol %	0	1.662E-05	5.315	5.228	0
Hydrogen	mol %	9.40E-03	1.07E-02	1.84E-09	9.67E-08	5.89E-06
Helium	mol %	8.46E-02	9.67E-02	8.61E-09	4.73E-07	2.88E-05
CO	mol %	1.88E-06	2.15E-06	3.93E-13	1.87E-11	0
Nitrogen	mol %	74.38	85.01	1.08E-05	5.24E-04	3.19E-02
Oxygen	mol %	7.04	8.05	1.93E-06	9.09E-05	5.54E-03
Heat Stable Salts	mol %	0	0	6.21E-02	6.11E-02	0
Temperature	^oC	38.00	39.00	40.5	56.5	30
Pressure	bar a	1.12	1.10	1.10	1.124	1.138
Mass Flow	kg/hr	30,110	24,610	157,700	163,200	5,522
CO_2 loading	mol/mol			0.101	0.402	

Table 4 Comparison between actual plant data and. modelling results

	Plant Data	**Modelling Results**	**% Deviation**
Lean Loading (mole of CO_2/mole of amine)	0.110 (avg.)	0.101	8.18
Rich Loading (mole of CO_2/mole of amine)	0.411 (avg.)	0.402	2.19
Rich Amine Discharge temperature from absorber bottom (^oC)	57.22	56.67	0.74
Off-gas Temperature (^oC)	40	38.89	1.92
Steam Consumption (kg/hr)	17,460[1]	17,240	1.30
Reflux Water Volumetric Flow (m^3/hr)	3.63-4.08	1.32	78.24
CO_2 Production (tph)	125.2	130.4	4.17
Off-gas Composition [vol%]			
CO_2	0.223	0.399	78.92
O_2	5.762	8.050	39.69
N_2	87.315	85.014	2.64
H_2O	6.672	6.430	3.62

[1] Steam flow rate to reboiler is before de-superheater.

3 Plant Optimization without Additional Investments

This section describes the optimization scenarios for optimum utilization of the existing plant resources. The plant operation is optimized without any change in plant configuration or equipment modification. The following two optimization approaches have been explored.

3.1 Optimizing the plant operating parameters to reduce operating cost

In this approach, several simulation runs were carried out to find the optimum lean-rich approach at the corresponding optimum recirculation rate and steam flow rate. Table 5 represents the optimum operating conditions for two cases. In the first case, the steam requirements can be reduced from 17,240 to 14,970 kg/hr when the plant is operated at a 0.173 mol/mol lean loading instead of a 0.101 mol/mol loading. The saving in this case amounts to 13% reduction in steam flow rate requirements while maintaining the current plant production capacity.

In the second case, the plant can be operated at 128.3 m^3/hr instead of 159 m^3/hr while maintaining the same production capacity. The steam requirement in this case will be reduced from 17,240 to 13,610 kg/hr because of the working capacity of the solvent is increased from 0.301 to 0.361 mol/mol at optimum lean/rich approach. This approach will reduce the power required for solvent circulation by 19% and steam requirement by 21%.

Table 5: Optimum lean loading, recirculation rate, and steam flow rate

Model	**Lean Loading** (mol/mol)	**Rich Loading** (mol/mol)	**Recirculation Rate** (m^3/hr)	**Steam Flow** (kg/hr)	**Unit Steam Consumption** (kg/kg)
Base Model	0.101	0.402	159.0	17,240	3.17
Case 1	0.173	0.461	159.0	14,970	2.86
Case 2	0.106	0.467	128.3	13,610	2.59

3.2 Increasing the production capacity of plant using the current available resources

Since the plant blowers are operated at 60% capacity and the existing columns are underutilized, it is possible to increase the production capacity of the plant using the existing resources. The flue gas rate to the capture plant can be increased by 30% without violating the main design parameters such as the flooding factor within the absorption column. Figure 2 shows the increase in production capacity with respect to flue gas flow rate while keeping the other current operating parameters unchanged; solvent concentration of 16 wt% MEA, solvent recirculation rate of 159 m^3/hr, and steam flow rate of 17,240 kg/hr. Increasing flue gas rate by 30% will increase CO_2 production by an additional 28 TPD at specific steam consumption of 2.61 kg/kg, instead of the current specific steam consumption of 3.17 kg/kg. In contrast, blower power consumption will increase because of the higher gas flow rate. Chemical consumption and cooling duty requirement will also increase in order to achieving current absorber flue gas inlet for SO_2 concentration and temperature.

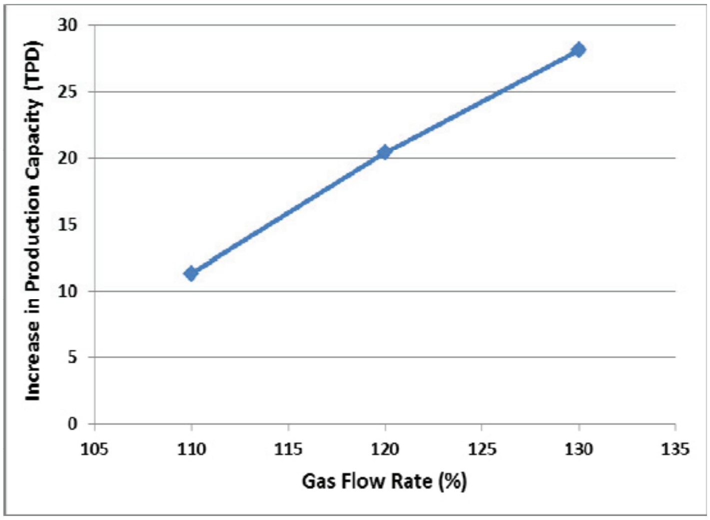

Figure 2: Increase in production capacity with respect to flue gas flow rate

4 Optimum Plant Operation by altering the solvent concentration and/or existing equipment

This section describes the feasibility of altering the solvent concentration and/or packing of the absorber column to further enhance the production capacity and/or further minimizing the operating cost. The following two optimization approaches have been explored:

4.1 Changing Solvent concentration from 16 to 20 wt%

In this approach, the solvent concentration was changed from 16 to 20 wt% in order to explore the effect of this change on the plant performance. For comparison purposes, approximately same flue gas flow rate and production capacity were maintained for 16 and 20 wt% cases.

As shown in Table 6, the 20 wt% case results in better performance than the 16 wt% cases; the base case and the optimized case. For the same production capacity, the optimized 20 wt% case will require 25% less solvent circulation rate as compare to 16 wt% optimized case, this will further reduce the power required for solvent circulation pumps by 25% as compare to 16 wt% optimized case.

Table 6: Performance comparison of 20 wt% versus 16 wt% solvent

Model	**Rec. Rate** (m^3/hr)	**Steam** (lb/hr)	**L/L** mol/mol	**R/L** mol/mol	**W/C** mol/mol
16 wt% (Base Case)	159	17,240	0.101	0.402	0.301
16 wt% (Optimized)	128.3	13,610	0.106	0.467	0.361
20 wt% (Optimized)	96.53	13,610	0.100	0.479	0.379

4.2 Changing Absorber column packing from 2 inch Polypropylene ring to IMTP40 and increasing flue gas flow rate

In this approach, we have compared 2-inch Polypropylene Ring (Base Case) with proposed more efficient IMTP40 packing while increasing the flue gas flow rate by 30% without violating the main design parameters such as flooding factor within the absorption column. As shown in Figure 3, changing the absorber column packing from 2-inch Polypropylene ring to IMTP40 and increasing the flue gas flow rate by 30% will increase plant production capacity by 38 TPD as compare to base case, and 10 TPD as compare to 2-inch Polypropylene ring at 130% flue gas flow rate. Also, as shown in Figure 4, changing the absorber column packing from 2-inch Polypropylene ring to the proposed IMTP40 and increasing the flue gas flow rate to 130%, will reduce the unit steam consumption from 3.17 to 2.46 kg/kg.

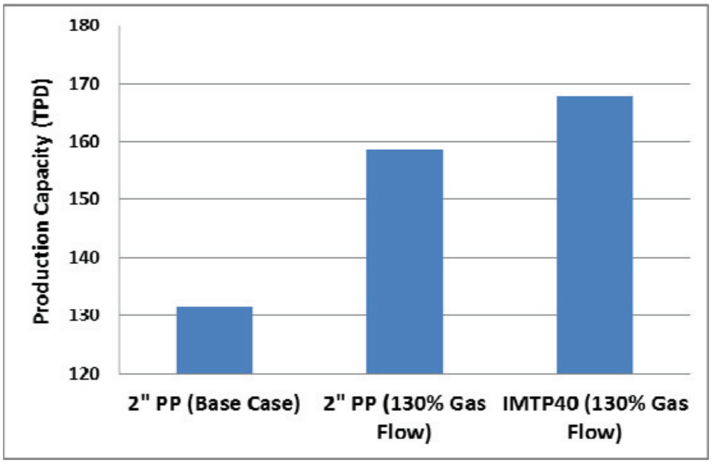

Figure 3: Increase in production capacity by changing the packing and the flue gas rate

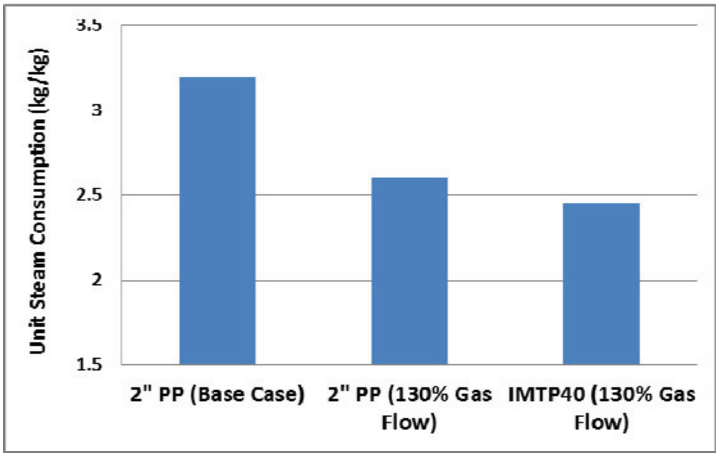

Figure 4: Reduction in unit steam consumption in proposed IMTP40 case as compare to 2-inch Polypropylene Ring (Base Case)

3. Conclusion

For the current CO_2 production capacity, the optimum solvent rate is 128.3 m^3/hr, instead of 159 m^3/hr, while maintaining the same production capacity. This can be achieved by increasing the solvent working capacity from 0.301 to 0.361 mol/mol. This will reduce the specific steam consumption from 3.17 to 2.59 kg/kg and the power requirement of re-circulating pumps by 19%. No additional capital expenditure is required to achieve these benefits.

Changing the solvent concentration from 16 to 20 wt% will reduce the solvent circulation rate by 40% and steam requirement by 21%. This will significantly reduce the operating expenses of the plant without any additional capital expenditure.

As the blowers are operating at 60% capacity, increasing gas flow rate up to 30% within the hydraulic capacity of the absorber will increase the production capacity by 28 TPD.

Changing the absorber column packing from 2-inch pall ring to high performance IMTP40 and increasing flue gas rate by 30% will increase production capacity by 38 TPD. Specific steam consumption for IMTP40 packing will be 2.46 kg/kg instead of 3.17 kg/kg for the 2-inch pall ring (Base Case).

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4. References

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