College of Engineering and Computer Science
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Announces the Ph.D. Dissertation Defense of

Abhishek Ratanpara

for the degree of Doctor of Philosophy (Ph.D.)

Microfluidic Investigation of Green Carbon Capture, Storage, and Utilization Using Waste Concrete and Seawater

3 PM, November 3rd, 2025
EW 36, Room 187
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ABSTRACT OF DISSERTATION:

Carbon capture, utilization, and storage (CCUS) technology has emerged as a primary engineering pathway to mitigate global warming and climate instability. For carbon capture, amine-based absorption and stripping are widely used due to their high capture efficiency and retrofit compatibility. However, these systems generate toxic wastewater, consume large volumes of freshwater, and require significant regeneration energy. For carbon utilization and storage, deep saline aquifers and carbon dioxide (CO_2)-assisted enhanced oil recovery (EOR) have been proven to be feasible options at the industrial scale; however, concerns remain about long-term subsurface storage integrity and limited efficiency in carbonate reservoirs containing more than 60% oil. Hence, there is a need for an environmentally aligned and economically viable solution that can achieve long-term, sustainable CCUS. This dissertation proposes a waste-derived seawater-based approach that couples CO_2 capture, utilization, and storage. The approach utilizes the most artificially abundant waste solid, waste concrete, with the most naturally abundant aqueous medium, seawater. Waste concrete increases seawater's alkalinity and supplies additional calcium ions, which eliminates the need for freshwater while enhancing seawater's CO_2 dissolution and stabilization capacity. Through well-controlled microfluidic investigations, we quantified that waste concrete can favorably alter seawater's chemistry, with an enhanced dissolution coefficient of 530 $\mu m^2/s$ to 835 $\mu m^2/s$, resulting in a 4-fold increase in dissolved inorganic carbon from 0.034 M to 0.13 M, equivalent to a 400% increase in carbon capture. To utilize carbonated seawater containing captured CO_2, a novel carbonate reservoir-mimicking microfluidic platform was fabricated from polydimethylsiloxane mixed with calcium carbonate. Sessile droplet tests confirmed strong oil-wet characteristics with contact

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angles of 138.6° in deionized water and 130.9° in seawater. Flooding experiments demonstrated that the carbonated seawater-concrete solution recovered 30.4% of the original oil in a random porous network, compared to 39.9% of the conventional toxic chemical flood. These results demonstrate that concrete-activated seawater can increase CO_2 capture, convert it into a mineral form, and function as a displacement fluid for enhanced oil recovery within a single integrated system. Most importantly, the proposed method replaces conventional, costly chemicals or freshwater with a greener and cost-effective CCUS medium. The findings provide a basis for further study on economic feasibility, scale-up, and long-term application of the proposed approach for CCUS.

BIOGRAPHICAL SKETCH

CONCERNING PERIOD OF PREPARATION
& QUALIFYING EXAMINATION

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Time in Preparation: August 2021 to December 2025

Qualifying Examination Passed: spring 2022.

Published Papers:

- **Ratanpara Abhishek,** Yaofa Li, and Myeongsub Kim." A Review of Microfluidic Approaches for Carbon Capture and Storage Research." Lab on a chip, 2025.

- **Ratanpara Abhishek**, Joshua Donjuan, Camron Smith, Marcellin Procak, Ibrahima Aboubakar, Philippe Mandin, Riyadh I. Al-Raoush, Rosalinda Inguanta, and Myeongsub Kim. "Hybrid Huff-n-Puff Process for Enhanced Oil Recovery: Integration of Surfactant Flooding with CO_2 Oil Swelling." Applied Sciences (2076-3417) 14, no. 24 (2024).

- **Ratanpara Abhishek**, Myeongsub Kim, Yeo Jun Kim, and Carlos H. Hidrovo. "Spectral Characteristics of Water-Soluble Rhodamine Derivatives for Laser-Induced Fluorescence." Journal of Fluorescence (2024): 1-13.

- Hafez, Mazen, Mahyar Ghazvini, Kostiantyn Ostapchuk, Mohammadhassan Kavosi, Yaofa Li, **Abhishek Ratanpara,** and Myeongsub Kim. "Understanding Characteristics of Gravitational Particle Settling Using Particle Image Velocimetry." Physics of Fluids 36, no. 3 (2024).

- **Ratanpara Abhishek**, and Myeongsub Kim. "Wettability Alteration Mechanisms in Enhanced Oil Recovery with Surfactants and Nanofluids: A Review with Microfluidic Applications." Energies 16, no. 24 (2023): 8003.

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- **Ratanpara Abhishek**, Alexander Shaw, Mallory Thomas, Rajesh N. Patel, and Myeongsub Kim. "Microfluidic Analysis of Seawater-Based CO_2 Capture in an Amine Solution with Nickel Nanoparticle Catalysts." Journal of CO_2 Utilization 53 (2021): 101712.

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- Mazen Hafez, **Abhishek P. Ratanpara**, Yoan Martiniere, Maxime Dagois, Mahyar Ghazvini, Mohammadhassan Kavosi, Philippe Mandin, and Myeongsub Kim. "CO_2-Monoethanolamine-Induced Oil Swelling and Viscosity Reduction for Enhanced Oil Recovery." Journal of Petroleum Science and Engineering 206 (2021): 109022.

Conference Proceedings and Presentations:

- **Abhishek Ratanpara**, Adib Narsabadi, and Myeongsub Kim. "Enhancing Oil Recovery Using Carbonated Seawater Based Waste Concrete Solution Flooding: A Microfluidic Approach." 77th Annual Meeting of the APS Division of Fluid Dynamics, Salt Lake City, Utah, 2024. (Presenter)

- Myeongsub Kim, Joshua Donjuan, and **Abhishek Ratanpara**. "Polymer-Dispersed Nanoparticles for Catalytic Carbon Capture in Natural Seawater." 77th Annual Meeting of the APS Division of Fluid Dynamics, Salt Lake City, Utah, 2024. (Presenter)

- **Abhishek Ratanpara** and Myeongsub Kim. "Waste Concrete and Seawater for Green Carbon Capture and Utilization." The University of Miami Clean Energy Summit, Florida, 2024. (Presenter)

- Participation in Whole Value Chain CCUS Conference Week, Colorado, 2022. (Selected Candidate)

- **Abhishek Ratanpara** and Myeongsub Kim. "Microfluidic Analysis of Seawater-Based Concrete Solution for Carbon Capture and Storage." 8th Thermal and Fluids Engineering Conference (Hybrid), Maryland, 2022. (Presenter)

- **Abhishek Ratanpara** and Myeongsub Kim. "Green CO_2 Capture using Waste Concrete and Natural Seawater." 74th Annual Meeting of the APS Division of Fluid Dynamics, Arizona, 2021. (Presenter)

- **Abhishek Ratanpara**, Alexander Shaw, and Myeongsub Kim "Environmentally Benign Carbon Capture and Storage using Seawater for Air and Ocean Water Quality." 13th International Conference on Challenges in Environmental Science and Engineering (CESE2020), 2020. (Presenter)

- **Abhishek P. Ratanpara**, Alexander Shaw, Saurabh Deshpande, and Myeongsub Kim. "Utilization of Ocean Water for CO_2 Capture via Amine Scrubbing." Proceedings of the ASME 2020 39th International Conference on Ocean, Offshore and Arctic Engineering, Virtual, Online, 2020. https://doi.org/10.1115/OMAE2020-19215