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IMPACTORS EVALUATION OF MEA-BASED CO_2 CAPTURE IN CEMENT INDUSTRY

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ABSTRACT

The development of CO_2 capture became great of importance in recent years. Apart from reducing the emissions from power generation sector, capturing CO_2 from industrial flue gas has not been a popular topic, especially in the cement industries which is quite energy intensive and a main resource of anthropogenic CO_2 emission in industries. The main purpose of this work was to systematically conduct techno-economic analysis of CO_2 capture based on MEA technology, in which the impactors such as the flue gas flow rate, flue gas CO_2 concentration and CO_2 recovery rate were studied with the commercialized software Aspen Plus. Meanwhile, the concentration of MEA solutions was studied. The results indicate that 20% MEA is more suitable for practical application. The CAPEX is more sensitive to these selected impactors than OPEX, but still OPEX dominates the major change in the overall cost. In addition, the gas flowrate and CO_2 concentration are the major impactors affect the cost rather than the CO_2 recovery rate.

Keywords: Carbon capture, CO_2 mitigation, MEA, Economic evaluation, Process simulation, Aspen Plus

NONMENCLATURE

Abbreviations	
ATC	Annualized total cost
CAPEX	Capital investment cost
CCS	Carbon capture and storage
GHG	Greenhouse gas
LF	Large flowrate
MEA	Monoethanolamine
MF	Medium flowrate
OPEX	Operational cost
REC	CO_2 recovery rate

Symbols	
i	Interest rate
N	Year
$M_{CO_2 total}$	Mitigated total CO_2 amount

1. INTRODUCTION

In terms of global climate change and temperature rise, solutions to reduction of greenhouse gas emission are of more importance. Particularly, CO_2 emissions, which account for 76% of total anthropogenic greenhouse gas emissions, is the major concern of reducing the climate change effect. Apart from the CO_2 emissions from fossil-fuel power plants, cement industry contributes about 5% of global anthropogenic GHG emissions, which is roughly 30% of industrial emissions[1]. This makes it important to concern the CO_2 emissions from cement industries.

In the cement industry, the CO_2 concentration in flue gas is normally between 10-30 mol%, and the rest of the gases are mainly N_2, O_2, H_2O.[1-2] However, the main carbon footprints trace from different sources and stages: approximately 50-60% of the total CO_2 emissions come from the calcination process, and the rest 40-50% percentage of CO_2 emissions comes from the fuel combustion for heat and electricity supply. This unique feature imposes more considerations when selecting the capture technologies.

The most techno-economic promising processes which have the potential to be implemented in the near future are pre-combustion capture, oxy-fuel combustion and post-combustion capture.[3] However, pre-combustion capture and oxy-fuel combustion capture have their limitations when applying in cement industry. In post-combustion CO_2 capture, chemical absorption methods is a well-studied thermal separation process and was already used in many chemical processes.[4]

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Moreover, this capture technology has its end-of-pipe advantage, which means it can be deployed with the target plant without significantly affecting the operation of the plant.[5] Although the post-combustion technology owns the drawbacks such as high energy penalty, it is still the most promising solution in short-medium terms to deal with the climate change issues.

The published articles regarding carbon capture and storage (CCS) mainly focused on power station. In cement industry, work has been conducted on assessing the CCS feasibility, or developing CO_2 reduction strategy theoretically or practically; the techno-economic analysis has been performed, costs between different solutions extracted from power station sector have been compared and evaluated. One of the largest joint research project carried by a Norway cement manufacturer Norcem AS and European Cement Research Academy has been established to test various post-combustion technologies in small-scale for studying and comparing their suitability for practical implementation.[2, 6-9] However, nearly none of the research efforts focused on how the cost will be fluctuated if the flue gas conditions change due to the modification or evolution of cement plant. For instance, switching between in full or partial capacity will lead to different *flue gas flowrate*; modification of the production methods will change the *CO_2 concentration*; also the *CO_2 recovery rate* can vary significantly due to different environmental strategies and policies. All of the *impactors* mentioned above may have significant effects on the cost of capture plant, and it is unclear how will the cost vary due to these changes.

In this work, the MEA-based CO_2 capture process with rate-based model was simulated to study how different impactors affected the process performance. The specific research work includes (1) to systematically study the effect of impactors (flue gas flow rate, CO_2 recovery rate and CO_2 concentration in the flue gas), (2) to perform techno-economic analysis, and (3) to obtain benchmark results as the cornerstone for future techno-economic comparison with other commercial or new developed CO_2 capture solvents.

2. METHODOLOGIES

2.1 Process description

The MEA-based capture processes is sketched in Fig 1. The flue gas from cement plant firstly goes through a dehydration unit. The treated gas is then fed into absorber. In the absorption column, CO_2 is reactively absorbed by MEA solvent. The CO_2-rich solvent leaving the absorber is pumped into the internal heat exchanger, and then fed into stripping column. The CO_2-rich solvent is regenerated in stripper by heating steam. The CO_2 leaving from the top of the stripping column then flows into a series of compression units to reach a specified conditions for transportation, storage or utilization. The make-up stream which contains water and MEA is added into the recycle stream. All the required input parameters, including fixed and studied, are summarized in Table 1.

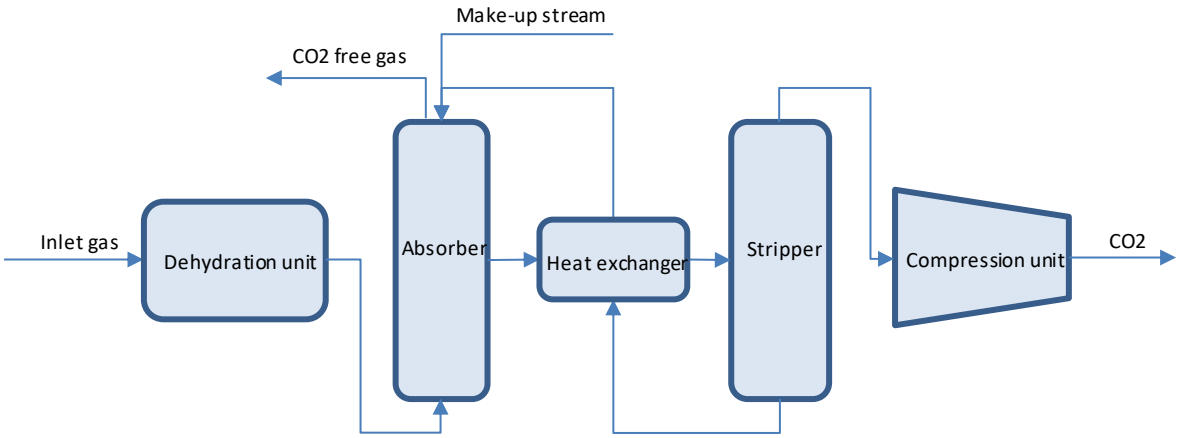

Fig 1 Schematic diagram of MEA-based CO2 capture process

2.2 Process simulation

Both of the columns were designed in equilibrium model and then switched to rate-based model which simultaneously models the mass and heat transfer rate phenomena with equilibrium and kinetic controlled reactions. Sensitivity analyses were then conducted by changing the packing height to calculate the necessary amount of lean MEA flow rate required and the minimum reboiler duty by varying the packing height.

To describe phase equilibrium, the electrolyte non-random two liquid model was used to describe the non-ideal behaviors for the liquid phase, and the Redlich-Kwong equation of state was chosen for the vapor phase. Both these two models have already been implemented in Aspen Plus and verified extensively.[10-12]

The widely used reaction mechanism described by *Freguia* and *Rochelle*[13] with three equilibrium reactions and two reversible kinetically controlled reactions[14] was adopted, and the corresponding parameters were taken from the work of *Austgen et al*.[15] as well as *Pinsent et al.* [16] and *Hikita et al*.[17]

In the rate-based simulation, the *Onda-68* correlation was selected to estimate both the mass transfer coefficient and interfacial area. The *Chilton and Colburn correlation* was applied to the heat transfer coefficient estimation. Packing hold-ups were calculated with the approach proposed by *Bravo et al*.[18]

2.3 Economic evaluation

The economic evaluation was conducted with Aspen Process Economic Analyzer. The annualized total cost (ATC) is a summation of operational cost (OPEX) and capital investment cost (CAPEX), and ATC per ton CO_2 captured was estimated with Eq 1.

$$ATC = \frac{OPEX + CAPEX\left(\frac{i(i+1)^N}{(i+1)^N - 1}\right)}{M_{CO_2 total}} \quad (1)$$

Table 1 Input parameters in process simulation

Input parameters	Values
CO_2 concentration	CO_2: 10%, 20%, 31.8%, 40%, 50% (wt%)
	O_2: 2.4wt%, H_2O: 4.2wt%, and the balanced N_2
CO_2 recovery rate	65%, 75%, 85%, 95% (mol%)
Gas flow rate	Large case: 252711 kg/hr
	Medium case: 126355 kg/hr
Flue gas condition	160 °C, at atmospheric pressure
CO_2 condition	30 °C, 150 bar
Inlet MEA condition	20 wt%, 40 °C, lean loading: 0.3 mol_{CO2}/ mol_{MEA}

In estimation, the interest rate *i* was set to be 10%, the operating life of the plant *N* was set to be 25 years. The US template was employed, and the plant operation time was assumed to be 8700 hours per year. Table 2 lists the energy and solvent prices used in OPEX calculation.

Table 2 Energy and solvent prices

Energy and solvent	Cost	Unit
Steam	6	$/GJ
Cooling water	0.35	$/GJ
Electricity	0.1	$/kWh
Refrigeration	4	$/GJ
MEA	1.3161	$/kg

3. RESULTS AND DISCUSSION

3.1 Effect of MEA concentration on specific energy

20 wt% and 30 wt% MEA solutions were selected as solvents since they were mostly used both in academic research and industrial applications. The effects of MEA concentration on absorber temperature and heat requirement of reboiler were studied. By decreasing the MEA concentration from 30 to 20 wt %, the overall temperature of absorber was significantly lowered, and the bulge temperature was reduced from 85 to 65 °C. Table 3 indicates 20 wt% MEA requires more solvent than 30 wt% MEA. In contrast, the specific heat requirement was lower with 20 wt% MEA. Since the bulge temperature was decreased drastically by lowering the MEA concentration, the high temperature effect was avoided. This phenomenon was also observed in the CO_2 rich loading difference. All these explain the advantages of lowering the MEA concentration. Therefore, 20 wt% MEA was selected for further study.

Table 3 Comparison of two MEA concentrations

MEA concentration (wt%)	Lean flowrate (kmol/h)	Specific energy ($MJ/kgCO_2$)	CO_2 rich loading (mol_{CO2}/mol_{MEA})
20	96566	3.95	0.553
30	73103	4.01	0.499

3.2 Cost estimation and comparison

The CAPEX and OPEX of all the studied cases (all the combinations of gas flowrates, CO_2 concentrations and CO_2 recovery rates) are depicted in Fig 2. Obviously, it can be concluded that, both CAPEX and OPEX decrease with: 1) increasing CO_2 concentration, 2) increasing recovery rate, 3) increasing gas flowrate. The individual study of each impactor on cost indicates that all of the three impactors have larger influence on CAPEX rather than OPEX in proportions. However, OPEX still dominates the total cost rather than CAPEX due to its much larger absolute value (approximately 3 times of CAPEX).

Therefore, a tiny change in the percentage of OPEX will affect much more than CAPEX in the absolute value.

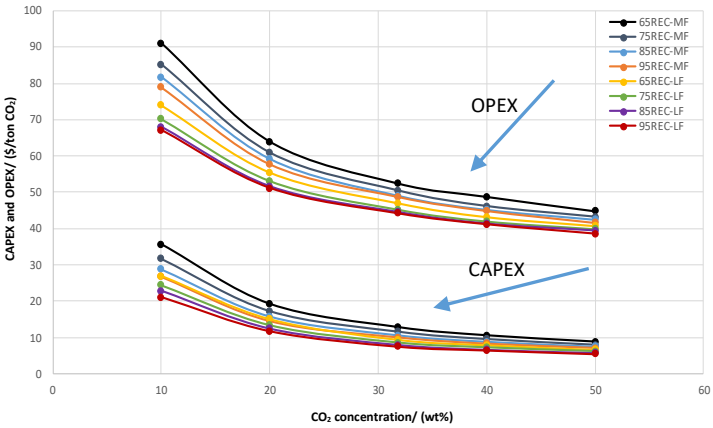

Fig 2 Annualized CAPEX and OPEX

4. CONCLUSIONS

The individual study of each impactor on cost indicates that the gas flowrate and CO_2 concentration are the most influencing impactors rather than the CO_2 recovery rate. However, it is hard to compare the influencing degree of each impactor studied in this work. The impactor varies in different magnitude when taken into practical consideration, for instance, the CO_2 concentration varies from 10 to 50 wt% (5 times) due to different cement production methods and configurations, while the CO_2 recovery rate cannot be too small (less than 50%) due to the purpose of carbon capture.

The conducted systematic techno-economic analysis about MEA-based CO_2 capture process in cement industry provides valuable economic data of the capture process with varied impactors. All of the MEA-based process data will be treated as a cornerstone, and further comparison will be made with others absorption solvent in the future work.

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