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USING ION BEAM IRRADIATION METHOD TO CHANGE THE ATOMIC STRUCTURES OF MATERIALS TO ENHANCE THEIR ABILITY TO TRAP CARBON DIOXIDE

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Abstract—**The reduction of atmospheric CO_2 requires thought-provoking ideas that would help reduce the concentration level in the atmosphere. In this study, the authors suggest the atomic modification of zeolite materials through controlled electron and ion beam damage to increase their carbon capture capacities. Zeolite samples were synthesized by hydrothermal method and subsequently, two different types of electron beam irradiation were performed on the samples. In the inert gas medium, zeolite samples were irradiated to restrict the structural degradation. In contrast, the vacuum medium which had a raster magnet was the other type which allowed a wide dispersion of the electron beam. The absorbed keratins ranged from 500 kGy to 1000 kGy, and the progression encouraged structural changes in the zeolites to increase the CO_2 adsorption uptake. The results have shown that lewis acid zeolite shows increased uptake of CO_2 forming an exceptionally high adsorbed volume of 87.86 cm^3/g at 500 kGy. The generation of modified zeolites has made it possible to use the innovative Carbfix technique which incorporates the dissolved CO_2 in water and then pumps it into the basalt layers and harnesses the natural occurrence of minerals to fix the CO_2. The methods of modified samples were examined by PXRD, FE-TEM and FE-SEM techniques, TGA and spectrometric methods.**

Keywords—**Zeolite, carbon capture, electron beam irradiation, carbfix technology, CO_2 sequestration, climate change mitigation, atomic modification, mineralization.**

I. INTRODUCTION

In the face of an increasing climate crisis around the world, one of the biggest concerns remains the lowering of emissionns of greenhouse gases, more specifically carbon dioxide. CO_2 is one of the barycentric gases associated with global warming and the development of newer methods for capturing and storing it will help in combating climate issues. Recently developed zeolites – a family of microporous aluminosilicate materials – represent a durable and tunable material which is optimal for carbon capture. However, the problem of CO2 sequestration is that its adsorption capacity remains low in ambient conditions thus making designs around them complex as they expect the respective structures to be efficient.

Herein we report a new approach based on electron and ion beam irradiation for altering the atomic structure of zeolite and expect an increase in CO2 adsorption capacity. Ion beam technology makes it possible to make atomic-scale changes to structure and hence introduce a range of defects and pores that will improve CO2 interaction with the material. In this experiments, zeolites (Na-A) samples are synthesized via hydrothermal method and were irradiated through the electron beam applying different doses of irradiation during advanced beam line setups.

In order to increase the effectiveness and utility of this modified zeolite, the study employs the Carbfix technology, which captures CO2 and transforms it into a stable carbonate mineral through reaction with the basalt formations. Such a combined method provides a synergy: improved efficiency of CO2 capture and its safe everlasting disposal, and thus solves both environmental and industrial problems.

Assessment of the principles of Powdered X-Ray Diffraction (PXRD), Field Emission Transmission Electron

Microscopy (FE-TEM), and thermogravimetric analysis was conducted in order to evaluate the irradiated zeolites for physical and chemical alterations. Preliminary findings show that there is an improvement in the capacity of the minerals to adsorb CO2 however the highest level was recorded at the point where an absorbed dose was 500 kGy.
The potentials of zeolites and carbon capture technologies are expanded with the contribution of this research by offering a novel approach towards the improvement of zeolite's performance in combination with gf technology. With the use of a two-pronged strategy that includes atomic modification and geological sequestration, this approach proposes a radical new paradigm to combat climate change and build a new environmentally friendly society.

II. LITERATURE REVIEW

The urgent demand for effective mitigation methods to combat climate change has generated a tremendous interest in materials capable of capturing and sequestering atmospheric carbon dioxide. Zeolites, which are classified as microporous aluminosilicates, are among the candidates that hold promise due to their large surface area and tunable framework structures, thereby allowing the selective sorption of gaseous species. Although promising, zeolites' carbon capture efficiency often becomes limited under ambient conditions and thus need innovative approaches to enhance their performance. One of the promising methods of improving the CO_2 adsorption capacity of zeolites is through radiation-induced modifications, in particular by electron beam irradiation.
Many studies have explored the possibility of atomic scale modification through structural changes using ion beam irradiation.
Ugurlu et al. in (2011) study electron beam irradiation-induced effects about zeolite destruction under it whereby increased defect concentrations are accounted for improved CO_2 capture characteristics. Vacancies, in particular, and also the interstitials need to be formed in the crystal lattice; these defects make gas molecules interact with which an effectuates to improve the overall sorption abilities of zeolite itself. Further study by Murge et al. (2019) shows that the alteration of zeolite structures using ion beam techniques can significantly affect their adsorptive characteristics. By optimizing irradiation conditions such as dosage and energy, it is possible to produce defective zeolites with higher capacities for CO_2 capture. The results of the experiment show that irradiated zeolites exhibit changes in porosity and surface chemistry, which impact their ability to adsorb greenhouse gases. The relationship between defect generation and CO_2 uptake has also been studied systematically.
For instance, a recent analysis shows that reduced levels of electron irradiation as low as around 500 kGy induce positive changes that result in improved CO_2 adsorption, whereas high doses resulted in degradation and lowered the adsorption capacity. This is supported by the theoretical models presented by Boer et al. (2023), which suggests that controlled irradiation may be used to transform zeolites into effective adsorbents for CO_2 capture via strategic defect engineering. Investigations into mechanistic understanding of knock-on damage transitions driven by electron beam irradiation provide key insights into the nature of effects of structural changes to the functionality of zeolites. According to Blaine et al. (2018), interaction of electrons with zeolite framework leads to significant changes in material's crystallinity and stability. Through their study, it brings out the importance of conserving structural integrity in acquiring high CO_2 adsorption efficiencies, especially in industry. Another area of research in which huge synergy has been reported is in the integration of improved zeolite structures with advanced carbon capture technologies, including Carbfix. Carbfix technology converts CO_2 into stable carbonate minerals; it is a permanent carbon sequestration solution. This process can be enhanced by modified zeolites, which capture the CO_2 effectively before undergoing mineralization in geological formations. Actually, this study by Harris et al. (2022) hence demonstrates that defect-engineered zeolites could integrate with mineralization techniques for holistic carbon management, therefore encompassing capture and storage. With these advances, it is clear that the intentional exposure of zeolites to electron beam irradiation not only enhances their CO_2 capture capabilities but also serves a broader purpose in the pursuit of sustainability by reducing atmospheric carbon levels. Future research into optimizing ion beam parameters and exploring a greater diversity of zeolite types will be critical in advancing this field and enhancing the applied relevance of these technologies in mitigating climate change.

III. AIM OF THE EXPERIMENT

The aim of the experiment is to investigate the efficacy of electron and ion irradiation as a method for enhancing the carbon capture capacity of zeolites, with the ultimate goal of mitigating climate change. By subjecting zeolite samples to controlled electron and ion beam irradiation, the experiment induces structural modifications in the zeolite framework enhancing its ability to adsorb yet trap carbon dioxide molecules. This enhanced carbon capture capability of zeolites holds significant promise for integrating Carbfix technology to mitigate CO2 emissions and combat climate change by capturing carbon dioxide, interacting it with reactive rock formations, to form stable minerals providing a permanent and safe carbon sink removing CO2.

IV. EXPERIMENTAL DESIGN

Firstly for preparation of sample, we would conduct hydrothermal synthesis of Zeolite (Na-A):

	Phase 1 (Preparing Solution A)	**Phase 2** (Preparing Solution B)	**Phase 3** (Adding Solution A+B)
Synthesis of Zeolite (Na-A) sample	Add 100mL bottle of 0.3615g of NaOH, add 8.258g of NaAIO2 and 40 g of H2O.	Add 15.48g of Na2SiO3-9H2O and 40g of H2O	Both solutions are rapidly added, stirred until a clear solution is observed. This is placed into scintillation vial, synthesized, filtered and washed with deionized water until filtrate is neutral

The following is a displayed process of hydrothermal synthesis of Zeolite (Na-A):
We are using 2 setups for this, simplified in a table below:

	Apparatus Required	**Research Objectives**
Setup 1	T9 Beamline, BRM dipole magnet, Quadrupole magnet, Beam limiting Spectrum, 5mm aperture, Liquid hydrogen inside chamber sample insert rod, Faraday cage (safety mechanism from electromagnetic force)	1. Observing the effects of using inert gas with electron beam on the process of irradiation 2. Optimizing electron beam energy minimizing damage on zeolite in a vacuum medium 3. Studying the effects of electron beam irradiation concentrated on specific parts of the Zeolite structure
Setup 2	T9 Beamline, BRM dipole magnet, Quadrupole magnet, Beam limiting Spectrum, 5mm aperture, Raster magnet, Vacuum Pump attached to chamber, sample insert rod, Faraday cage (safety mechanism from electromagnetic force)	1. Observing the effects of using vacuum medium, with electron beam on process of irradiation 2. Understanding the material susceptibility of zeolites with minimum irradiation damage due to Hydrogen 3. Examining Structural changes of Zeolite resistance to electron beam irradiation 4. Studying the effects of electron beam irradiation localized evenly on the majority of Zeolite structure

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V. EXPERIMENT PROCEDURE

a) We prepare the zeolite sample and place it on the chip carrier in the chamber to ensure its stability during electron sputtering.
b) For Setup 1, we use a 1.6Gev electron beam from the Synchrotron that passes via bend 1, collimator, bend 2, and finally through the Cherenkov exiting the cyclic accelerator.
c) The BRM dipole applies a magnetic field to the electron beam, bending it. The electron beam next passes through quadrupole magnets, where it is focused and shaped, resulting in a well-collimated and controlled beam.
d) Eventually, the beam approaches the beam limiting spectrum, where uniform dosage distribution of radiation is controlled via aluminum plates.
e) The beam passes via an aperture with a gap of 5 mm, entering the chamber and impacting with the surface of the zeolite, atomic sputtering occurs, causing atom displacement in the zeolite composition and radiation synthesis of Na-A components in zeolites.
f) Once the Zeolite has absorbed approximately 500kGy, we will conduct radiation for about 8 minutes for an absorbed dose of 300kGy, increasing to 27 minutes for an absorbed dose of 1000kGy.
g) Solid products will be filtered, washed with deionized water until the filtrate reaches a neutral state, where they will be dried for approximately 12 hours at 80 °C.

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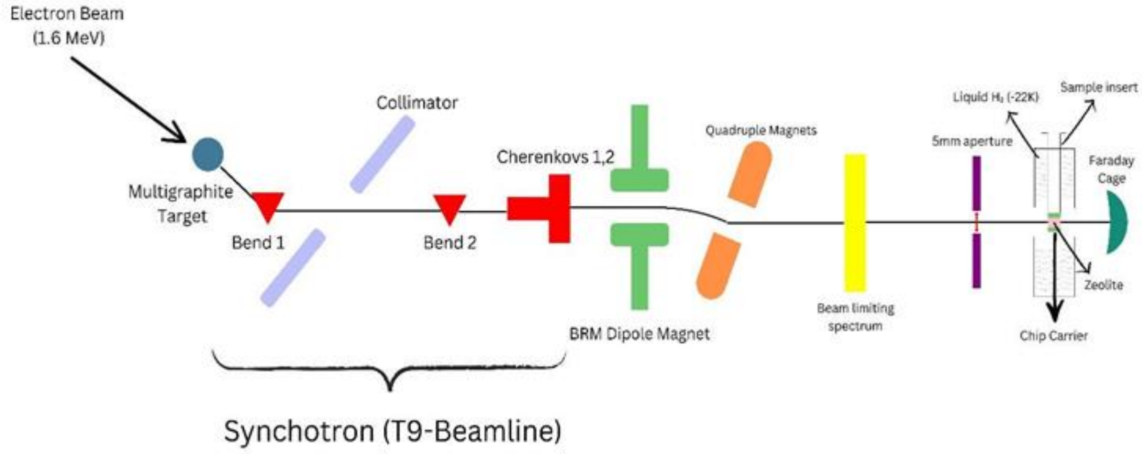
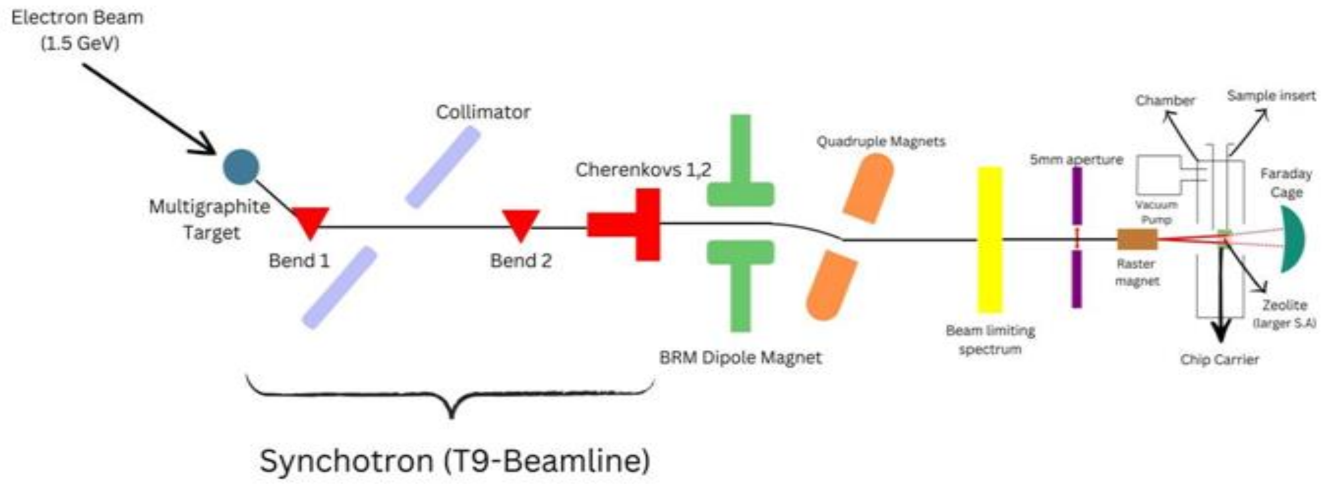


For Setup 2 the rest remains the same except we add a raster magnet after aperture for dispersion of electron beam, testing larger surfaces areas of Zeolite, this time observing the reduced and evenly localized damage on the surface of the zeolite, we use a vacuum chamber instead of inert gas, observing any produced effects a vacuum medium would have on atomic irradiation process.



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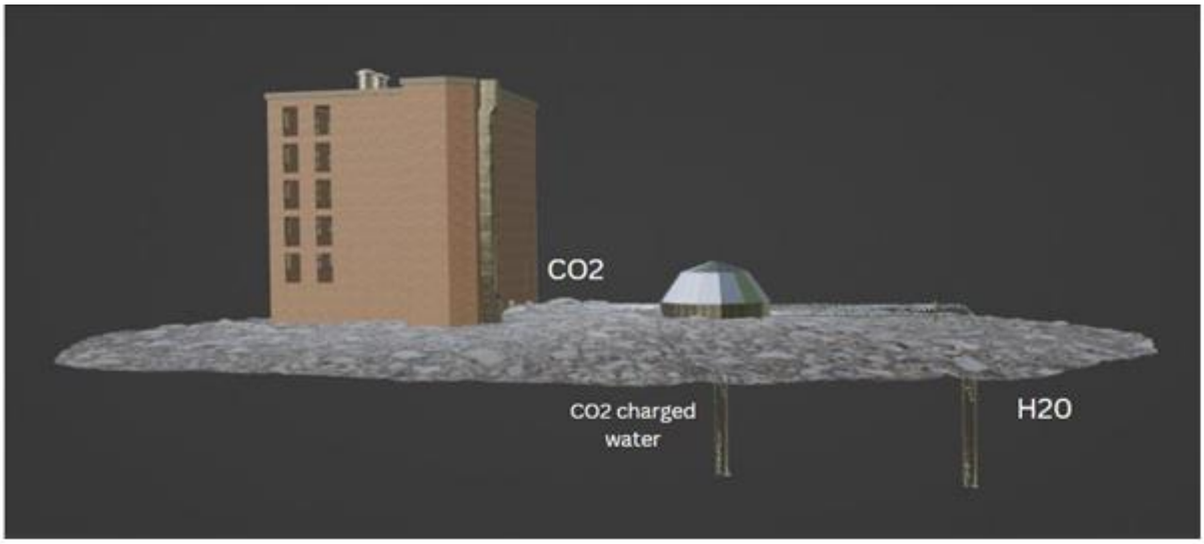
After carbon dioxide is captured, we will integrate it with the Carbfix technology to turn it into stone underground. We dissolve the carbon dioxide in water, pumping it into basaltic rock formations. Through a naturally occurring mineralization process, the carbon dioxide reacts with the basalt and solidifies into stable carbonate minerals over a few years. This way, not only do we permanently store carbon, yet also preventing its release into the atmosphere, being a promising solution in the fight against climate change.



Expected increase in Carbon dioxide adsorption capacity after electron beam irradiation:

Samples	**C02 Adsorption Capacity (cm3/g)**	**CO2 Adsorption Capacity / Mass Fraction (wt%)**
Zeolite (Na-A)- 1000kGy	86.09	17.02
Zeolite (Na-A)- 750kGy	81.77	16.17
Zeolite (Na-A)- 500kGy	87.86	17.37

VI. DATA COLLECTION AND ANALYSIS

After irradiation, enhanced observation and data will be collected by observing the structure of our crystalline zeolite, most importantly noticing how much light zeolite samples absorb at each wavelength will be conducted by the use of the following electron microscopes:

a. Powdered X-Ray Diffraction (PX-RD)
b. Field Emission transmission electron microscope (FE-TEM)
c. Field Emission scanning electron microscope (FE-SEM)
d. Fourier transform infrared spectroscopy

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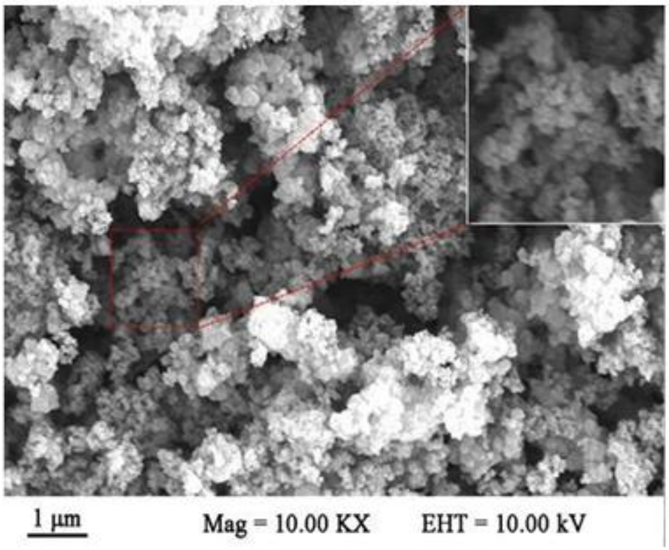
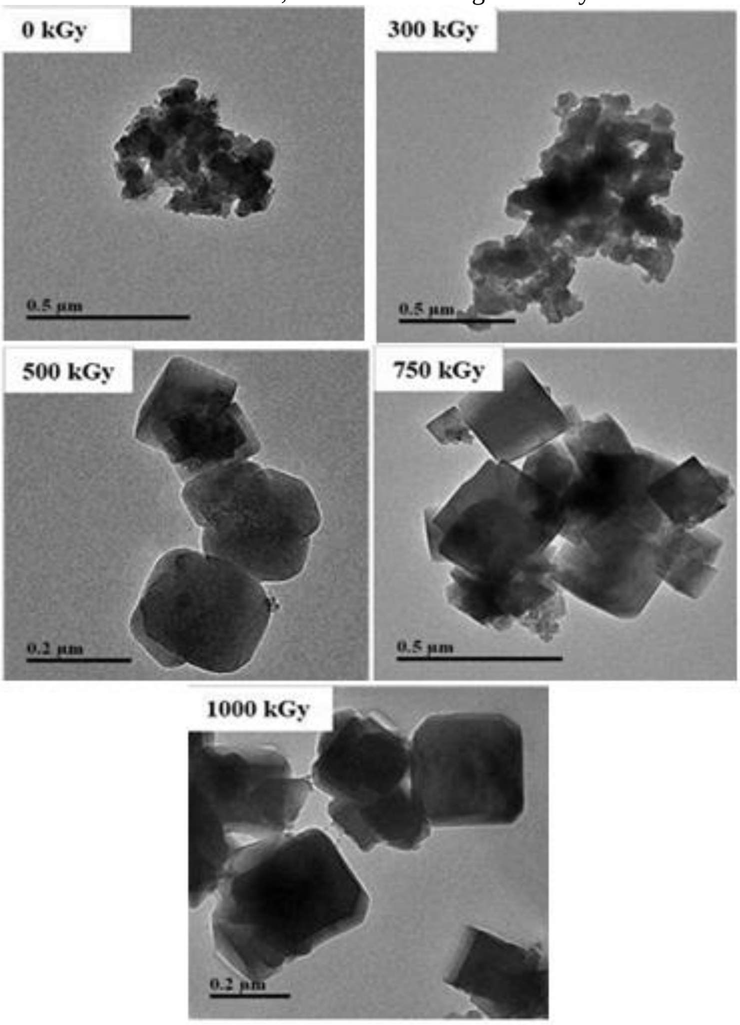


SEM image of Zeolite (Na-A) before electron irradiation, at absorbed dosage of 0kGy



TEM images capturing Zeolite (Na-A) synthesis with an electron beam with absorbed dosages of 0, 300, 500, 750, 1000kG

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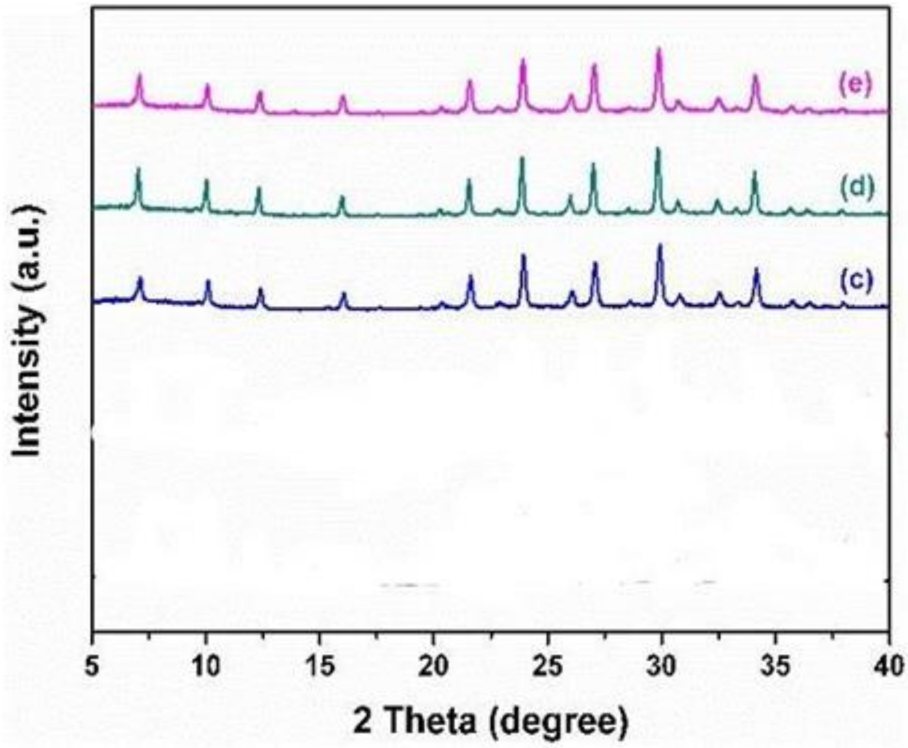
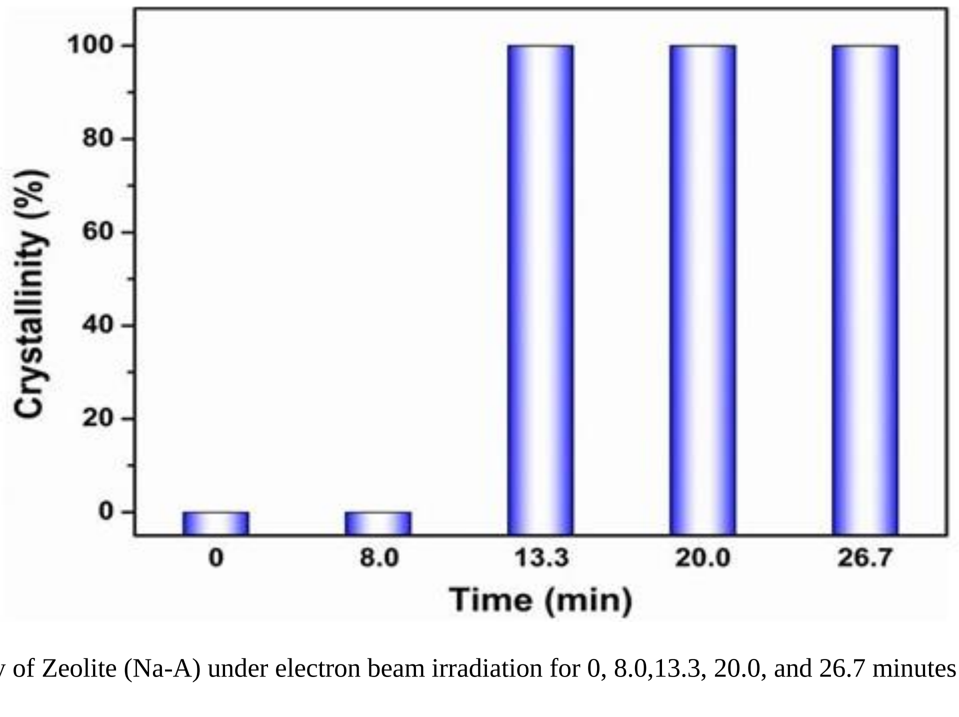
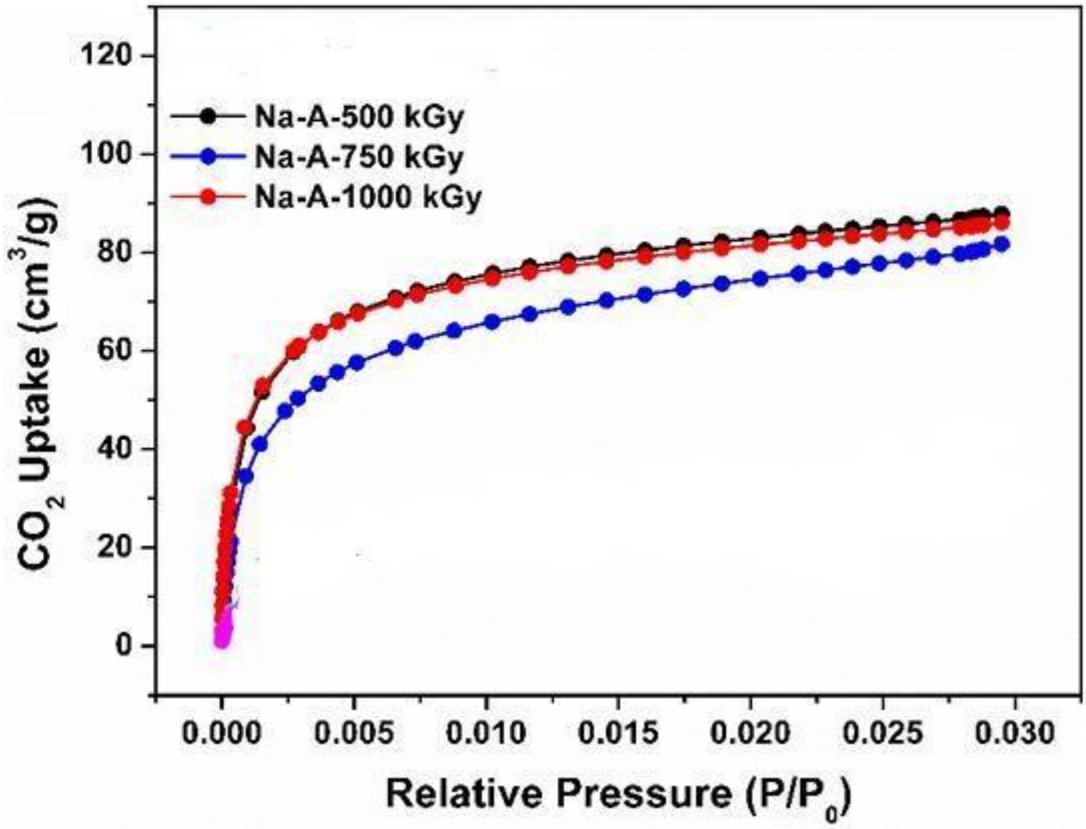


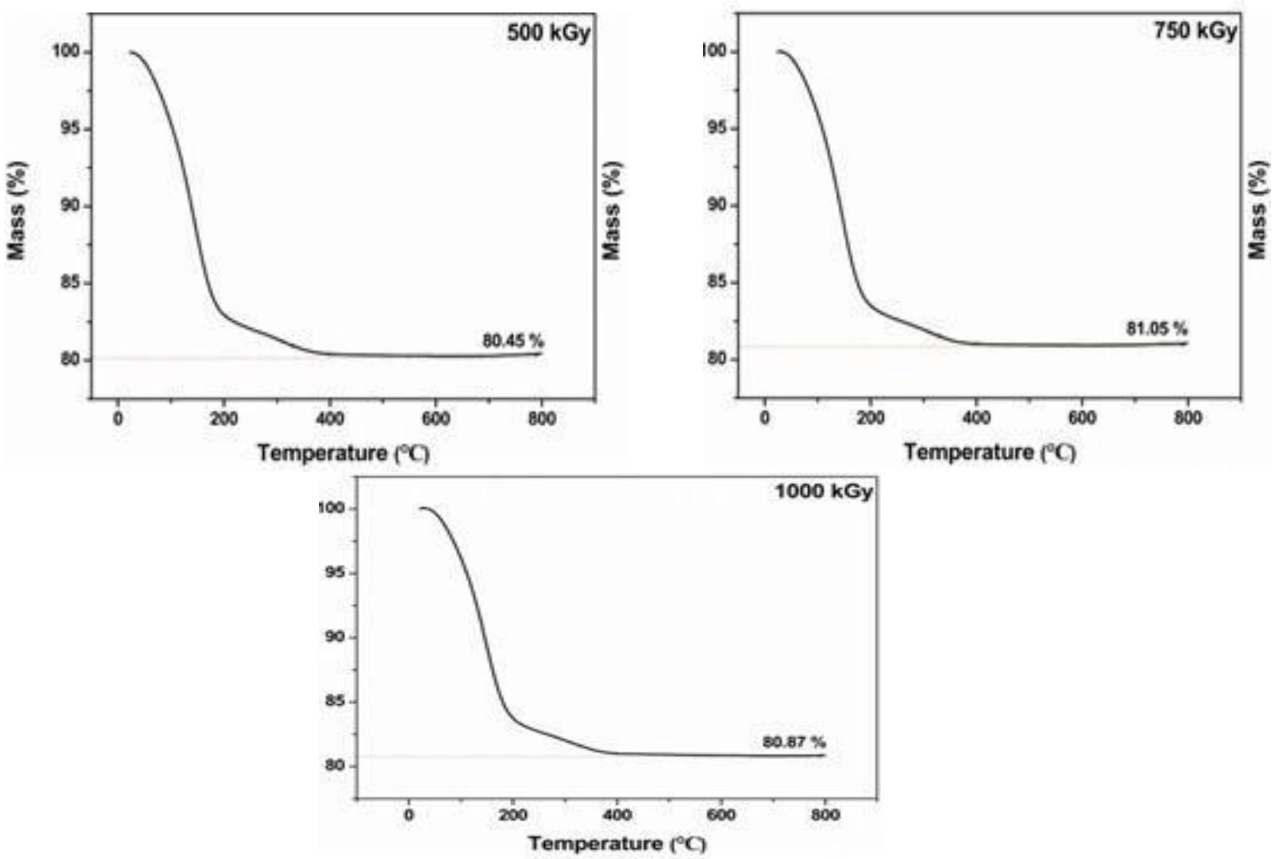
Powder X-Ray diffraction patterns of (c) Zeolite (Na-A)-500kGy, (d) Zeolite (Na-A)-750kGy,
(e) Zeolite (Na-A)-1000kGy assessing purity, particle size and lattice parameters



Observing Crystallinity of Zeolite (Na-A) under electron beam irradiation for 0, 8.0,13.3, 20.0, and 26.7 minutes



Expecting such trend of Carbon dioxide adsorption of Zeolite (Na-A) at 273 K



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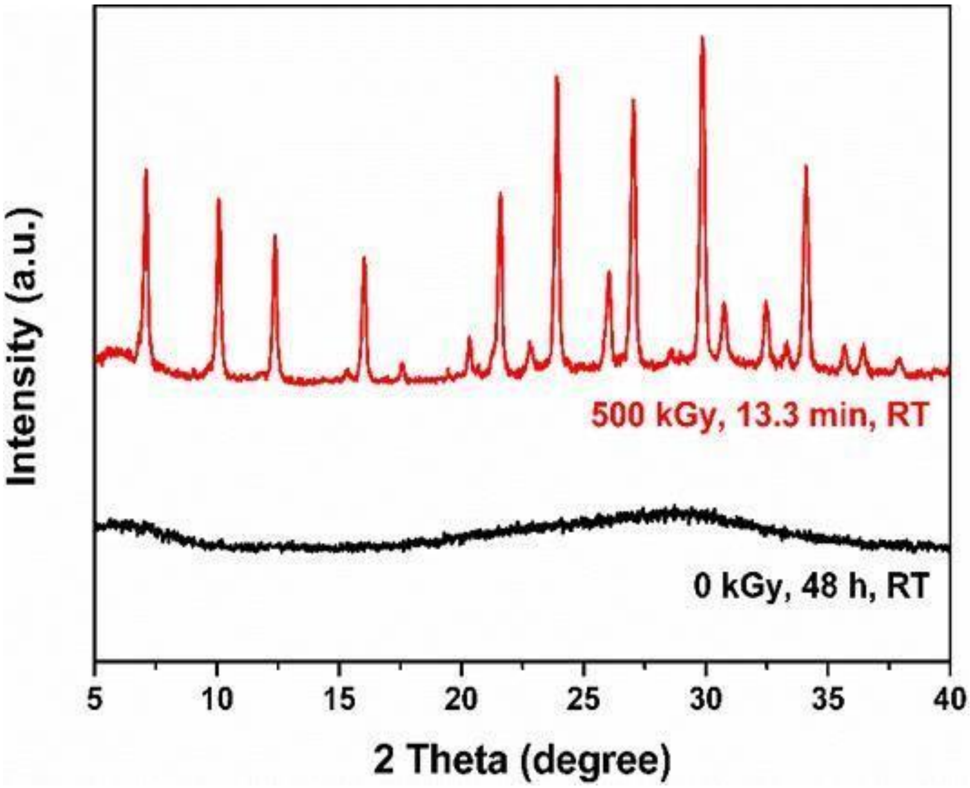
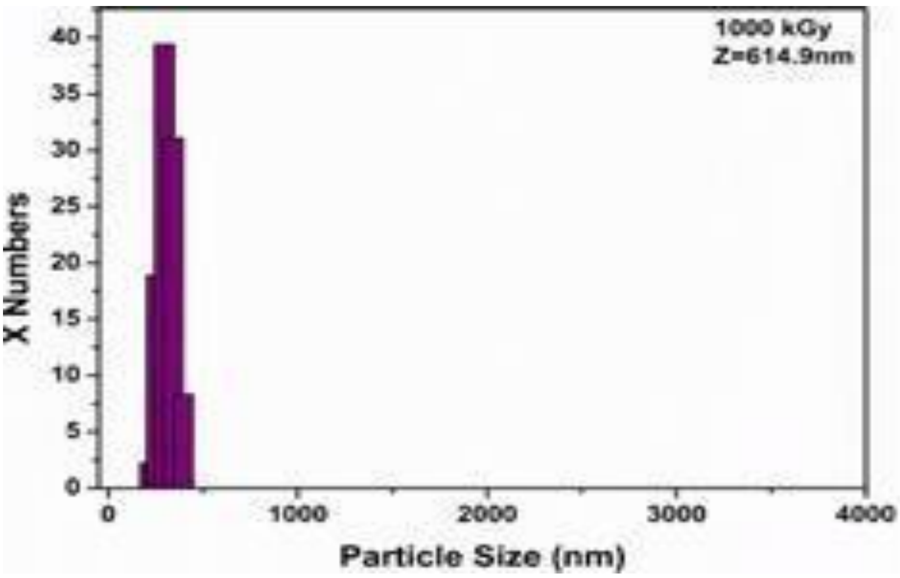
Respective Thermogravimetric Analysis (TG) curves of Zeolite (Na–A) synthesized with electron beams at doses from 500, 750 and 1000kGy displaying behavior of zeolite with temperature change



PXRD Patterns of Zeolite (Na-A) with and without electron beam irradiation



If Fourier transform infrared spectroscopy is available then such a dynamic light scattering pattern of Zeolite (Na-A) is expected to be observed, displaying particle size at radiation dosage 1000kGy:

VII. CONCLUSION

Our research results would lead us to revolutionize the atomic modification of zeolite by increasing its CO2 absorption capacity, yet simultaneously transferring CO2 to Carbfix technology, converting carbon to stone.

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