

Performance Analysis of a Laboratory Carbon Dioxide Absorption Setup Using Aqueous Monoethanolamine Solution

Naruphol Janwiruch, Thananat Lungkadee, and Nakorn Tippayawong

Abstract—Electricity Generating Authority of Thailand is the largest power producer in Thailand, owning and operating power plants at 45 sites across the country. With forthcoming global climate crisis, current effort in improving energy efficiency and adopting alternative sources of energy may not be sufficiently rapid. Post-combustion carbon capture with amine based solutions is a well-established technology and offers a further option in reducing carbon dioxide emissions from existing power plants. In this work, a laboratory-scale, amine based CO₂ absorption setup was developed and its performance test was carried out, using Monoethanolamine at 30% concentration handling flue gas conditions similar to those from Mae Moh power plant. The preliminary results revealed high carbon capture efficiency (>97%) could be achieved in a continuous operation.

Index Terms—Amines, chemical absorption, CCS, decarbonization, power generation.

I. INTRODUCTION

The situation on the current world CO₂ emissions is still on a continuous ascending trend, mainly due to the use of fossil fuels. This is an important catalyst causing the accumulation of greenhouse gases in the atmosphere and ultimately resulting in potential risk of severe climate change throughout many regions of the world.

Electricity Generating Authority of Thailand (EGAT) is the largest power producer in Thailand, owning and operating power plants at 45 sites across the country. Mae Moh power plant is located in the north and is the biggest coal-fired thermal power plant in Thailand. There are a total of seven units with overall gross capacity of 2455 MW.

The thermal power plant uses lignite from the Mae Moh mine as fuel. The burning process occurs in a boiler that produces steam with high pressure and temperature to drive the turbines and generators, and in the coal combustion process, ash, carbon dioxide, and sulfur dioxide are emitted. The fly ash is trapped by an electrostatic precipitator while sulfur dioxide is treated by a flue gas desulfurization system before being released into the atmosphere. So far, carbon dioxide is also released without any treatment.

Carbon capture and storage (CCS) is a novel technology for EGAT in dealing with carbon emissions. Post-combustion carbon capture with amine based solutions is a well-established technology [1]. An aqueous solution of

30wt% MEA, a standard solvent used in the actual CO₂ capture plant, was usually utilized where the advantages are high absorption rate and capacity [2]-[6] indicated the relationship of important parameters occurring in the absorption system including the height of the absorber that affects the percentage of CO₂ capture efficiency and rich CO₂ loading, the height of the stripper that affects the power for separation of CO₂ from the MEA solution and lean CO₂ loading that affects heat for reboiler. From other research results [6]-[8] other important variables of interest such as flue gas temperature, absorber temperature and pressure were also considered.

Research and reports [7], [8] can summarize the factors suitable for the operation of the carbon dioxide capture process as follows in Table I.

TABLE I: OPTIMIZED FACTORS FOR THE PERFORMANCE OF CARBON DIOXIDE CAPTURE PROCESS

Parameter		Unit
Flue gas temperature	40-50	°C
Temperature in absorber	40-60	°C
Pressure in absorber	1	atm
Temperature in stripper	100-120	°C
Pressure in absorber	1.5-2	bar
MEA concentration	30	%
Lean CO ₂ Loading	~0.20 - 0.22	mol CO ₂ /mol MEA
Rich CO ₂ Loading	~0.4 - 0.5	mol CO ₂ /mol MEA

This research aimed to setup and carry out performance testing of a laboratory carbon capture system including absorber and stripper for treating gas with similar conditions to the Mae Moh power plant flue gas (shown in Table II). [9]

An aqueous solution of 30wt% MEA, a standard solvent used in the actual CO₂ capture plant, was utilized.

TABLE II: MAE MOH POWER PLANT'S FLUE GAS COMPOSITION

Parameter		Unit
Ambient pressure	744	mmHg
Ambient temperature	30.0	°C
Type of fuel	Coal	
Stack temperature	72.2	°C
Moisture	21.96	%
Oxygen	5.3	%
Carbon dioxide	15.3	%
Gas velocity	19.8	m/s
Gas flow rate	1284242	Nm ³ /hr

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II. EXPERIMENTAL

A. Laboratory Setup

The test bed consists of an absorber column to capture CO_2 where the absorber is made from stainless steel consisting of two 1-m high packed beds packed with bio-balls. The diameter of packed column is 160 mm while the stripper size is the same as the absorber and is packed with many screen nets arranged in layers. The distance between each layer is 5 mm. The schematic diagram and picture of the laboratory setup are shown in Fig. 1 and Fig. 2.

The gas flows from N_2 and CO_2 cylinders are controlled by ball valves which then flows to a gas mixing chamber to mix both gases before feeding them to the absorber column. The lean solvent is fed into the column at the top of absorber via a chemical pump. The CO_2 -rich solvent flows down into the rich solvent tank where it is pumped through a pre-boiler to raise its temperature to 110°C before feeding it to the top of the stripper. The hot rich solvent then moves down to the lower part of the stripper and its temperature is maintained by a heater wrapped around the lower part of the stripper column. At the stripper, the CO_2 is carried upwards. High purity CO_2 is released at the condenser and finally, the remaining hot lean solvent at the outlet of stripper flows into the lean solvent tank.

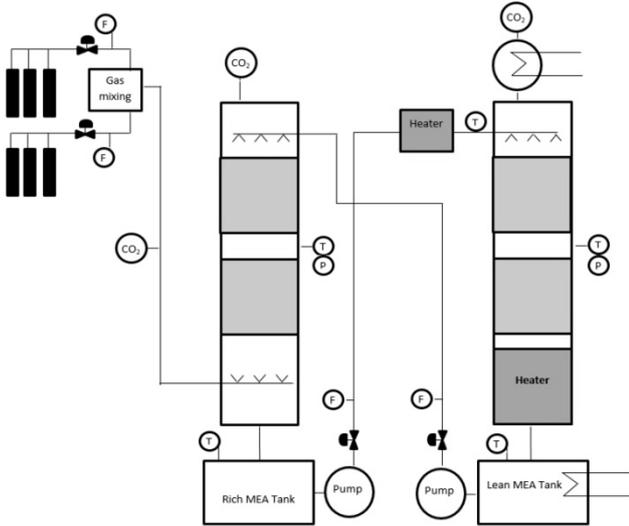


Fig. 1. Schematic diagram of laboratory scale carbon capture system.

B. Experimental Test Conditions and Procedure

The procedure of this experimental campaign is depicted in Fig. 3, to run the system and test the performance and efficiency of the laboratory-scale carbon capture system. This system was affected by many parameters. Appropriate parameters for the operation of the carbon capture process are shown in Table III. The research test variables included the absorber packed height, the lean CO_2 loading and the regeneration temperature. The experiment started with the preparation of the 30% MEA solution. Then the CO_2 sensors were connected with the Gaslab v2.2 for preparing the 15% CO_2 gas, after which all pumps were run and the solution began to absorb CO_2 and fully circulate it in the system and lastly, the heater and condenser were operated. Resulting data were collected with the system running continuously.

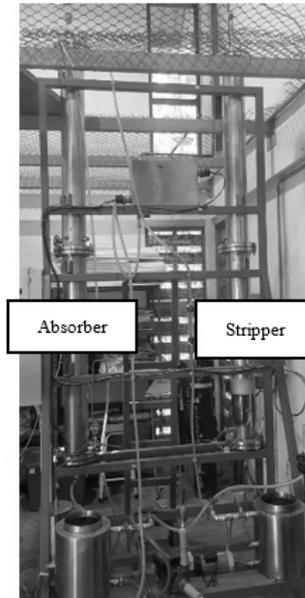


Fig. 2. Picture of laboratory scale carbon capture system.

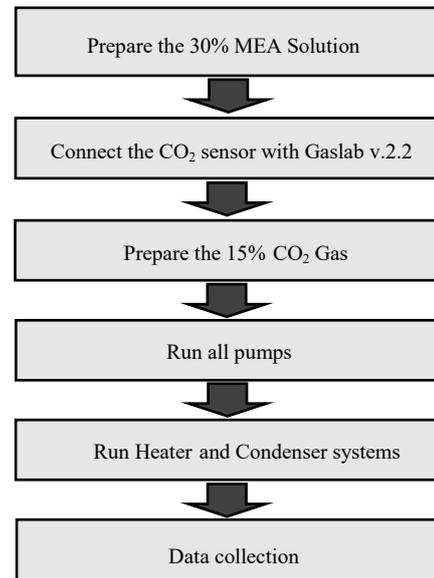


Fig. 3. Experimental procedure.

TABLE III: TEST CONDITIONS AND PARAMETERS USED

Parameter		Unit
Flue gas temperature	40	$^\circ\text{C}$
Absorber temperature	40	$^\circ\text{C}$
Absorber pressure	~ 1	atm
Stripper pressure	1.5	bar
Regeneration temperature	110, 120	$^\circ\text{C}$
MEA concentration	30	%wt
Absorber packing height	50 - 100	%
Lean CO_2 Loading	0.25 - 0.5	mol CO_2 /mol MEA
Rich CO_2 Loading	0.25 - 0.5	mol CO_2 /mol MEA

Gas sampling were carried out at various locations, including the inlet of the absorber, the outlet of absorber and the outlet of the stripper during which the process must be stable. All sampling points were mounted with the CO_2 sensing kit from CO_2 Meter Inc. The accuracy of the sensor was within ± 70 ppm. Fig. 4 shown real time CO_2 gas after lean solvent absorb CO_2 from flue gas.

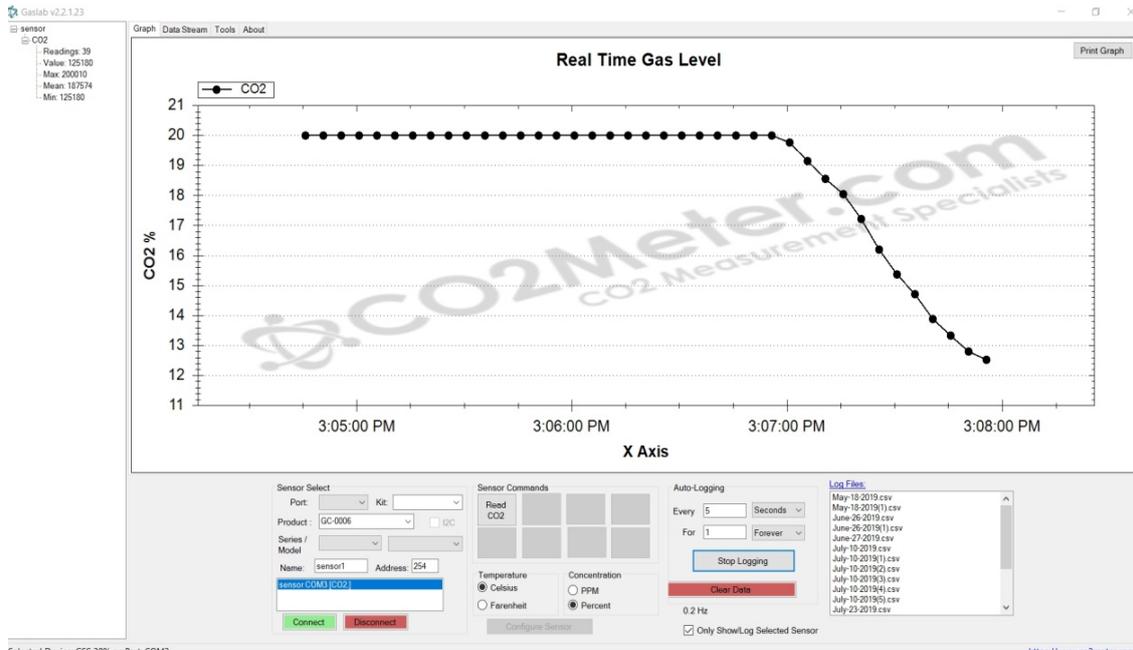


Fig. 4. Real time CO₂ gas from Gaslab.

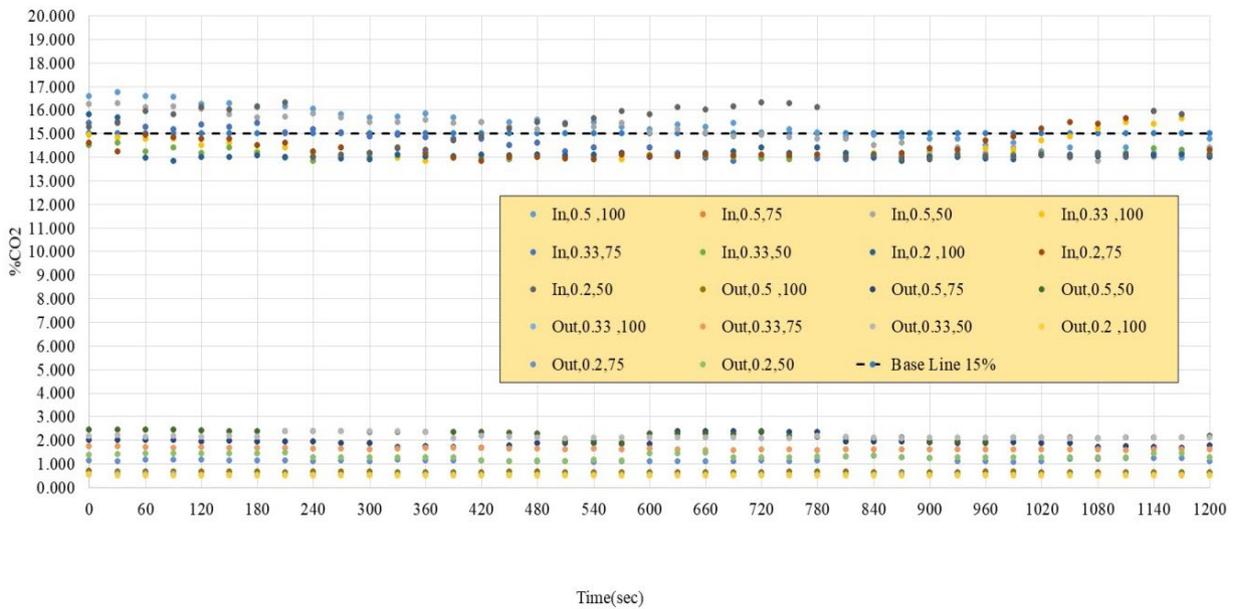


Fig. 5. Evolution with inlet and outlet CO₂ concentrations of the absorber.

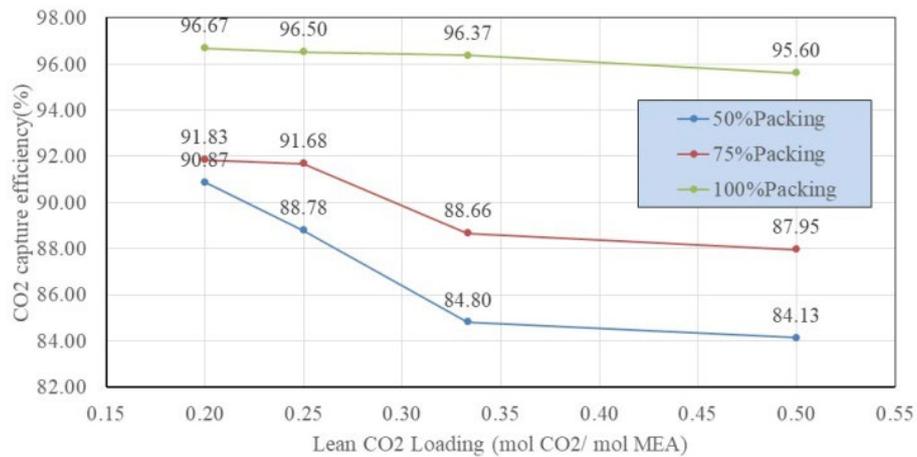


Fig. 6. Variation of CO₂ capture efficiency with different packing height and lean CO₂ loading.

C. Data Analysis

The experimental gas contained 15% CO₂ that flowed through the absorber packed column. In the absorber, the rising gas reacted with the lean amine solution flowing downwards. The amine then absorbed CO₂ from the gas via a chemical reaction, then the treated gas exited from the top of absorber. The efficiency of CO₂ capture was calculated from the proportion of CO₂ at the outlet of absorber to the CO₂ at the inlet of absorber.

$$\text{Capture Eff} = \frac{CO_{2,feed} - CO_{2,out}}{CO_{2,feed}} \quad (1)$$

The process used a chemical solvent that can be regenerated for continuous processing where the regeneration energy of the rich solvent was derived from thermal energy and was composed of solvent heat up energy, water vaporization energy and desorption energy.

$$Q_{reboiler} = Q_{solvent\ heating} + Q_{vaporization} + Q_{desorption} \quad (2)$$

III. RESULT AND DISCUSSION

After I complete the laboratory scale of absorber tower section. This paper will test about the absorption efficiency of the absorber tower by 9 conditions (shown in Table IV).

TABLE IV: ABSORBER TEST CONDITIONS

Absorber packing height	Lean CO ₂ Loading	
50%	0.2	mol CO ₂ Per mol MEA
	0.33	
	0.5	
75%	0.2	
	0.33	
	0.5	
100%	0.2	
	0.33	
	0.5	

The test results of the carbon absorption experiments are shown in Fig. 5 and Fig. 6. Fig. 5 shows variation of inlet and outlet CO₂ concentrations of the absorber with time for all test cases considered. The input CO₂ was rather constant at about 15 ± 1.5 %, while the outlet concentrations were fluctuated between 0.5 – 2.5%. Fig. 6 illustrates changes in capture efficiency with packing height and lean CO₂ loading. From the experiment, it was found that the efficiency was between 95-96.7% at full packing height. Higher CO₂ loading led to reduction in capture efficiency. For the effect of packing height, the capture efficiency was reduced markedly when the packing height was decreased from 100%, to 75% and 50%.

IV. CONCLUDING REMARK

Post combustion carbon capture is a promising technology

for EGAT Mae Moh power plant. A conceptual study was carried out in a laboratory scale for CO₂ absorption process using aqueous monoethanolamine solution. The capture efficiency was high, but further tests with other parameters and operating conditions are needed. Amine based absorption of carbon dioxide appeared to be robust and ready for larger scale testing.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

AUTHOR CONTRIBUTIONS

This paper contributes to the tasks of author Dr. Nakorn Tippayawong (Adviser): analysis, writing, translation, drafting, and author Naruphol Janwiruch (Undergraduate) is responsible for data simulation, debugging, and collation. All authors have approved the final version.

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