Rate-based simulation study of boric acid promoted potassium carbonate capture system

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Abstract. This study presents parametric analysis and process modification on a post-combustion carbon dioxide (CO₂) capture system using boric acid promoted potassium carbonate (K₂CO₃) solution. The model was simulated in Aspen Plus® V10 and ELECNRTL property package was employed. Un-promoted K₂CO₃ system was adopted as a base case study and its simulation was validated using literature data. The K₂CO₃ concentration in the lean solvent makeup was then varied from 25 wt% to 40 wt% to examine the effect of lean solvent concentration on key operating variables such as stripper reboiler duty, stripper condenser duty and CO₂ capture rate. A 2 wt%, 4 wt% and 6 wt% aqueous boric acid solutions were then added as promoter to the hot K₂CO₃ solvent and the simulation results indicated that capture rate efficiency can be enhanced by 0.7%, 0.9% and 1.2% respectively. Energy saving process modification was also carried out to the stripper column. Compared to the conventional unmodified H₃BO₃/K₂CO₃ system, the modified promoted system is able to achieve 21.09% savings in reboiler duty.

1. Introduction
The current alarming phenomena of global warming and global climate change are deemed to be as a result of increasing anthropogenic activities which are fatally contributing to the accumulative emission of heat-trapping (greenhouse) gases into the atmosphere [1]. Almost half of these greenhouse gases is believed to be carbon dioxide (CO₂), making it the single most predominant contributor to global warming [2]. The carbon emission from principal sources such as cement production and the combustion of coal, oil and natural gas, which are expected to keep increasing according to reports from the Global Carbon Project, are documented to be of major concern [3]. Among these industries, coal-fired power plants contribute to 30-40% of total CO₂ emissions. Hence, capturing CO₂ from the power plant flue gas has significant impact on controlling carbon emission [2,4].

On the average, the global level of CO₂ concentration is recorded to have ascended from 280 ppm to 404 ppm in May 2016, the optimum observed in the previous 650 millennia [5]. According to the National Oceanic and Atmospheric Administration (NOAA), the current value however stands at 409.36 ppm as of December 2018, an increase of 2.83 ppm over the level in December 2017. A similar observation by the National Aeronautics and Space Administration (NASA) on global climate change is presented in figure 1 [6].
Figure 1. Carbon dioxide levels measured at Mauna Loa Observatory, Hawaii [6].

It is obvious from Figure 1 that the CO\textsubscript{2} concentration in the atmosphere has been increasing quite steadily over the years, with the current value standing at about 410 ppm. Figure 2 represents the global earth’s surface temperature anomaly over time as a result of the increasing greenhouse gas emissions. It could be observed that the atmospheric temperature shot up from well below 0 °C in the 1900s to an astonishing value close to 1 °C in 2019. The trends in these two figures are the compelling factors for the Paris agreement which aims at holding the global average temperature rise to well below 2 degrees Celsius over the pre-industrialization era by the end of the 21st century.

Figure 2. Change in global surface temperature relative to 1951-1980 average temperatures [6].

To achieve the 2015 Paris agreement, many nations have developed and submitted their Intended Nationally Determined Contributions (INDCs) sketching out their post-2020 climate policies. These INDCs address a scope of issues, which can identify with abstaining from, adjusting or adapting to climatic changes, in addition to other things. Nonetheless, plans and activities for minimizing ozone depleting gas emissions are central components [7]. In figure 3 below, apart from end-use fuel and electricity efficiency and renewable energy sources, carbon capture and storage is observed to be the third most important technology contributing to global cumulative CO\textsubscript{2} reductions. According to the International Energy Agency (IEA) modelling, this technology could attain 13% of the emissions reductions needed by the year 2050 to limit the global increase in temperature to 2°C. This is the reason why the IEA observed in their report in 2015 that carbon capture and storage is the sole
technology capable of delivering substantial emissions reductions from the use of fossil fuels. This technology is not only able to minimize emissions from power generation, but equally from industrial sectors such as cement production, petrochemical, refineries, as well as iron and steel manufacturing [8].

Figure 3. Contribution of technologies and sectors to global cumulative CO$_2$ reductions [8].

Considering the rising global population, energy demand and the increasing share of coal as fuel for power generation, climate model indicates the continuance of increasing trends in CO$_2$ level and global warming [9]. To prevent the rise of atmospheric CO$_2$ concentration above 750 ppm by the end of the twenty-first century, which could detrimentally affect global climate, experts are of the view that effective actions need to be adopted to curb the situation [10]. Since thermal power plants remain integral sources of carbon emission, CO$_2$ mitigation in coal-fired power plants is essential to reduce the effects of global warming [11,12].

A number of researchers have investigated diverse ways of reducing the carbon emission from the coal-fired power plants. Among the various strategies, carbon capture and sequestration or storage (CCS) appears to be the most readily applicable means of achieving substantial emission reductions for some time to come [13]. Several research works which have looked into the various CCS technologies have revealed that the most effective method is absorption using chemical solvents [14]. Over the years, amines have dominated the chemical solvents that have been put into commercial use in the various capture plants. The most common amine being monoethanolamine (MEA) [15]. Despite its wide applications and high capture efficiency, MEA is known to have associated high cost of operation. The regeneration energy requirement in MEA-based carbon capture process is recognized to be significantly high, requiring high steam demand from the power plant. Aside the high cost of operation, this chemical solvent has the tendency of irreversibly reacting with some flue gas stream contaminants to yield heat stable salts which interfere with the absorption process. Another associated issue with the use of MEA is its high volatility and degradation in the presence of Sulphur dioxide and oxygen at high temperatures. This requires for fresh solvents to be fed into the absorber column on frequent basis. As an added disadvantage, the MEA-based process cannot be operated at high concentrations of the solvent due to the corrosive nature of the chemical [16,17].

Due to the aforementioned operational issues with the use of MEA, many projects have considered the discovery of other chemical solvents which could possibly replace MEA. Some of the most widely researched solvents are ammonia and potassium carbonate [18-20]. The higher instability and volatility nature of ammonia (NH$_3$) however requires the process to be carried out at lower temperatures than MEA-based process. This has led to the discovery of the popularly known chilled ammonia process (CAP). The CAP technology requires the use of refrigeration system to cool major streams of the process and to keep the absorber cool enough to alleviate the otherwise negative effects of the
exothermic absorption process. The refrigeration requirements of the CAP process render it somewhat expensive too, although some researchers still claim that the CAP process is cheaper than the MEA process. That notwithstanding, the overall carbon footprint related to the large scale applications of both MEA and \( \text{NH}_3 \) are major causes of concern. This has shifted the focus of many projects to investigate aqueous potassium carbonate (\( \text{K}_2\text{CO}_3 \)) as a possible alternative to both MEA and \( \text{NH}_3 \) [21].

The use of potassium carbonate as a capture solvent is mostly associated with high temperature, and this is the reason the process is usually referred to as hot potassium carbonate (HPC) process. The chemical can be applied at low temperatures as well, but may require higher energy for regenerating the solvent than in the HPC system. The HPC process was first invented by Benson and Field in the early 1950s [22]. Since then, the process has been in commercial applications for acid gas cleaning for many years. The HPC process has several advantages over the amine-based capture process. Firstly, the regeneration heat duty needed in this process is much lower than average requirement in an amine-based process. Potassium carbonate also stands as a more environmentally friendly solvent than both MEA and \( \text{NH}_3 \). Also, since the high stability and low volatility of \( \text{K}_2\text{CO}_3 \) allows the absorption process to be undertaken at high temperatures, there is usually no cross heat exchanger required to preheat the \( \text{CO}_2 \) rich solvent stream before the regeneration process. The stripping of the \( \text{CO}_2 \) molecules and regenerating the chemical solvent could therefore be achieved by means of pressure swing desorption. Corrosion of process equipment is also found to be so much insignificant in the HPC process. For this reason, the HPC process can be operated at high concentrations without any issues. Additionally, the much less carbon footprint associated with commercial applications of the HPC process makes the process far more laudable than both MEA and \( \text{NH}_3 \) absorption processes [23].

The major hindrance in the use of aqueous \( \text{K}_2\text{CO}_3 \) solutions for carbon capture is the slow nature of the absorption process which is normally encountered in the absorber column. This requires a much larger size of absorber than what is needed in MEA-based process to attain similar capture efficiency. Consequently, several researches in the manner of lab scale experiments, pilot plant trials and simulations have been directed towards the discovery of possible catalysts for the HPC process. These catalysts, often called rate promoters, are meant to improve the reaction kinetics in the absorber system, thereby increasing the carbon capture efficiency of the capture process. Amines [24] and amino acids [17] are among the most widely researched promotors for the HPC process. That notwithstanding, the high volatility as well as the hazardous and corrosive nature of these chemicals have shifted much attention to the use of boric acid (\( \text{H}_3\text{BO}_3 \)) [25-27].

Although many experimental and computational works have revealed this novel promoter (boric acid) as environmentally friendly, and able to enhance the carbon capture efficiency of the HPC process, no detailed projects with regards to parametric and sensitivity analyses have been completed in literature to find out the optimal conditions of the boric acid assisted HPC process. Aside this research gap, no current work has investigated modified processes for promoted and uppromoted HPC process for the purpose of minimizing the reboiler duty requirement for the solvent regeneration process. Thus, the focus of the present study is to perform parametric analyses for the boric acid assisted HPC process for a post-combustion carbon capture technology. Additionally, energy saving modification is applied to the system to reduce the reboiler steam demand, and minimize the regeneration heat duty.

2. Model Development and Validation

Using a solvent absorption process, post-combustion carbon capture with \( \text{K}_2\text{CO}_3 \) solvent was demonstrated in the works of Mumford et al. 2011 [28]. The flue gas used in the pilot plant trials was obtained from a 1600 MW brown-coal-fired power station located at the International Power’s Hazelwood power station in Victoria’s Latrobe Valley, Australia. The pilot plant, which was built to capture up to 25 tons/day of \( \text{CO}_2 \) (expandable to 50 tons/day of \( \text{CO}_2 \)), was originally designed based on a proprietary solvent, BASF PuraTreat F. The plant was, however, operated using 30 wt% \( \text{K}_2\text{CO}_3 \) to demonstrate its performance in a post-combustion \( \text{CO}_2 \) capture process. Although the pilot plant trials only yielded \( \text{CO}_2 \) absorption of about 20-25% from the flue gas when using \( \text{K}_2\text{CO}_3 \), valuable operating data were collected, which enabled process modelling and simulations to be compared to real plant data. The flue gas composition as obtained from the Hazelwood power station, the pilot plant and
simulation details as used in Mumford et al. 2011 [28] and Kothandaraman 2010 [29] were adopted as the reference case for this study.

The electrolyte non-random two-liquid (ELECNRTL) thermodynamic property method for liquid and Redlich-Kwong (RK) equation of state for vapor, which are the most widely used property methods for chemical absorption carbon capture simulations, were used in a rigorous rate-based model in Aspen Plus® V10 for the K₂CO₃-CO₂-H₂O system. The following reaction equations, equilibrium constants ($K_{eq}$) and kinetic constants ($r$) from Wu et al. 2018 [30] and Aspen Tech (2008) [31] were included in the model development.

2.1 Model Reactions

The equilibrium, dissociation and kinetic equations used in the simulation model development are presented in equations 1 to 8 below [31]:

1. Equilibrium: $CO_2 + 2H_2O \leftrightarrow H_3O^+ + HCO_3^-$
2. Equilibrium: $HCO_3^- + H_2O \leftrightarrow H_3O^+ + CO_3^{2-}$
3. Equilibrium: $2H_2O \leftrightarrow H_3O^+ + OH^-$
4. Dissociation: $KOH \rightarrow K^+ + OH^-$
5. Dissociation: $K_2CO_3 \rightarrow 2K^+ + CO_3^{2-}$
6. Dissociation: $KHC_3O \rightarrow K^+ + HCO_3^-$
7. Kinetic: $CO_2 + OH^- \rightarrow HCO_3^-$
8. Kinetic: $HCO_3^- \rightarrow CO_2 + OH^-$

2.2 Equation Constants

The equilibrium constants for reactions 1-3 were determined using the Aspen Plus built-in equation: $ln(K_{eq}) = A + \frac{B}{T} + C*ln(T) + D*T$, where A, B, C and D are constants and T is temperature in Kelvin units.

The kinetic constants for reactions 7&8 were obtained using the Aspen Plus built-in reduced power law expression: $r = k \exp\left(-\frac{E}{RT}\right)$, where $k$ is pre-exponential factor, $E$ is activation energy, $R$ is universal gas constant and $T$ is temperature in Kelvin units.

| Reaction No. | A     | B     | C       | D     |
|--------------|-------|-------|---------|-------|
| 1            | 231.465 | -12092.1 | -36.7816 | 0     |
| 2            | 216.05  | -12431.7 | -35.4819 | 0     |
| 3            | 132.899 | -13445.9 | -22.4773 | 0     |

| Table 1. Equilibrium constants for K₂CO₃-CO₂-H₂O system [30,31]. |

| Reaction No. | k       | E (cal/mol) |
|--------------|---------|-------------|
| 6            | $4.32 \times 10^{13}$ | 13249 |
| 7            | $2.38 \times 10^{17}$ | 29451 |

| Table 2. Kinetic constants for K₂CO₃-CO₂-H₂O system [30,31]. |

2.3 Model Flowsheet

Figure 4 shows a schematic flowsheet for the simulation model. The flue gas (FLUEGAS, 110 °C, 15 atm) which was fed at the bottom stage (stage 12) of the packed absorber column (ABSORBER, operating at 15 atm), was contacted with the lean aqueous K₂CO₃ solution (LEANIN, 80 °C, 15 atm) with ~40 wt% concentration, which was fed at the top stage (stage 1) of the column, at the rate of 8250 kg/hr (11,170 kg/hr with makeup), 80 °C and 15 atm. The lean gas (CLEANGAS) after absorption is released into the atmosphere at the top of the absorber column while the rich-solvent (RICHIN) from the bottom of the column is fed to stage 2 of the packed stripper column (STRIPPER, operating at atmospheric condition). The CO₂ product stream (CO₂) is condensed and compressed for storage whereas the lean-solvent regenerated (LEANOUT) is cooled and recycled to the ASORBER as...
LEANIN. For convergence purposes and as a means of removing some impurities which would otherwise accumulate in the system, a portion of the recycle stream is purged in the SPLITTER in other to control the rate of lean-solvent entering the ABSORBER. The 2920 kg/hr MAKEUP (80 °C, 15 atm) stream serves as the makeup block to replenish the lost water and K$_2$CO$_3$ in the system.

![Figure 4. Model flowsheet for simulation work.](image)

### 2.4 Model Design

The absorber and stripper columns were designed using the RadFrac column model with the following specifications as obtained from Mumford et al. 2011 [28] and Kothandaraman 2010 [29]:

| RadFrac properties        | Absorber         | Stripper        |
|---------------------------|------------------|-----------------|
| Number of stages          | 12               | 8               |
| Packing material          | Raschig Norton Metal 10 mm | Raschig Norton Metal 6 mm |
| Total packed height       | 14 m             | 12 m            |
| Column diameter           | 1.5 m            | 1.4 m           |
| Flow model                | Mixed            | Mixed           |
| Initial liquid hold up    | 0.03 L           | 0.03 L          |
| Film resistance           | Discrxn for liquid; Film for vapour | Discrxn for liquid; Film for vapour |
| Discretization points for liquid film | 10               | 10              |

It could be seen from Table 4 that the simulation results of the current study compare closely with the results from Kothandaraman 2010 [29] with minimal deviations of 8.04% in the carbon capture efficiency and 13.75% deviation in the specific reboiler duty. As increasing carbon capture level usually incurs higher reboiler duty requirement, the lower reboiler duty recorded in the current work could be deemed to be as a result of the lower carbon removal rate observed. That notwithstanding, the current result compares closely with other literature data as found in Oexmann et al. 2008 [32]. In this work, the authors reported 2.92 MJ/kgCO$_2$ and 3.16 MJ/kgCO$_2$ for carbon capture rates of 70% and 90% respectively. The authors however adopted lower lean solvent concentration in their work. The use of 29.3 wt% K$_2$CO$_3$ in their work could possibly be the source of disparities between their results and those obtained in the current study. As higher concentration of the lean solvent stream contributes to better system performance, it is no surprise that the reboiler duty in the current study is lower than that obtained by Oexmann et al. 2008 [32]. Compared to the conventional MEA-based carbon capture system, which uses approximately 4 MJ/kgCO$_2$ [33] as the reboiler duty, the K$_2$CO$_3$-based absorption
Process appears to be a far more energy efficient technology. Aside the carbon capture rate and the stripper reboiler duty, the energy usage of the condenser system as well as the recycled lean solvent stream cooler were evaluated in this study. As shown on Table 4, the total energy usage in the hot potassium carbonate-based capture system is estimated to be 5.15 MJ per kilogram of CO$_2$ captured.

### Table 4. Validation Results for K$_2$CO$_3$-CO$_2$-H$_2$O system.

| Design specifications          | Values          |
|-------------------------------|-----------------|
| Inlet flue gas flowrate, kg/h | 4740            |
| Inlet flue gas CO$_2$, vol%   | 13              |
| Lean flowrate, kg/hr          | 11,170          |
| Lean MEA conc., wt%           | 40              |

| Base case performance         | K$_2$CO$_3$ Base Case | Kothandaraman 2010 [29] | Deviation (%) |
|-------------------------------|------------------------|-------------------------|---------------|
| CO$_2$ capture level, %       | 78.17                  | 85                      | 8.04          |
| Reboiler duty, MJ/kgCO$_2$    | 2.76                   | 3.20                    | 13.75         |
| Condenser duty, MJ/kgCO$_2$   | 1.22                   | -                       | -             |
| Cooling duty, MJ/kgCO$_2$     | 1.17                   | -                       | -             |
| Total duty, MJ/kgCO$_2$       | 5.15                   | -                       | -             |

### 3. Parametric Studies

This section investigates how variations in the lean aqueous K$_2$CO$_3$ concentration from 25 wt% to 45 wt% affect the system performance. All other operation conditions, aside changes in the lean solvent concentration, were maintained during this sensitivity analysis. The results are presented in Figure 5.

The results disclose that increasing the lean solvent concentration improves upon the system performance of the HPC process. The maximum carbon capture efficiency of 81.73% was obtained at the maximum K$_2$CO$_3$ concentration of 45 wt%. Also, the least regeneration heat duty of 2.59 MJ/kgCO$_2$ was recorded at the maximum lean solvent concentration. This implies that the system performance of hot potassium carbonate capture process could be improved significantly by increasing the lean solvent concentration. Nevertheless, since increasing the potassium carbonate concentration increases capital cost and probably results in higher salt precipitation in the column, it is necessary that rigorous techno-economic analyses are conducted to investigate the optimum value.

![Figure 5](image.png)

**Figure 5.** Effect of lean solvent concentration on carbon capture rate and reboiler duty.
4. $\text{H}_3\text{BO}_3$ Promoted $\text{K}_2\text{CO}_3$ System

To analyze the impact of boric acid catalyst on the rate of carbon capture for the hot potassium carbonate system, aqueous boric acid was dosed into the fresh make-up stream at concentrations of 2wt%, 4wt% and 6wt%. It is important to note that during this analysis, the lean solvent concentration was maintained at 40 wt% to avoid its influence on the system. The results obtained are shown in Table 5.

Table 5. Results for $\text{H}_3\text{BO}_3$ Promoted $\text{K}_2\text{CO}_3$ System.

| System performance       | 40wt% $\text{K}_2\text{CO}_3$ | 40wt% $\text{K}_2\text{CO}_3$/2wt% $\text{H}_3\text{BO}_3$ | 40wt% $\text{K}_2\text{CO}_3$/4wt% $\text{H}_3\text{BO}_3$ | 40wt% $\text{K}_2\text{CO}_3$/6wt% $\text{H}_3\text{BO}_3$ |
|--------------------------|-------------------------------|-------------------------------------------------------------|-------------------------------------------------------------|-------------------------------------------------------------|
| CO$_2$ capture level, %   | 78.17                         | 78.70                                                       | 78.88                                                       | 79.14                                                       |
| Reboiler duty, MJ/kgCO$_2$ | 2.76                          | 2.75                                                        | 2.75                                                        | 2.75                                                        |
| Condenser duty, MJ/kgCO$_2$ | 1.22                          | 1.22                                                        | 1.22                                                        | 1.21                                                        |
| Cooling duty, MJ/kgCO$_2$ | 1.17                          | 1.17                                                        | 1.18                                                        | 1.18                                                        |
| Total duty, MJ/kgCO$_2$  | 5.15                          | 5.14                                                        | 5.15                                                        | 5.14                                                        |

The addition of small amounts of boric acid is seen to improve upon the carbon capture efficiency of the hot potassium carbonate capture process. As shown on Table 5, the improvement increases with increasing amount of boric acid concentration, with the highest capture efficiency of 79.14% obtained for 40wt% $\text{K}_2\text{CO}_3$/6wt% $\text{H}_3\text{BO}_3$ system. It is however interesting to note that even though the catalysis of the $\text{K}_2\text{CO}_3$ system using $\text{H}_3\text{BO}_3$ appears to enhance upon the mass transfer efficiency of the absorption process, thereby increasing the decarburization rate ultimately, the specific reboiler duty is observed to decrease slightly from 2.76 MJ/kgCO$_2$ to 2.75 MJ/kgCO$_2$. This decrease is also observed not to be affected by the amount of boric acid. On the other hand, the total energy usage shows slight variations for the different amounts of boric acid. These variations could be seen to result from differences in the condenser duty and the cooling duty in the different systems. This could be caused by the slight temperature differences that could occur in the stripper column for the different amounts of boric acid. As changes in the reboiler temperature affects cooling duty in the system, any slight changes in this system parameter as a result of the promotion could alter the total energy consumption of the system.

5. Modified $\text{H}_3\text{BO}_3$ Promoted $\text{K}_2\text{CO}_3$ System

To further decrease the energy usage in the boric acid promoted potassium carbonate capture system, an energy saving process configuration was proposed. This section discusses the proposed modification and the results obtained.

The lean vapor compression (LVC) configuration as shown in Figure 6 is a widely investigated process modification [34,35]. The principle of this modification is to flash the hot lean solvent stream exiting the bottom of the stripper, compress the vapor and re-inject it into the stripper in order to reduce the steam requirement of the reboiler. The idea in this modification is to harness the energy in the hot lean stream since it is mostly the highest temperature-bearing stream in the system. Due to the compression process, the recycled gaseous stream has a higher temperature and works effectively to reduce reboiler duty [36]. Ahn et al. 2013 [34] and Fernandez et al. 2012 [35] reported reboiler duty reductions of 21.6% and 15.1% respectively for this modification in an MEA-based system. Researchers at the DONG Energy pilot plant also reported reboiler duty minimization of 20% for the same modification [37]. These high energy saving quotas make this modification one of the most effective heat pump configurations in literature. Reddy et al. 2007 [38] stated that the flash vessel should preferably be operated near atmospheric pressure to incur less operating cost. In the current
study, the flash was operated at approximately 1 atm, 113 °C and vapor fraction of 0.03 by mole (188.912 kg/hr). The gaseous stream exiting the top of the flash vessel was then compressed to 2 atm to attain a temperature of 204 °C before re-injecting into the 7th stage of the stripper. The results from this modification are presented in Table 6.

![Diagram of LVC for H₃BO₃/K₂CO₃ System](image)

**Figure 6.** LVC for H₃BO₃/K₂CO₃ System

| System performance    | 40wt% K₂CO₃/6wt% H₃BO₃ | Modified 40wt% K₂CO₃/6wt% H₃BO₃ | Deviation (%) |
|-----------------------|------------------------|----------------------------------|---------------|
| CO₂ capture level, %  | 79.14                  | 78.93                            | 0.27          |
| Reboiler duty, MJ/kgCO₂ | 2.75                  | 2.17                             | 21.09         |
| Condenser duty, MJ/kgCO₂ | 1.21                  | 1.22                             | 0.83          |
| Cooling duty, MJ/kgCO₂ | 1.18                  | 1.11                             | 5.93          |
| Compressor duty, MJ/kgCO₂ | -                    | 0.04                             | -             |
| Flasher duty, MJ/kgCO₂ | -                     | 0.47                             | -             |
| Total duty, MJ/kgCO₂  | 5.14                  | 5.01                             | 2.53          |

As shown on Table 6, the LVC modification, applied to the 40wt% K₂CO₃/6wt% H₃BO₃, is able to attain 21.09% energy minimization in the reboiler duty requirement over the unmodified process. This value compares closely with literature information at the DONG Energy pilot plant [37], where this modification was able to achieve 20% reduction (reducing reboiler duty from 3.60 MJ/kgCO₂ to 2.88 MJ/kgCO₂) in an amine-based capture plant. A slight decrease of 0.27% in the carbon capture level was observed in the carbon capture efficiency upon the implementation of the modified configuration. This could be as a result of the lower reboiler duty in the modified process. Furthermore, the modified process proved to have capabilities of reducing cooling duty as well. This is due to the fact that the lean solvent stream retrieved from the bottom of the flash vessel contains less vapor than in the unmodified system. This reduces the heat of condensation, and ultimately minimizes the overall cooling duty. Due to the extra energy usage in the auxiliary equipment (compressor and flash column)
introduced in the modified process, the total energy saving achieved in the modified configuration is only 2.53%.

6. Conclusion
This studies completed a rigorous rated based simulation for unpromoted and boric acid promoted potassium carbonate based post-combustion carbon capture system. The results from the simulation showed that increasing the lean solvent concentration as well as adding boric acid is able to increase the carbon capture efficiency of the hot potassium carbonate capture process. The level of improvement was also seen to be dependent on the quantity of boric acid added to the system, implying that increasing the amount of boric acid is likely to increase the impact of the promotion on the system. Aside the catalysis, an energy saving process modification was also proposed to reduce the reboiler duty in the boric acid promoted K$_2$CO$_3$-based capture system. This modification was seen to cut down the reboiler duty by 21.09%, while scaling down the total energy usage by 2.53%.

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