Enhancing Carbon Capture Efficiency through Rotating Packed Beds: A Study on the Impact of Solvent Selection and Mass Transfer Coefficients for Industrial Adoption in Carbon Mitigation

Mohammadu Bello Danbatta[1], *Nasser* Ahmed Al-Azri[1*], *Muhammad Abdul* Qyyum[2] and *Nabeel* Al-Rawahi [1]

[1]Mechanical and Industrial Engineering Department, College of Engineering, Sultan Qaboos University, Oman
[2]Petroleum and Chemical Engineering Department, College of Engineering, Sultan Qaboos University, Oman

Abstract. The pressing need for effective carbon dioxide capture solutions in the wake of climate change has catalyzed the exploration of innovative technologies and methodologies. This study investigates the utilization of Rotating Packed Bed systems to enhance the mass transfer coefficient for carbon dioxide absorption using various solvent types. Rotating Packed Bed offer a high-intensity, compact alternative to conventional packed columns, presenting an opportunity for significant advancements in carbon capture efficiency. By systematically analyzing different solvents within RPBs, this research evaluates their impact on mass transfer coefficient and the resultant carbon dioxide absorption efficacy. The findings underscore the potential of specific solvent- Rotating Packed Bed pairings to improve mass transfer rates, essential for achieving higher carbon dioxide loading and overall capture capacity. This work aligns with global climate action goals, promoting scalable solutions to meet the demands of the industry's carbon mitigation strategies. Through a focus on both technological efficacy and practical implementation, this study provides critical insights for the adoption of Rotating Packed Bed technology, laying a foundation for its integration into industrial carbon capture systems.

1 Introduction

Carbon capture and storage (CCS) technology has emerged as a crucial solution to mitigate the increasing concentrations of greenhouse gases in the atmosphere, a key driver of global climate change. As the world grapples with the need to reduce carbon emissions, CCS offers a promising avenue to trap carbon dioxide (CO_2) from industrial processes and power generation, preventing its release into the atmosphere[1][2]. Among the various carbon

* Corresponding author: nalazri@squ.edu.om

capture methods, the Rotating Packed Bed (RPB) technology stands out for its ability to efficiently capture CO_2 from both high- and low-concentration sources. This makes RPB an attractive solution for a wide range of industrial applications, including power plants, chemical manufacturing, and natural gas processing[3]. An RPB is a process intensification device that utilizes centrifugal forces to enhance the mass transfer between gas and liquid phases, significantly improving the efficiency of absorption processes. Unlike traditional packed bed reactors, which rely solely on gravitational forces, the RPB optimizes mass transfer by spreading fluids over high-surface-area packing material in a compact, high-performance configuration. This mechanism allows for more effective absorption, distillation, and reactive processes[4] [5]. As illustrated in Fig. 1, the compactness of RPB systems, when compared to conventional tower-packed beds, highlights their potential for reducing the spatial requirements and increasing the efficiency of CO_2 capture. The smaller footprint and higher mass transfer rates make RPB a transformative technology in the field of carbon dioxide capture, as it addresses many of the limitations of traditional systems, such as high energy consumption and large operational space [6].

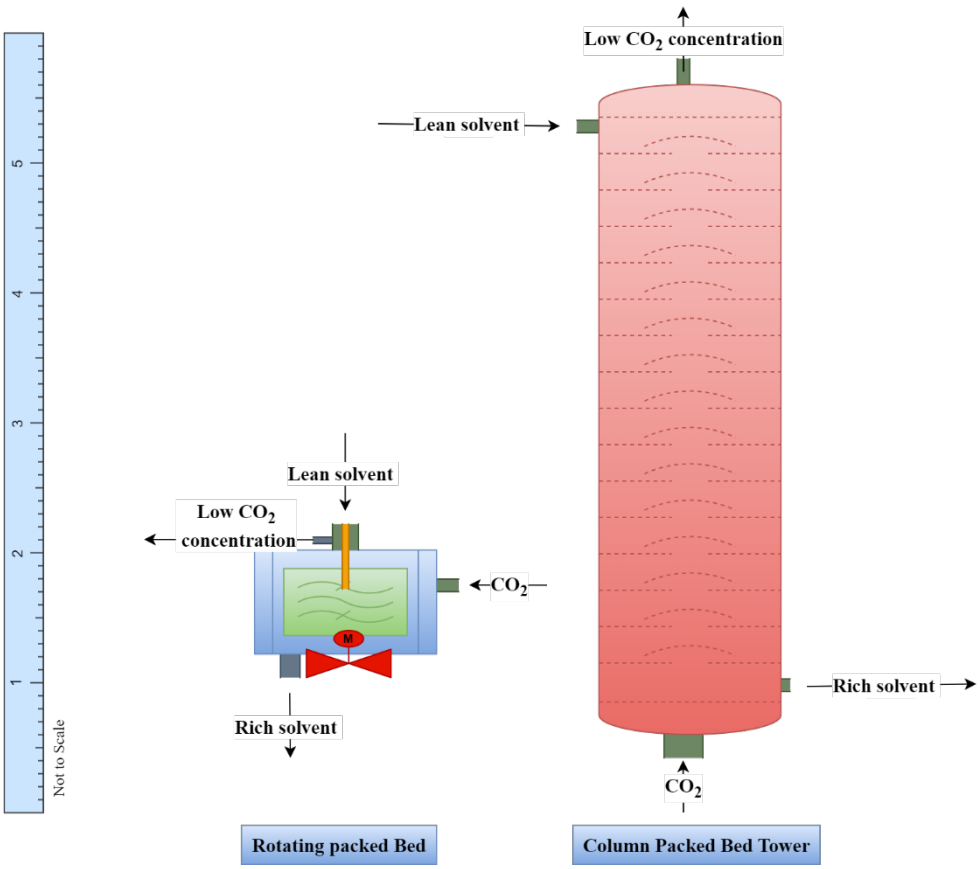

Fig. 1. Comparison of Rotating Packed bed and traditional Column Bed.

The mass transfer coefficient (KGa), a key performance metric in CO_2 capture, plays a pivotal role in evaluating the efficiency of RPB systems. This coefficient quantifies the rate at which CO_2 is transferred from the gas phase to the liquid phase per unit area, driven by a concentration gradient[7][8]. This coefficient combines the effects of both molecular and convective mass transfer phenomena and is generally expressed in units of mol/(m^3·s·Pa) or m^3/(m^2·s)[9]. It is influenced by various factors, including solvent properties, flow dynamics,

and operational conditions. The ability of an RPB to achieve higher KGa values, through centrifugal force, allows for faster absorption and greater capture efficiency, often exceeding 90% in real-world applications. This makes RPB a superior choice in terms of both performance and operational cost-effectiveness, as it minimizes solvent usage while enhancing CO_2 capture efficiency [10][11].The selection of appropriate solvents is a critical determinant of RPB system performance. The effectiveness of CO_2 absorption depends largely on the solvent's absorption capacity and its regeneration efficiency. Solvents that possess high absorption capacities for CO_2 and low regeneration energy requirements are particularly desirable in RPB applications, as they contribute to higher KGa values and reduced operational costs. Recent research has shown that innovative solvent formulations, including blends and new chemical classes, can significantly improve the performance of RPB systems by optimizing the absorption process, reducing the need for large volumes of solvent, and decreasing the size of the equipment [12] [13]. By selecting the right solvent, it is possible to enhance both the efficiency and the sustainability of CO_2 capture processes, which are crucial for industrial-scale adoption.

Moreover, RPB technology's scalability is another key advantage. The ability to adapt the technology for use in diverse industrial contexts, ranging from large-scale power plants to smaller-scale manufacturing facilities, positions RPB as a versatile solution for global carbon mitigation efforts [14] [15] [16]. Its compact design and high efficiency make it suitable for retrofitting existing infrastructure, thereby facilitating the widespread adoption of CO_2 capture technologies across various sectors. The potential for scaling RPB systems allows industries to reduce carbon emissions cost-effectively, helping to meet stringent environmental regulations while supporting the transition to a low-carbon economy.
In this context, this study aims to investigate the impact of solvent selection on the mass transfer coefficient. This study aims to explore the relationship between solvent selection and the performance of RPB systems, focusing on their impact on mass transfer coefficients and CO_2 capture efficiency. By examining various solvent formulations and their interactions within RPB units, we seek to provide valuable insights into optimizing carbon capture processes. Understanding how solvent properties influence performance is key to enhancing RPB technology and promoting its adoption in real-world applications. Ultimately, this research will contribute to advancing the industrial-scale deployment of CO_2 capture solutions and supporting global efforts to mitigate climate change through more efficient and sustainable carbon capture technologies [17].

2 Methodology

An overview of the methodology used in this study is illustrated in Fig. 2. The approach begins with comprehensive data collection, focusing on carbon capture technologies using RPB systems. The primary source of data was literature obtained from the Scopus database, specifically limited to studies investigating CO_2 capture in RPB systems. This ensured that the scope of analysis remained relevant and consistent with the study's objectives. The data collection targeted key parameters critical to evaluating RPB performance. These parameters included solvent types (such as primary, secondary, tertiary, and blended amines, as well as other emerging solvents), operational variables (rotational speed in RPM, gas flow rate, and liquid flow rate), and performance metrics (overall mass transfer coefficient, KGa). This selection aimed to provide a holistic view of the operational and performance characteristics of RPBs for CO_2 capture. To ensure the data was reliable and suitable for analysis, a rigorous preprocessing step was undertaken. First, the raw data from various sources were screened for completeness and consistency. Any duplicate or irrelevant entries were removed. Key operational and performance variables were converted into a common unit system where

necessary, allowing for a standardized comparison across studies. For example, gas and liquid flow rates were adjusted to uniform units of m^3/s or kg/s, while KGa values were expressed in consistent units ($mol/m^2 \cdot s \cdot Pa$) to ensure comparability. Missing data were addressed through a systematic process. Entries with significant gaps that could bias the analysis were excluded. For less critical variables, interpolation or estimation techniques were considered if sufficient contextual information was available. This step minimized data loss while maintaining analytical integrity.

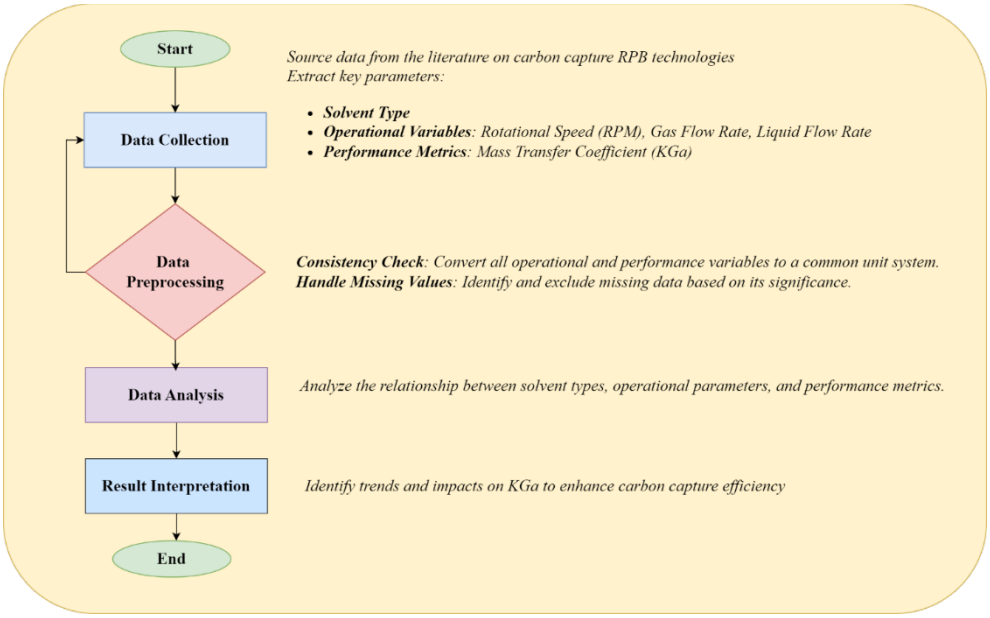

Fig. 2. Overview methodology.

3 Results and Discussion

Mitigation, highlights key descriptive statistics of various solvents used in the process as highlighted in Table 1. These solvents exhibit distinct characteristics that directly influence their performance in carbon capture applications. DETA demonstrated moderate mean efficiency (3.54) with a relatively low variability (standard deviation of 0.88). The range spanned from a minimum of 2.38 to a maximum of 4.63, with interquartile values indicating stable performance (25th percentile: 3.05, 75th percentile: 4.12). Similarly, MEA showed a mean efficiency of 2.51, with a smaller sample size and reduced variability (standard deviation: 0.50), suggesting consistent results. In contrast, MDEA exhibited a significantly lower mean efficiency of 0.07 with minimal variability (standard deviation: 0.01). Its compact range (minimum: 0.055, maximum: 0.09) reflects limited deviation in performance, indicating its use in highly controlled environments. NaOH [18], with the largest sample size (n=80), had a mean of 0.54 and higher variability (standard deviation: 0.33), revealing its broad applicability across varying conditions. Blended solvents demonstrated more diverse performances. PZ/DETA[19] stood out with the highest mean efficiency (6.03) and variability (standard deviation: 1.51), emphasizing its potential for high-capacity capture systems. Similarly, PZ/MEA recorded a mean of 5.79 with a slightly higher variability (standard deviation: 1.67), reflecting its robustness. Other blends, like PZ/H2O and PZ/DEG/H2O[20], exhibited mean efficiencies of 3.34 and 2.62, respectively, with moderate variability, highlighting their versatility.

Table 1. Descriptive statistics of various solvents [$\mathbf{s^{-1}}$]

Solvent	Count	Mean	Std Dev	Min	25%	50%	75%	Max
DETA	5	3.54	0.88	2.38	3.05	3.53	4.12	4.63
MDEA	32	0.07	0.01	0.05	0.06	0.07	0.08	0.09
MEA	5	2.51	0.50	1.80	2.27	2.53	2.84	3.10
NaOH	80	0.54	0.33	0.13	0.25	0.46	0.78	1.42
PZ/DEG	9	2.72	1.12	0.78	2.05	3.17	3.55	3.99
PZ/DEG/H_2O	18	2.62	1.04	0.67	1.94	2.85	3.45	3.76
PZ/DETA	37	6.03	1.51	3.12	4.85	5.81	7.23	8.75
PZ/H_2O	18	3.34	1.10	1.071	2.85	3.90	4.12	4.41
PZ/MEA	37	5.79	1.67	2.58	4.52	5.45	7.23	8.75

This statistical analysis underscores the critical role of solvent selection in enhancing carbon capture efficiency. Solvents like PZ/DETA and PZ/MEA demonstrate exceptional potential for high-performance industrial applications, while others, such as MDEA, are suited for niche applications. These insights pave the way for optimizing solvent systems in rotating packed beds, enabling targeted industrial adoption for effective carbon mitigation. The scatter plot in Fig. 3 illustrates the impact of rotational speed (RPM) on the kGa across various solvents used in rotating packed beds for carbon capture, with data points color-coded by solvent type. High-performing solvents such as PZ/MEA and PZ/DETA consistently achieve the highest kGa values, particularly at mid-range RPMs (600–1000), demonstrating their superior responsiveness to increased rotational speeds and enhanced mass transfer performance. In contrast, moderate-performing solvents like MEA, PZ/H_2O, and PZ/DEG show intermediate kGa values, with gradual improvements as RPM increases, though their peak performance remains lower than that of PZ/MEA and PZ/DETA. Low-performing solvents such as NaOH and MDEA display consistently low kGa values across all RPMs, indicating minimal sensitivity to rotational speed and limited mass transfer efficiency. Variability in performance is evident, particularly for high-performing solvents, which exhibit significant scatter, potentially influenced by operational conditions or experimental factors. The results highlight that optimal kGa for solvents like PZ/MEA and PZ/DETA is achieved within specific RPM ranges, beyond which further increases in RPM offer diminishing returns. This analysis underscores the critical role of both solvent selection and operational parameters, such as RPM, in optimizing the efficiency of rotating packed beds for industrial carbon capture applications.

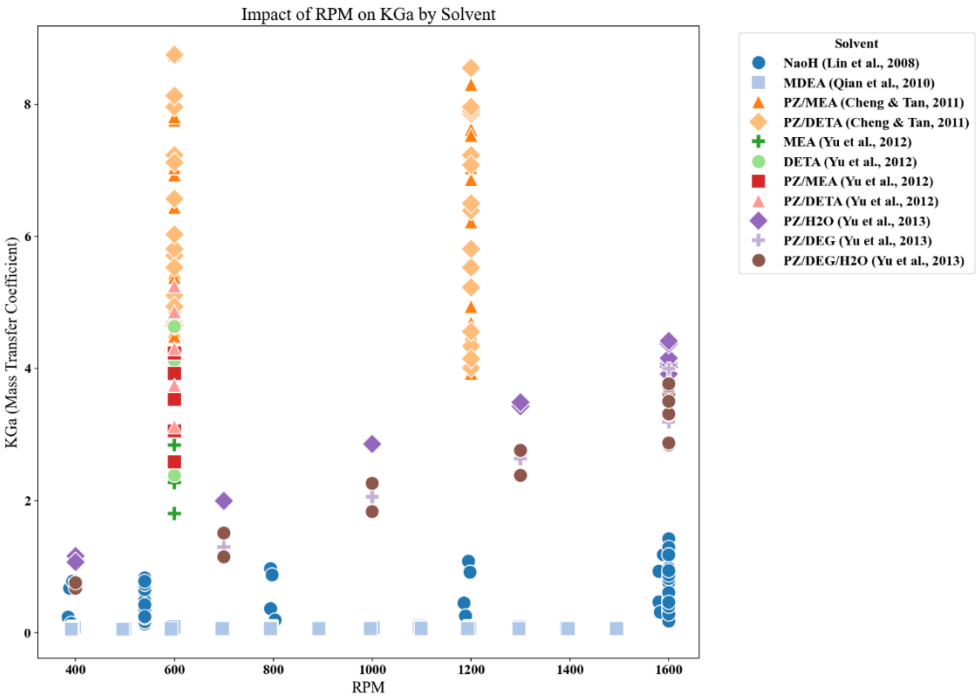

Fig. 3. Impact of rotational speed on the mass transfer coefficient.

Fig. 4 visualizes the relationship between gas flow rate and KGa for different solvents in a rotating packed bed system used for carbon capture. The x-axis shows the gas flow rate, ranging from approximately 500 to 4000 (likely in units of m^3/h or similar), while the y-axis represents the KGa, which appears to range from 0 to 8 (in units of s^{-1}). The data points are color-coded and marked with different symbols to represent various solvents, as indicated in the legend. the scattered distribution of the data points, suggest that different solvents exhibit varying mass transfer performance at different gas flow rates. There appears to be a cluster of higher KGa values around the 2500-3000 gas flow rate range for some solvents, indicating potentially optimal operating conditions. The plot effectively demonstrates that solvent choice significantly affects the mass transfer efficiency in the carbon capture process. Some solvents show consistently higher mass transfer coefficients across different flow rates, while others display more variable performance. This information would be valuable for industrial applications, as it helps identify which solvents might be most effective for carbon capture under specific operating conditions in rotating packed bed systems.

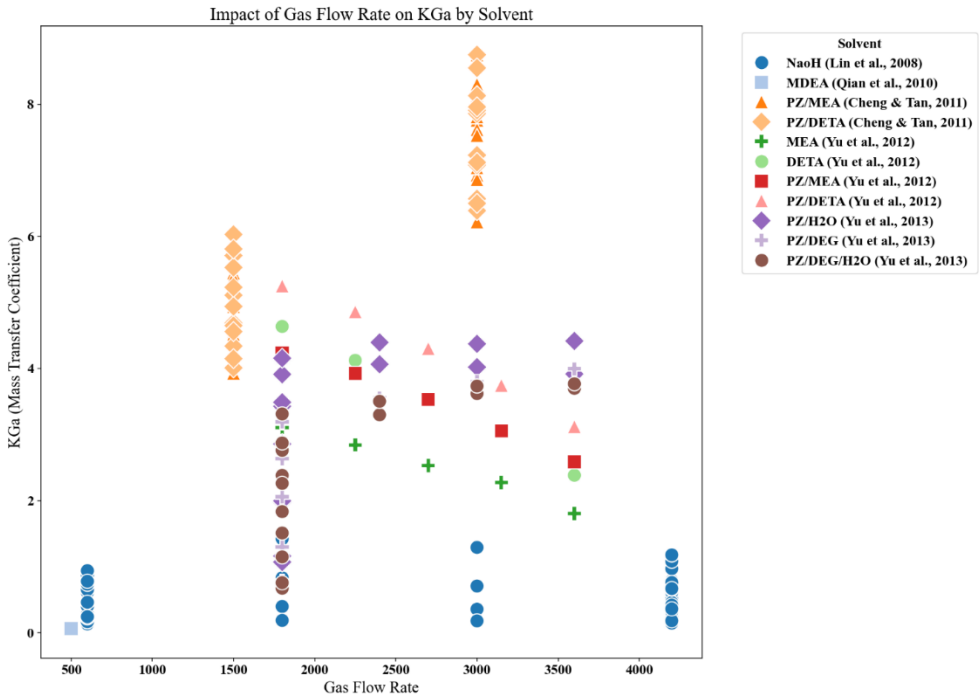

Fig. 4. Gas flow rate and mass transfer coefficients for different solvents.

The relationship between liquid flow rate and KGa for different solvents in a rotating packed bed system is illustrated in Fig. 5. The concentration of higher KGa values at lower liquid flow rates. There appears to be a clear trend where mass transfer efficiency generally decreases as liquid flow rate increases. This suggests that higher liquid flow rates might actually be detrimental to the carbon capture efficiency in these systems. The data points are most densely clustered in the lower flow rate region, with several solvents showing their best performance there. In contrast, at higher liquid flow rates, the KGa values are consistently lower, typically below 2, regardless of the solvent used. This could indicate that there's an optimal liquid flow rate range for operating these systems, likely in the lower end of the spectrum. This visualization complements the previous gas flow rate plot by showing that the liquid phase behavior is just as critical in determining the overall efficiency of the carbon capture process.

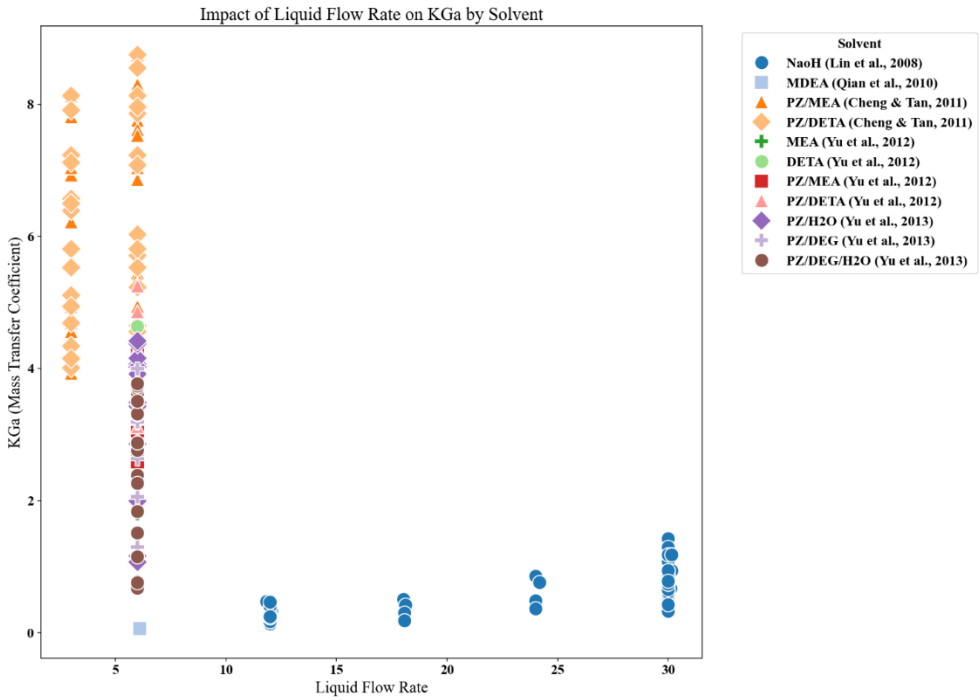

Fig. 5. Liquid flow rate and KGa for different solvents in a rotating packed bed system.

The box plot in Fig. 6 illustrates the variation in mass transfer coefficients (kGa) across different solvents used in rotating packed beds for carbon capture. NaOH and MDEA exhibit the lowest kGa values, with narrow ranges, indicating limited mass transfer efficiency and minimal variability. In contrast, PZ/MEA[21] and PZ/DETA achieve the highest kGa values, with significantly higher medians and wider ranges, reflecting superior performance but also greater variability. MEA shows moderate kGa values, with its median positioned between the higher-performing solvents (PZ/MEA and PZ/DETA) and the lower performing ones (NaOH and MDEA). Solvents like PZ/H_2O, PZ/DEG, and PZ/DEG/H_2O display intermediate kGa values with narrower interquartile ranges, indicating consistent but slightly less efficient performance compared to PZ/MEA and PZ/DETA[22]. The absence of significant outliers suggests consistent data across all solvents. Overall, the plot highlights that solvent choice plays a critical role in determining the mass transfer efficiency, with PZ/MEA and PZ/DETA[23] standing out as the most effective for enhancing carbon capture in rotating packed beds.

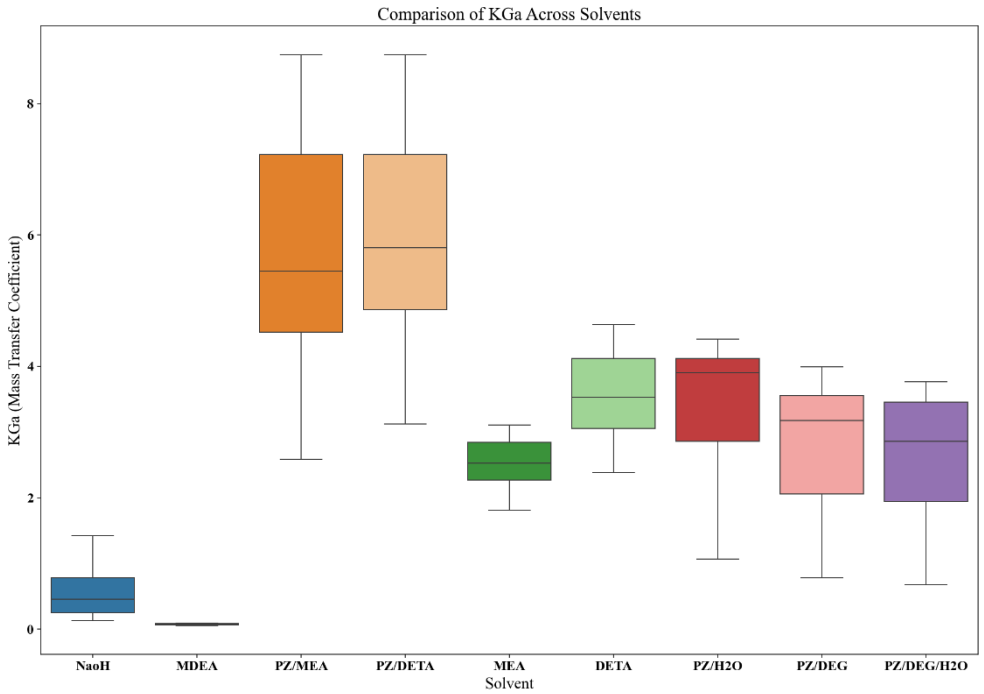

Fig. 6. Box plots to compare kGa performance across different solvents.

The correlation matrix illustrates the relationships between key operational parameters rpm, gas flow rate, liquid flow rate, and kGa in the context of carbon capture efficiency using rotating packed beds in Fig. 7. The diagonal values represent a perfect correlation (1.00), as each variable is entirely correlated with itself. The correlation between rpm and both gas flow rate (0.03) and liquid flow rate (0.07) is very weak, indicating that rotational speed has minimal influence on these flow rates. Additionally, the slightly negative correlation between rpm and kGa (-0.05) suggests that changes in rpm have negligible effects on the mass transfer coefficient. A moderate positive correlation is observed between gas flow rate and kGa (0.24), indicating that increasing the gas flow rate can moderately enhance the mass transfer coefficient and, potentially, carbon capture efficiency. Conversely, there is a moderate negative correlation between liquid flow rate and kGa (-0.49), suggesting that higher liquid flow rates may reduce the mass transfer coefficient due to potential limitations in mass transfer efficiency under higher liquid loads. Furthermore, the weak positive correlation between gas flow rate and liquid flow rate (0.13) indicates limited interaction between these two variables. Overall, the analysis highlights the critical need to balance operational parameters to optimize performance. While rpm appears to have a negligible impact in this setup, the interplay between gas flow rate, liquid flow rate, and kGa underscores the importance of carefully managing flow rates to maximize mass transfer efficiency in rotating packed beds.

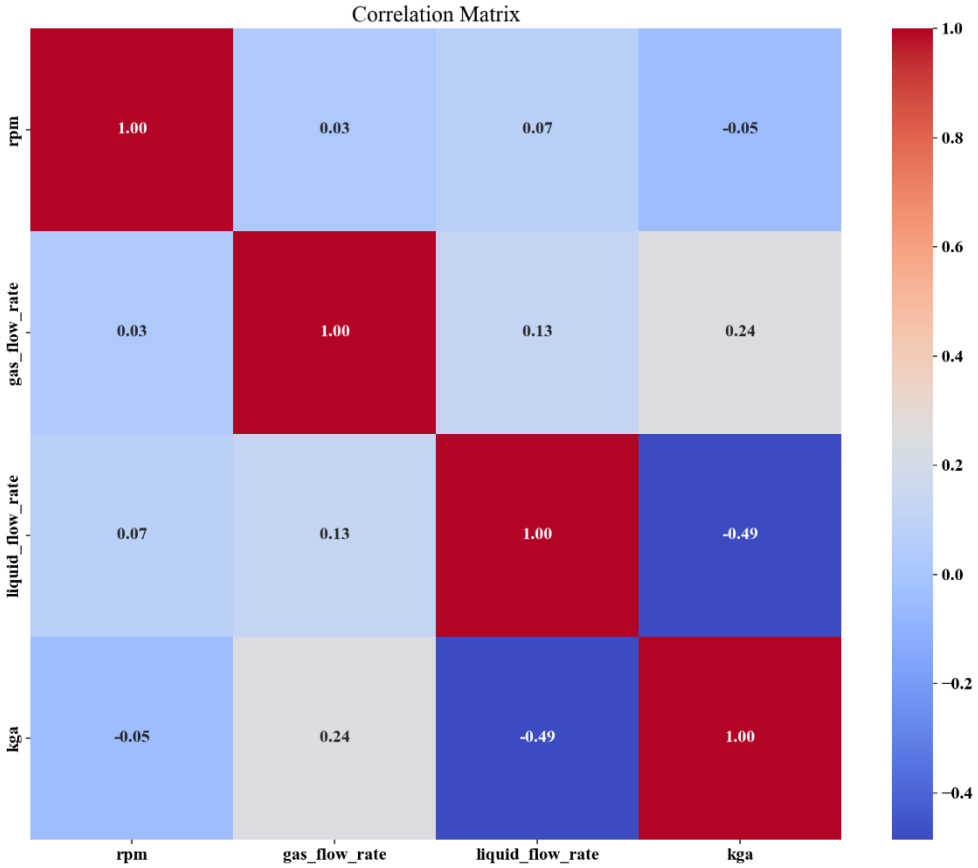

Fig. 7. This study. Heat maps - correlations between variables

The dataset highlights a limited range of solvents studied, potentially restricting the generalizability of conclusions. Solvent properties, such as viscosity, volatility, chemical stability, and absorption capacity, significantly influence the mass transfer performance. A broader spectrum of solvents, including primary, secondary, tertiary amines, and blended amines, would enable a comparative evaluation to identify optimal candidates for specific industrial contexts. This limitation underscores the need for further experimental exploration and data collection to include both conventional and emerging solvents. Key operational parameters RPM, gas flow rate, and liquid flow rate show varied impacts on KGa across solvents. RPM, reflecting the intensity of rotational mixing, demonstrates a positive correlation with KGa, particularly for low-viscosity solvents. This finding aligns with the hypothesis that higher mixing rates improve the interfacial area for mass transfer. Similarly, gas flow rates contribute to enhanced mass transfer by increasing contact between gas and liquid phases. However, the liquid flow rate's influence appears more nuanced, with a potential trade-off between maximizing liquid film renewal and avoiding flooding or excessive liquid holdup. The correlation matrix indicates moderate to strong relationships between operational parameters and KGa, suggesting that parameter tuning could significantly enhance system performance. However, industry-specific influences, such as feed composition and temperature, remain underrepresented in the dataset. Incorporating these variables in future studies would provide a more comprehensive understanding of real-world performance. The lack of industry-specific reporting in the dataset restricts the

application of findings to practical scenarios. Carbon capture technologies must account for diverse industrial emissions, ranging from power plants to refineries, each with unique challenges such as flue gas composition, pressure, and operational constraints. Bridging this gap requires collaboration with industries to generate contextual data and validate lab-scale findings at a pilot or industrial scale.

4 Conclusion

This study highlights the superior performance of PZ-based blended solvents in RPB systems for carbon capture, emphasizing several key findings. Firstly, the rotational speed significantly affects mass transfer efficiency, with higher RPMs generally leading to improved performance. These results provide valuable insights for the industrial implementation of RPB technology in carbon capture processes, indicating that optimized solvent selection and tailored operating conditions can significantly enhance capture efficiency. However, the study also reinforces the critical role of solvent choice and operational parameters in maximizing the effectiveness of rotating packed beds. While promising trends in mass transfer enhancement are observed through parameter optimization, limitations in solvent diversity and a lack of industry-specific reporting may restrict the broader applicability of these findings. To facilitate industrial adoption and realize the transformative potential of RPB technology for carbon mitigation, future research should focus on expanding the solvent database to encompass a wider range of chemical categories, integrating industry-specific operational data for contextual analysis, and developing predictive models using machine learning to identify optimal parameter-solvent combinations for various industrial applications. Addressing these gaps will not only enhance the effectiveness of carbon capture technologies but also support global climate goals and promote sustainable industrial practices.

References

1. K.-L. Zhu, Y.-J. Li, Q. Ma, H.-K. Zou, G.-W. Chu, and B.-C. Sun, Removal of catalyst particles in the fluid catalytic cracking slurry oil by chemical settling in a rotating packed bed, *Sep Purif Technol*, 332, 125722, (2024). https://doi.org/10.1016/j.seppur.2023.125722
2. V. Kumar et al., CO_2 Capture from Flue Gas on a Pilot Scale Using Porous Carbon Prepared from Cotton Stalk Crop Residues through an Industrially Viable Activation Process, *Ind Eng Chem Res*, 63(10), 4714–4729, (2024). https://doi.org/10.1021/acs.iecr.3c04117
3. S. Munjal, M. P. Duduković, and P. Ramachandran, Mass-transfer in rotating packed beds-II. Experimental results and comparison with theory and gravity flow, *Chem Eng Sci*, 44(10), 2257–2268, (1989). https://doi.org/10.1016/0009-2509(89)85160-7
4. H. Jung, N. Park, and J. H. Lee, Evaluating the efficiency and cost-effectiveness of RPB-based CO_2 capture: A comprehensive approach to simultaneous design and operating condition optimization, *Appl Energy*, 365, 123251, (2024). https://doi.org/10.1016/j.apenergy.2024.123251
5. J. Koop et al., Separation of Volatile Organic Compounds from Viscous Liquids with RPB Technology, *Ind Eng Chem Res*, 62(34), 13637–13645, (2023). https://doi.org/10.1021/acs.iecr.3c01597
6. C. Shukla, P. Mishra, and S. K. Dash, A review of process intensified CO_2 capture in RPB for sustainability and contribution to industrial net zero, *Front Energy Res*, 11, 1135188, (2023). https://doi.org/10.3389/fenrg.2023.1135188
7. Y. Liu, Z. Liu, R. Kang, and Y. Guo, Characteristics of gas pressure drop in cross-flow rotating-packed bed, *Huagong Xuebao/Journal of Chemical Industry and Engineering (China)*, 58(4), 869–874, (2007). [Online]. Available: https://www.scopus.com/inward/record.uri?eid=2-s2.0-34248659428&partnerID=40&md5=d1fc745be16686b9a6b73d9b1b92e0e7

8. V. M. Nouroddinvand and A. Heidari, CFD simulation of geometrical parameters effects on the hydrodynamic characteristics and CO_2 absorption efficiency of Arc-RPB, *Chem Eng Res Des*, 200, 157–168, (2023). https://doi.org/10.1016/j.cherd.2023.10.036
9. J.-H. Li, X.-P. Li, and Y.-Z. Liu, Mass-transfer studies in a rotating packed bed, *Huabei Gongxueyuan Xuebao/Journal of North China Institute of Technology*, 26(1), 42–45, (2005). [Online]. Available: https://www.scopus.com/inward/record.uri?eid=2-s2.0-15744375074&partnerID=40&md5=48785dd1858eafbb32c99b367a585f9c
10. N. Sarna, Rotating packed bed technology: An effective approach to carbon capture, *TND India*, (2024). [Online]. Available: https://www.tndindia.com/rotating-packed-bed-technology-an-effective-approach-to-carbon-capture/
11. A. S. Joel and Y. M. Isa, Experimental study on the effect of process parameters on postcombustion CO_2 capture using rotating packed bed technology, *Energy Sci Eng*, 1736, (2024). https://doi.org/10.1002/ese3.1736
12. M. Sheng et al., Mass-Transfer Characteristics of the CO_2 Absorption Process in a Rotating Packed Bed, *Energy Fuels*, 30(5), 4215–4220, (2016). https://doi.org/10.1021/acs.energyfuels.6b00074
13. O. Akpolat, ROTA-CAP: An Intensified Carbon Capture System Using Rotating Packed Beds, (2023). [Online]. Available: https://netl.doe.gov/sites/default/files/netl-file/O-Akpolat-GTI-Rotating-Packed-Beds.pdf
14. T.-W. Wu, Y.-T. Hung, M.-T. Chen, and C.-S. Tan, CO_2 capture from natural gas power plants by aqueous PZ/DETA in rotating packed bed, *Sep Purif Technol*, 186, 309–317, (2017). https://doi.org/10.1016/j.seppur.2017.05.040
15. C. Xie et al., Low-Concentration CO_2 Capture from Natural Gas Power Plants Using a Rotating Packed Bed Reactor, *Energy Fuels*, 33(3), 1713–1721, (2019). https://doi.org/10.1021/acs.energyfuels.8b02780
16. L. N. Tande, E. Resendiz-Mora, and V. Dupont, Bioh2, heat and power from palm empty fruit bunch via pyrolysis-autothermal reforming: Plant simulation, experiments, and CO_2 mitigation, *Energies (Basel)*, 14(16), 4767, (2021). https://doi.org/10.3390/en14164767
17. G. Gecim, Y. Ouyang, S. Roy, G. J. Heynderickx, and K. M. Van Geem, Process Intensification of CO_2 Desorption, *Ind Eng Chem Res*, (2022). https://doi.org/10.1021/acs.iecr.2c01689
18. C.-C. Lin, B.-C. Chen, Y.-S. Chen, and S.-K. Hsu, Feasibility of a cross-flow rotating packed bed in removing carbon dioxide from gaseous streams, *Sep Purif Technol*, 62(3), 507–512, (2008). https://doi.org/10.1016/j.seppur.2008.02.019
19. H. Li, Z. Qian, Y. Yao, and K. Guo, Removal of H_2S by N-methyldiethanolamine and diethanolamine in a rotating packeal bed, *Beijing Huagong Daxue Xuebao (Ziran Kexueban)/Journal of Beijing University of Chemical Technology (Natural Science Edition)*, 37(5), 21–24, (2010). [Online]. Available: https://www.scopus.com/inward/record.uri?eid=2-s2.0-78049255327&partnerID=40&md5=26661d9a2355f4cd56e6a8e000dc1e3f
20. Z. Qian, L. Xu, Z. Li, W. Dai, and K. Guo, Gas-liquid mass transfer accompanied by reversible reaction in rotating packed bed, *Huagong Xuebao/CIESC Journal*, 61(4), 832–838, (2010). [Online]. Available: https://www.scopus.com/inward/record.uri?eid=2-s2.0-77951998847&partnerID=40&md5=a1002e437d3ef253f75aa4ec47bb44e5
21. H.-H. Cheng and C.-S. Tan, Removal of CO_2 from indoor air by alkanolamine in a rotating packed bed, *Sep Purif Technol*, 82(1), 156–166, (2011). https://doi.org/10.1016/j.seppur.2011.09.004
22. C.-H. Yu, H.-H. Cheng, and C.-S. Tan, CO_2 capture by alkanolamine solutions containing diethylenetriamine and piperazine in a rotating packed bed, *Int J Greenh Gas Control*, 9, 136–147, (2012). https://doi.org/10.1016/j.ijggc.2012.03.015
23. C.-H. Yu, H.-H. Cheng, and C.-S. Tan, CO_2 capture by alkanolamine solutions containing diethylenetriamine and piperazine in a rotating packed bed, *Int J Greenh Gas Control*, 9, 136–147, (2012). https://doi.org/10.1016/j.ijggc.2012.03.015