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Comparison of NaOH and Na_2CO_3 as absorbents for CO_2 absorption in carbon capture and storage technology

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Abstract: CO_2 gas is a greenhouse gas that causes global warming. Greenhouse gases are gases in the atmosphere that can absorb and reflect infrared radiation from the Earth's surface. Currently, the energy demand still depends on fossil fuels. On the other hand, CO_2 emissions from burning fossil fuels continue to increase and contribute as greenhouse gases to the atmosphere. CO_2 capture is an effort to reduce the burden of CO_2 emissions into the atmosphere and is part of the Carbon, Capture, and Storage (CCS) protocol. The CO_2 absorption process applied in the chemical industry is one of the CO_2 absorptions using NaOH and Na_2CO_3 solutions as absorbents. This research aims to determine the effect of absorbent flow rate on the percentage of absorbed CO_2. The method used in this research is the SLR (Systematic Literature Review) method to identify all available research. The absorbent flow rate variations used are 1 liter/minute, 1.5 liters/minute, 2 liters/minute, 2.5 liters/minute, and 3 liters/minute. The absorption process using NaOH absorbent is capable of absorbing CO_2 gas with a maximum absorption of 95.52% and a minimum of 79.14%. Meanwhile, in the Na_2CO_3 absorbent, it is capable of absorbing CO_2 gas with a maximum amount absorbed of 72.45% and a minimum of 35.47%.

Keywords: CO_2; NaOH; Na_2CO_3; Absorption; Absorbent

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1. Introduction

CO_2 capture is one effort to reduce the burden of CO_2 emissions in the atmosphere and is part of the Carbon, Capture and Storage (CCS) procedure. Global warming is now a major issue and deserves attention. One of the causes of global warming is CO_2 gas. CO_2 emissions will increase by 2.1% every year due to high energy consumption and fossil fuel combustion (Acién Fernández et al., 2012). Carbon dioxide (CO_2) gas emissions into the atmosphere are suspected to be the cause of natural phenomena such as extreme climate change, global warming, greenhouse effects, and ecological problems (Nisa et al., 2019). CO_2 gas is not only produced from combustion but also from several industries such as natural gas, fertilizer, biogas industries, etc. (Ningsih et al., 2017). Only by increasing energy efficiency and the use of alternative energy sources, it will be difficult to control and reduce CO_2 emissions from fuel combustion (Kanniche & Bouallou, 2007). Thus, a method is needed to capture or absorb CO_2 gas (Ningsih et al., 2017). Additionally, efficient, safe, and environmentally friendly technology for capturing and storing carbon dioxide such as carbon, capture, and storage (CCS) is also required (Zhao et al., 2012).

Numerous research and development activities are being conducted to identify and develop technologies that contribute to the implementation of CCS. These activities include steps to reduce costs, particularly for carbon capture, as well as steps to ensure that suitable storage locations are identified, executed, and monitored. However, these barriers cannot be overcome by simply requiring technological improvements. Regardless of how CCS develops, there will always be additional costs beyond the use of fossil fuels that cannot be reduced. If significant reductions in CO_2 emissions can be achieved, these costs can be regulated legally during emissions accounting and trading. Similarly, while carbon dioxide injection into suitable geological formations is scientifically credible, it is important to consider to what extent it is subject to legal frameworks and regulations (Gibbins & Chalmers, 2008).

There are several methods used in the process of capturing or absorbing CO_2 gas, including membrane, cryogenic, and absorption methods. However, the most used method is chemical absorption (Karali et al., 2022). Absorption is a separation process where one substance in a gas mixture is absorbed through contact with a liquid, where one component is absorbed while the other component is not (Robiah et al., 2021). Chemical absorption is absorption accompanied by a chemical reaction of the gas dissolved in the absorbent. An example of this absorption is the absorption with a chemical reaction between CO_2 and amine compounds. MEA, DEA, and MDEA are solvents (absorbents) commonly used to absorb CO_2 (Sembiring et al., 2020). Among the various methods, absorption with chemical solvents has been further researched and proven to be the most effective and suitable method for CO_2 gas absorption (Astarita et al., 1983; Yu et al., 2012).

Several researchers have conducted studies on the absorption of carbon dioxide. In a previous study, sodium hydroxide was used as an absorbent in the absorption process. They prepared 40 grams of solid NaOH, which was dissolved to obtain a concentration of 0.1N. The study found that good absorption was obtained with a high flow rate of the absorbent. This is because the interfacial volume in the column is filled as the absorber flow rate increases (Yu et al., 2012). Another study showed that by increasing the waste flow rate from 2 liters/minute to 5 liters/minute in the CO2 absorption process using a spray column, the interfacial surface area per unit volume inside the column increased (Javed et al., 2010). The percentage of CO2 gas absorption is affected by the flow rate of the absorbent. The higher the flow rate, the greater the number of mol K_2CO_3 and H_2O, which results in more carbon dioxide gas reacting. Therefore, the percentage removal of CO_2 gas from the gas phase to the liquid phase increases (Altway et al., 2015).

Previous research has shown that a flow rate of 0.2, 0.4, and 0.6 liters per minute results in lower CO_2 absorption, and therefore the optimal flow rate is unknown. To address this, a wider range of NaOH flow rates was used in this study, including 1, 1.5, 2, 2.5, and 3 liters per minute. The flow rate used in this study was higher than that used by (Trisnaliani et al., 2020), likely due to the larger absorber used. If the flow rate is too low, the pressure drop can be high. According to (Javed et al., 2010), the size of the absorber and the high flow rate can affect overall mass transfer.

To determine the optimal concentration for CO_2 reduction, a study was conducted on the effect of Na_2CO_3 solvent concentration on the absorption process (15%, 20%, 25%, 30%, 35% by weight). The optimal concentration for CO_2 reduction was found to be 25% by weight in this study. This is because the reaction between Na_2CO_3 and CO_2 is an equilibrium reaction, so at high concentrations (30% and 35%), absorption leads to a turning point in the reaction and the absorption process becomes less ideal compared to the 25% concentration (Žalys et al., 2023). In another study, (Purba et al., 2018) investigated the effect of adding boric acid (H_3BO_3) to Na_2CO_3 solution to enhance its ability to absorb CO_2. The variable in this study was the concentration of boric acid (1%, 1.5%, 2%, 2.5%, 3% by weight). As a result, adding the optimal concentration of boric acid at 3% by weight resulted in a CO_2 absorption rate of 67.81% and a 2.4-fold increase in the absorption rate of the solution (Ghosh et al., 2009).

To further investigate the absorption of CO2 using NaOH and Na2CO3 as absorbents, but at different flow rates, more research is needed. In the absorption process, the flow rate is related to the mass and heat transfer time between two connected fluids in the absorption tower and affects the rate of CO_2 absorption. The objective of this study is to determine the optimal flow rate of both absorbents in reducing the CO_2 content and the percentage of CO_2 absorption. This report is expected to serve as a reference and a solution for reducing atmospheric CO_2 gas in the future to mitigate the greenhouse effect. This work will make it easier for researchers to find information regarding which absorbent is the most optimal in capturing CO_2.

2. Methods

In this study, the method used is Systematic Literature Review (SLR). This method involves the researcher identifying, reviewing, evaluating, and interpreting all available studies. In this method, the researcher systematically reviews and selects journals according to the procedures identified in each process (Snyder, 2019). Based on the above steps, the researcher searched for reference articles on the keywords NaOH and Na_2CO_3 as the absorbents. Data collection was done by documenting all the articles received in this research report. Several references have been collected on the absorption of carbon dioxide by NaOH and Na_2CO_3. The limitation of this work is the data are only acquired from previous work, not directly from the plant.

3. Results and discussion

In this study, the flow rate of each absorbent was determined using a pump and fed into the top of the absorption column with varying flow rates of 1 liter/minute, 1.5 liters/minute, 2 liters/minute, 2.5 liters/minute, and 3 liters/minute. The study resulted in several data on the effect of flow rate variation on the percentage of CO2 absorption in the absorption column output. The data are presented in Tables 1.

Tabel 1. Percentage of absorbed CO_2 gas with variation of NaOH flow rate (Purba et al., 2018)

Flow rate (Liters/minute)	Percentage of CO_2 absorption (%)	
	NaOH	Na_2CO_3
1	79,14	35,47
1,5	89,36	47,46
2	88,88	47,18
2,5	93,95	60,02
3	95,52	72,45

3.1 Effect of NaOH flow rate on CO_2 absorption percentage

The figure 2 shows that most of the CO_2 absorption from NaOH solution occurs at a flow rate of 3 liters/minute. The figure indicates that the percentage of CO_2 absorption tends to increase with the increase of the absorbent (NaOH) flow rate. The increase in absorbance is in sequence from the lowest to the highest. It increases from 79.14% to 89.36%, then slightly decreases to 88.88%, then increases to 93.95% and finally to 95.52%. This is because the packing volume filling at the interfacial area of the column increases with the increase of the absorption flow rate. Previous study, CO_2 absorption in NaOH using a spray column indicated that increasing the fluid flow rate from 2 liters/minute to 5 liters/minute increases the interfacial surface area larger per unit volume inside the spray column (Ghosh et al., 2009).

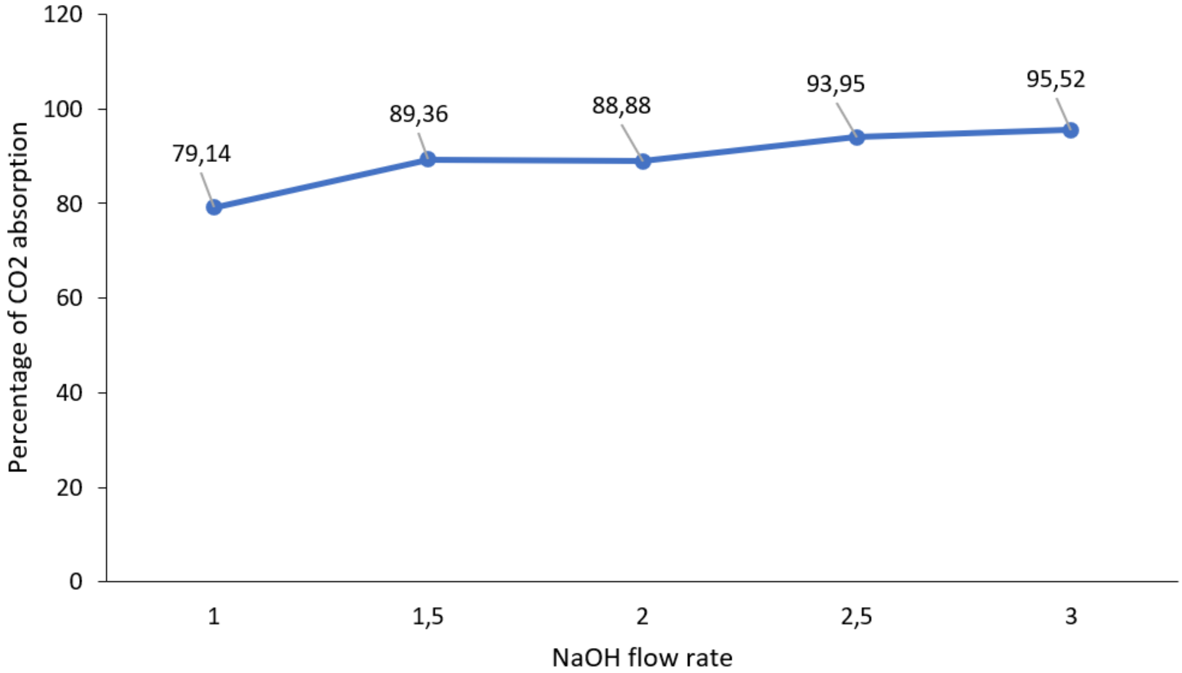

Figure 2. The influence of NaOH flow rate on CO_2 absorption percentage

The fluid flow rate affects the value of the fluid's Reynolds number. The higher the fluid flow rate used, the higher the Reynolds number of the fluid. As the Reynolds number increases, the fluid flow becomes more turbulent. In turbulence, particles in the liquid move in all directions, resulting in more collisions between particles, and creating more gaps or holes where gas can be absorbed and trapped (Trisnaliani et al., 2020). Gas absorption is theoretically a mass transfer process between phases, and mass transfer can occur when there is a driving force from one phase to another. The driving force is a form of collision between molecules that occurs when the liquid and gas phases mix at an increasing liquid flow rate, so collisions between larger molecules result in greater absorption (Sutanto, 2021). The higher the absorption flow rate used, the higher the number of moles of NaOH and H_2O. With an increasing number of moles of NaOH and H_2O, the gas CO_2 becomes more reactive. This leads to an increase in the percentage of CO_2 gas absorption from the gas phase to the liquid phase (Altway et al., 2015; Yi et al., 2009).

3.2 Effect of Na_2CO_3 flow rate on CO_2 absorption percentage

The chart in Figure 3 shows that the percentage of CO_2 absorption tends to increase as the flow rate of the absorbent increases. The highest percentage of CO_2 absorption occurs at a flow rate of 3 liters/minute, which is 72.45%, and the lowest occurs at a flow rate of 1 liter/minute, which is 35.47%. As the flow rate increases, the Reynolds number and turbulence of the fluid in the absorption tower also increase. In the case of turbulence, the particles in the liquid move in all directions, which increases collisions between them.

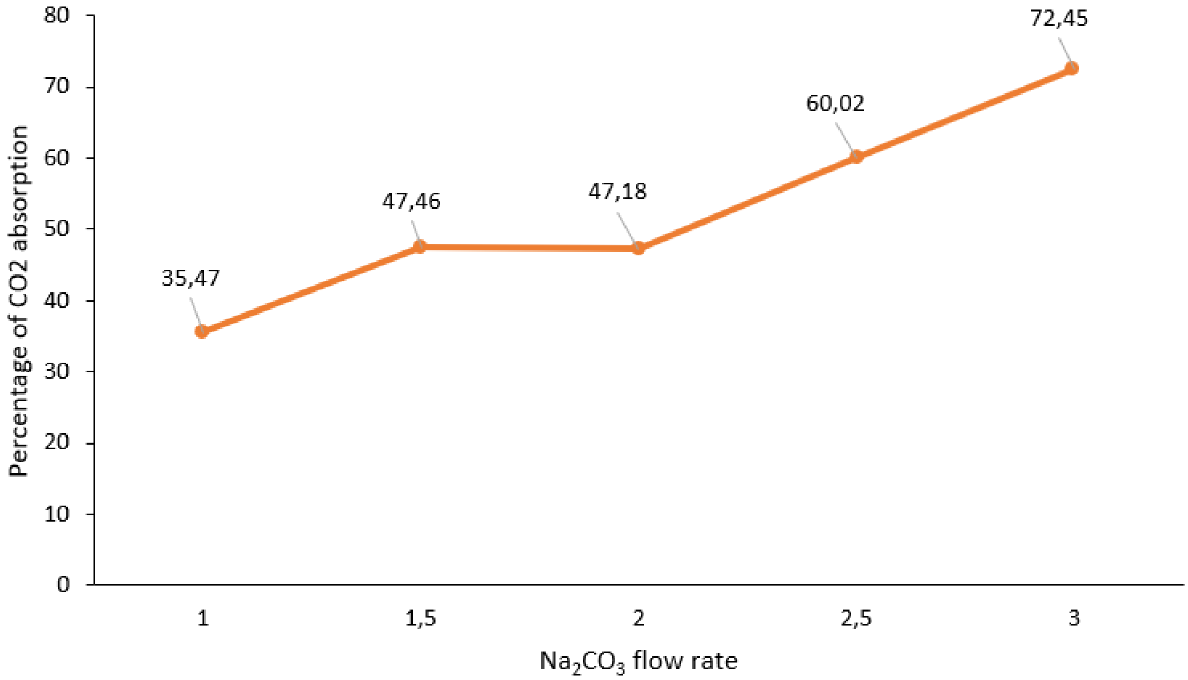

Figure 3. Effect of Na_2CO_3 flow rate on the percentage of CO_2 absorption

The gas absorption process is a mass transfer process between two liquids where the transfer occurs when there is a driving force from one phase to another. The collisions create gaps/cracks where gas can be absorbed and trapped in these cracks (Purba et al., 2018; Trisnaliani et al., 2020). According to the Reynolds theory, the larger the flow rate, the more turbulent the flow becomes and breaks up, causing the flow to propagate on the surface of the packing. This increases the interfacial packing area of the absorption column and enhances the carbon dioxide binding process that occurs in the absorption column.

Furthermore, the flow rate of the absorbent will affect the amount of reactant in the solution. A higher flow rate will also increase the amount of reactant in the absorbent solution, resulting in more Na_2CO_3 solution reacting with carbon dioxide. This is supported by a previous study the effect of flow rate on CO2 gas absorption (Hikita et al., 1976; Yincheng et al., 2011). In their study, it was shown that increasing the gas flow rate can increase the gas mass transfer coefficient, and thus, increasing the flow rate can enhance the gas absorption rate. The higher the gas mass transfer coefficient, the greater the gas absorption by the fluid.

4. Conclusion

Based on the conducted research, it can be concluded that the absorption of CO_2 gas by NaOH is higher than Na_2CO_3. The optimum flow rate for the CO_2 absorption process is 3 liters/minute with a CO_2 gas absorption percentage by NaOH solution of 95.52%. On the other hand, the CO_2 gas absorption percentage by Na_2CO_3 solution is 72.45%. This is because the larger the contact between gas and liquid, the greater the absorption capacity of the liquid towards the components contained in the CO_2 gas flow and the interfacial area. Additionally, the higher the absorber flow rate used, the greater the number of moles between the absorber and absorbate, resulting in a more reactive CO_2 gas. This increases the percentage of CO_2 gas absorption from gas phase to liquid phase.

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Declarations

Author contribution

Fadhilah Ikhsan Dinul, Hendri Nurdin, and Dieter Rahmadiawan contributed to drafting articles, analyzing data, and writing articles. Nasruddin, Imtiaz Ali Laghari, and Tarig Elshaarani contributed to editing the structure of the article, interpreting data, and correcting the final article.

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Complict of interest

The authors declare no conflict of interest.

Ethical clerance

There are no human subjects in this manuscript and informed consent is not applicable.

References

Acién Fernández, F. G., González-López, C. V., Fernández Sevilla, J. M., & Molina Grima, E. (2012). Conversion of CO2 into biomass by microalgae: how realistic a contribution may it be to significant CO2 removal? *Applied Microbiology and Biotechnology*, *96*(3), 577–586. https://doi.org/10.1007/s00253-012-4362-z

Altway, A., Susianto, S., Suprapto, S., Nurkhamidah, S., Nisa, N. I. F., Hardiyanto, F., Mulya, H. R., & Altway, S. (2015b). Modeling and Simulation of CO2 Absorption into Promoted Aqueous Potassium Carbonate Solution in Industrial Scale Packed Column. *Bulletin of Chemical Reaction Engineering & Catalysis*, *10*(2), 111–124. https://doi.org/10.9767/BCREC.10.2.7063.111-124

Astarita, G., Savage, D. W., & Bisio, A. L. (1983). *Gas treating with chemical solvents*.

Ghosh, U. K., Kentish, S. E., & Stevens, G. W. (2009). Absorption of carbon dioxide into aqueous potassium carbonate promoted by boric acid. *Energy Procedia*, *1*(1), 1075–1081. https://doi.org/10.1016/j.egypro.2009.01.142

Gibbins, J., & Chalmers, H. (2008). Carbon capture and storage. *Energy Policy*, *36*(12), 4317–4322. https://doi.org/10.1016/J.ENPOL.2008.09.058

Hikita, H., Asai, S., & Takatsuka, T. (1976). Absorption of carbon dioxide into aqueous sodium hydroxide and sodium carbonate-bicarbonate solutions. *The Chemical Engineering Journal*, *11*(2), 131–141. https://doi.org/10.1016/S0300-9467(76)80035-4

Javed, K., Mahmud, T., & Purba, E. (2010). The CO2 capture performance of a high-intensity vortex spray scrubber. *Chemical Engineering Journal*, *162*, 448–456.

Kanniche, M., & Bouallou, C. (2007). CO2 capture study in advanced integrated gasification combined cycle. *Applied Thermal Engineering*, *27*(16), 2693–2702. https://doi.org/10.1016/J.APPLTHERMALENG.2007.04.007

Karali, D., Peloriadi, K., Margaritis, N., & Grammelis, P. (2022). CO2 Absorption Using Potassium Carbonate as Solvent. *ASEC 2022*, 39. https://doi.org/10.3390/ASEC2022-13824

Ningsih, E., Sato, A., Nafiuddin, A., Putranto, W. S., Kimia, T., Adhi, T., Surabaya, T., Arief, J., & Hakim, R. (2017). Absorpsi Gas CO 2 Berpromotor MSG Dalam Larutan K2CO3. *Seminar Nasional Inovasi Dan Aplikasi Teknologi Di Industri*, *3*(2), 1–5. https://doi.org/10.36040/SENIATI.V3I2.1941

Nisa, N. I. F., Altway, A., & S, S. (2019). Simulasi Unit Stripping CO2 Dalam Packed Column Skala Industri Dengan Kondisi Non-Isothermal. *Jurnal Rekayasa Kimia & Lingkungan*, *14*(1), 53–62. https://doi.org/10.23955/rkl.v14i1.13547

Purba, E., Agustina, D., Pertama, F. P., & Senja, F. (2018). Absorption of CO2 from modified flue gases of power generation Tarahan chemically using NaOH and Na2CO3 and biologically using microalgae. *IOP Conference Series: Earth and Environmental Science*, *141*, 012023. https://doi.org/10.1088/1755-1315/141/1/012023

Robiah, R., Renaldi, U., & Melani, A. (2021). Kajian pengaruh laju alir NaOH dan waktu kontak terhadap absorpsi gas CO2 menggunakan alat absorber tipe sieve tray. *Jurnal Distilasi*, *6*(2), 27–35. https://doi.org/10.32502/JD.V6I2.4136

Sembiring, S., Sembiring, S., Panjaitan, R. L., Susianto, S., & Altway, A. (2020). Pemanfaatan Gas Alam sebagai LPG (Liquified Petroleum Gas). *Jurnal Teknik ITS*, *8*(2), F206–F211. https://doi.org/10.12962/j23373539.v8i2.47079

Snyder, H. (2019). Literature review as a research methodology: An overview and guidelines. *Journal of Business Research*, *104*, 333–339. https://doi.org/10.1016/J.JBUSRES.2019.07.039

Sutanto, R. (2021). Performance of 100 CC Combustion Engine with Refined Biogas Fuel With Coconut Ash as Adsorbent. *International Journal of Advances in Engineering and Management (IJAEM)*, *3*, 608. https://doi.org/10.35629/5252-0304608613

Trisnaliani, L., Eka Pranata, D., Fatria, Tahdid, Ridwan, K., Nurizzman Alfarizi, M., & Pandapotan Lumbantoruan, M. (2020). The Effect of flowrate and NaOH Concentration to CO2 Reduction in Biogas Products Using Absorber. *Journal of Physics: Conference Series*, *1500*(1), 012054. https://doi.org/10.1088/1742-6596/1500/1/012054

Yi, F., Zou, H. K., Chu, G. W., Shao, L., & Chen, J. F. (2009). Modeling and experimental studies on absorption of CO2 by Benfield solution in rotating packed bed. *Chemical Engineering Journal*, *145*(3), 377–384. https://doi.org/10.1016/J.CEJ.2008.08.004

Yincheng, G., Zhenqi, N., & Wenyi, L. (2011). Comparison of removal efficiencies of carbon dioxide between aqueous ammonia and NaOH solution in a fine spray column. *Energy Procedia*, *4*, 512–518. https://doi.org/10.1016/j.egypro.2011.01.082

Yu, C. H., Huang, C. H., & Tan, C. S. (2012). A Review of CO2 Capture by Absorption and Adsorption. *Aerosol and Air Quality Research*, *12*(5), 745–769. https://doi.org/10.4209/AAQR.2012.05.0132

Žalys, B., Venslauskas, K., Navickas, K., Buivydas, E., & Rubežius, M. (2023). The Influence of CO2 Injection into Manure as a Pretreatment Method for Increased Biogas Production. *Sustainability*, *15*(4), 3670. https://doi.org/10.3390/su15043670

Zhao, B., Su, Y., Tao, W., Li, L., & Peng, Y. (2012). Post-combustion CO2 capture by aqueous ammonia: A state-of-the-art review. *International Journal of Greenhouse Gas Control*, *9*, 355–371. https://doi.org/10.1016/J.IJGGC.2012.05.006