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Photocatalytic Degradation of Carcinogenic N-Nitrosodiethylamine (NDEA) in Amine-Based CO_2 Capture Using Carbon Nitride under Visible Light

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Abstract

This study aimed to degrade Nitrosodiethylamine (NDEA), a carcinogenic compound formed during CO2 capture processes due to the use of amines. CO2 emissions are one of the major contributors to global warming, and although various techniques have been developed for carbon capture, amine-based technologies remain among the most effective. However, these systems lead to the formation of hazardous nitrosamines such as NDEA. In this study, NDEA degradation was investigated under visible light (sunlight simulator) using a photocatalyst in the presence of amines, i.e., Monoethanolamide (MEA) and Diethanolamine (DEA), to simulate real-time CO2 capture conditions. Carbon nitride (C3N4) was synthesized using the thermal condensation method from urea and utilized to enhance surface area and maximize light absorption for effective electron activation and pollutant removal. UV-Vi's spectrophotometry was employed to monitor the degradation of NDEA in both catalytic and non-catalytic systems over a wavelength range of 325 nm to 1100 nm. The results indicated significant degradation with noticeable variations in absorbance due to the formation of intermediate products. A validated HPLC method using gradient elusion was further applied to quantify NDEA degradation and confirm the formation of multiple degradation products, indicating a complex degradation pathway. The findings demonstrate that while UV-Vis provides rapid monitoring of degradation trends, HPLC enables precise quantification and differentiation between NDEA and its byproducts. The study confirms that photocatalytic degradation using carbon nitride under visible light is an energy-efficient and effective approach for the removal of NDEA from amine-based CO2 capture.

Keywords: *Photocatalysis; Nitrosodiethylamine (NDEA); Carbon Nitride (C_3N_4); CO_2 Capture; Visible Light; Reactive Oxygen Species*

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1. Introduction

Climate change (CC) is one of the most serious global challenges, primarily caused by the accumulation of greenhouse gases (GHGs) in the atmosphere. These gases can trap heat, leading to a rise in global temperatures and significant environmental impacts. Among these gases, CO_2 is a major contributor and plays a key role in driving global warming. These gases have a great tendency of absorbing heat and then reverting on the surface of the earth. Emissions produced by anthropogenic means are imparting a major part of it. Among these harmful gases the CO_2 is the most pervasive Green House Gas in the Earth's atmosphere [1]. Though several forms of renewable energy sources have been developed, however, still reliance of energy production is on the use of fossil fuels [2][3][4]. Global energy demand is expected to rise two times by 2050 as compared to the present energy stock mainly because of the surge in population growth keeping in view the vast advancements in the industrial sector [5], [6], [7]. Consistent rise in industrial activities has significantly backed the environmental problems due to the production of unwanted hazardous organic pollutants, oxides of Nitrogen and CO_2. Photocatalysis has been proved to be a sustainable technology which has addressed several major issues by the means of Hydrogen produced energy and dilapidation of pollutants simultaneously [8], [9], [10], [11].

N-Nitrosamines have been reported in both the systems i.e. lab-scale and pilot scale CO_2 capture especially having flue gas and oxides of Nitrogen [12], [13]. Amine solvents upon oxidative degradation results in the creation of nitrites in the absorber. Nitrites upon reacting with secondary amines result in the formation of nitrosamines in the stripper. The chance of formation of N-Nitrosamine strongly depends on the structure of the amines used for the CO_2 capture. Amines has three degrees i.e. primary, secondary and tertiary which possess varying capabilities of forming nitrosamines. Such as, secondary amines have much more tendency to form nitrosamines than primary and tertiary amines [14], [15], [16].

Nitrosamines are potent carcinogens, especially NDEA which has been found in industrial wastewater, food and air. They are formed when secondary amines (diethanolamine) react with nitro-sating agents (nitrites, NOx). The United States' agency pertaining to environment which is commonly known as Environmental Protection Agency (EPA) has described and classified NDEA as a group B2 i.e. probable carcinogen, with a strict permissible limit of 07ng/L in drinking water. In amine-based CO_2 capture plants, nitrosamines like NDEA are byproducts of amine degradation, posing risks to environmental and human health. There is some traditional removing methods i.e. activated carbon and UV/H_2O_2 but are found to be energy-intensive or inefficient at low concentrations [17]. One of the prominent agencies of the world i.e. "The International Agency for Research on Cancer (IARC)" has categorized N-Nitrosamines as extremely potent human carcinogens, therefore, several countries have developed limits for it and are implementing strict laws on it [18].

There are three key technologies being used for CO_2 capture i.e. pre-combustion, post-combustion and oxyfuel. Post-combustion is most used due to its promising results [20]. Amine based technology being used for CO_2 capturing is the sequel of absorption method and has proved to be the most capable technology with a carbon capture efficiency of 60% [21]. The most used solvents for carbon capture are Monoethanolamine (MEA), Diethanolamine (DEA), N-methyl-diethanolamine (MDEA) and amine-blends [22]. Despite MEA & DEA being used at extensive level possess some drawbacks as well which causes the creation of nitrosamines and other toxic byproducts. Amines used in CO_2 capturing technologies and amine degradation products are water soluble, hence, water-wash systems are widely used [17]. There have been found some potential sources of nitrosamine establishment such as scrubbing systems used in post-combustion CO_2 system [24] and in disinfection of drinking water and tobacco smoke [25][32]. In addition, several other industrial manufacturing processes such as for rubber, cosmetics, food and detergents could also be deemed responsible sources of these compounds [26], [27], [28], [29].

Photocatalysis is specifically an advance "oxidation process" which practices a light source and semi-conductor catalysts to study the degradation of pollutants which might be organic or inorganic. Semi-conductors are used as photocatalysts because energy gap between their valance band and conduction band is narrow. In this process, a photocatalyst absorbs light and a chemical transfer of reactants takes place. Upon transfer of electrons from valance band to conduction band a hole is produced in the valance band and photo induced electrons in the conduction band; pair of hole-electron is known as exciton. This exciton reacts with oxidants and reductants producing oxidized and reduced products respectively [19], [30], [31].

The photocatalysis process suffers from rapid recombination of photo generated electrons and holes, limiting its practical application. Therefore, structural modification of the semi-conductor has been found effective to reduce recombination and enhance photocatalytic activity [33], [34], [35], [36].

Extensive emissions of CO_2 and the formation of Nitrosamines as a byproduct of amine-based CO_2 capture have caused severe environmental and health concerns. To the finest of our knowledge, the potential usage of carbon nitride (C_3N_4) as a photocatalyst for nitrosamine degradation in CO_2 capture has not been studied with respect to the NDEA degradation analysis. This research aims to evaluate the effectiveness of photocatalytic degradation of nitrosamines, offering an energy-efficient solution to enhance CO_2 capture processes and investigate the degradation process along with the resulting degradation products [19], [30], [31]. Comparison of recent carbon nitride-based photocatalytic studies with the present work, highlighting key differences and the novelty of NDEA degradation under CO_2 capture conditions is given below in Table 1.

Table 1 Comparison of recent carbon nitride-based photocatalytic studies with the present work, highlighting key differences and the novelty of NDEA degradation under CO_2 capture conditions.

Ref.	Study	Catalyst System	Target Pollutant	Light Source	Analytical Method	Key Findings	Limitation	Novelty in This Study
[37]	RSC Advances (2025)	Modified g-C_3N_4 composites	Dyes / emerging pollutants	UV/Visible	UV-Vis, advanced techniques	Enhanced degradation via ROS	Focus on model pollutants	This study targets NDEA in

								CO_2 capture
[38]	AIP Advances Review (2025)	Bulk and modified g-C_3N_4	Organic pollutants	Visible light	General characterization	Metal-free visible-light catalyst	Limited real-system validation	This study uses MEA/DEA system
[39]	Scientific Reports (2024)	Ag/g-C_3N_4 composite	Dye (Acid Orange 7)	UV & Visible	Kinetic analysis	High degradation efficiency	Requires metal doping	This study uses pure C_3N_4
[40]	Chemical Engineering Journal (2025)	Crystalline CN	Environmental pollutants	Visible light	Mechanistic studies	Improved charge separation	Complex synthesis	This study uses simple thermal synthesis
—	Present Study	C_3N_4 (thermal condensation)	NDEA (nitrosamine)	Visible light (420 nm)	UV-Vis + HPLC	Effective degradation via ROS	Intermediate formation	Real CO_2 capture simulation + dual validation

2. Methodology

The experimental work was conducted with careful consideration of all relevant aspects of the study, ensuring that each step was carried out with precision and attention to detail. Nitrosodiethylamine (NDEA) was targeted to be degraded through utilizing a catalyst i.e. polymeric carbon nitride (C_3N_4) under visible light having a wavelength of 420 ± 10 and thereafter, under direct sunlight, in the water-wash solution. The overall methodology for this experiment was carried out in the following order: materials collection, equipment, synthesis of C_3N_4, experimental procedure, sampling & analysis and analytical methods as shown in Fig 1.

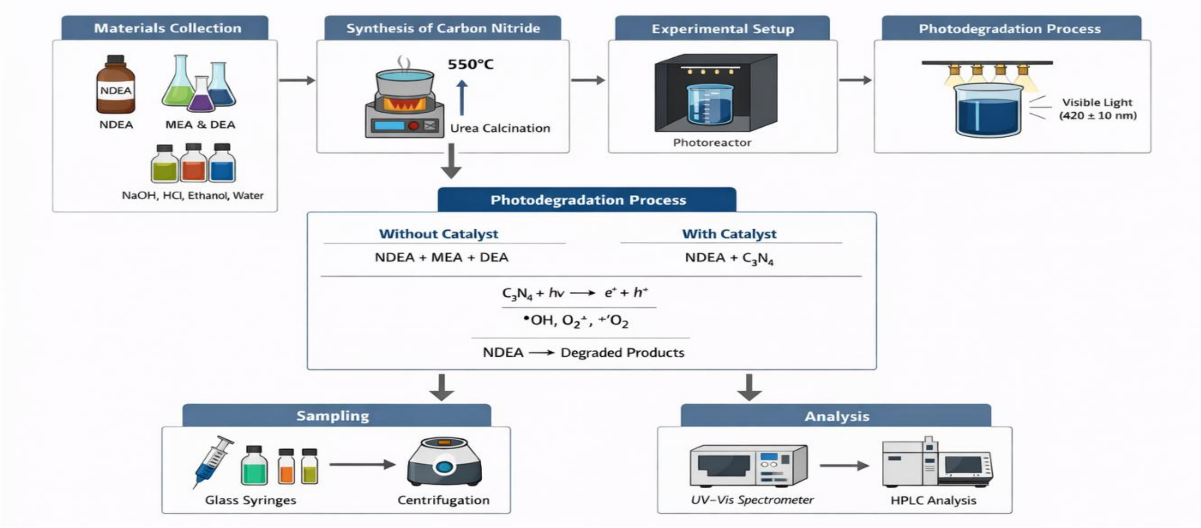

Figure 1 Schematic conceptual illustration of the experimental methodology for photocatalytic degradation of N-nitrosodiethylamine (NDEA) using carbon nitride (C_3N_4) under visible light irradiation, illustrating material preparation, catalyst synthesis, photoreactor setup, degradation pathways (with and without catalyst), sampling, and analytical techniques (UV–Vis and HPLC).

For experimental work, material collection is the main step. The targeted pollutant was N-Nitrosodiethylamine (NDEA) (purity ≥99%) which was used without any further purification. Monoethanolamine (MEA) purity ≥98% and Diethanolamine (DEA) purity ≥98% were used to mimic the real time scenario of an industrial system. Sodium Hydroxide (NaOH), Hydrochloric Acid (HCL), ethanol, methanol and distilled water were also used.

The photoreactor was made of glass beakers having a capacity of 1000 mL and 500 mL solution was used. It was transparent and covered with aluminum foil from all sides to obstruct external light. Visible light (tube lights) having a wavelength of 420 nm ±10 was used as a sunlight simulator and five tube lights were installed in series above the reactor box. A square shaped wooden box having dimensions of 2’x2’x2.5’ was used to provide dark milieu, with its inner side painted black and equipped with a door and exhaust fan. The distance between light source and solution was maintained at 6 inches and temperature was around 23°C. A UV-Vis Dual Beam Scanning Spectrophotometer (GENESYS 150) was used for measuring absorbance at different intervals.

Carbon nitride was synthesized by thermal condensation method. 30 g urea was taken in an alumina crucible and was placed in an oven for 03 hours at a fixed temperature of 550 degrees centigrade. Upon fulfilment of the said procedure the pale-yellow powder was dried at normal room temperature for 08 hours. The obtained nanoparticles were designed as C_3N_4.

Photodegradation experiments were conducted in a cylindrical glass photoreactor made of glass and wrapped with aluminum foil from its surroundings and open from the top side for the

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penetration of light. Stock solutions were made from the original/pure chemicals and used later on in various concentrations. Magnetic stirrer was also used for thorough mixing of the catalyst in the solution. The stirrer functioned as a mixing machine to mingle the solution upon the accumulation of catalyst. Samples were taken diligently with the help of glass syringe and put into the sample bottles. Aliquots were further curtailed to 05 mL when put to cuvette of UV-Vis for checking absorbance.

The stock solution of Nitrosodiethylamine (NDEA) was prepared with the concentration of 1000 mg/L and stored in a glass bottle which was heavily wrapped with aluminum foil to avoid any light penetration and stored at 04°C. Similarly, stock solutions of Monoethanolamine and Diethanolamine were also prepared and working solutions were obtained by dilution to achieve NDEA 50 mg/L, MEA 50 mg/L and DEA 25 mg/L in 500 mL solutions.

Carbon nitride was used as catalyst with loading of 500 mg per 500 mL solution, selected to avoid light scattering and ensure effective photocatalysis. Visible light (420 ±10 nm) was used to initiate photocatalysis, where carbon nitride absorbs photons and generates electron-hole pairs:

$$C^3N^4 + hv \rightarrow C^3N^4(e^-, h^+)\#(1)$$

$$C^3N^4 + hv\ (\lambda \leq 460\ nm) \rightarrow e^-(CB) + h^+(VB)\#(2)$$

The generated charge carriers migrate to the catalyst surface and participate in redox reactions:

$$C^3N^4(e^-, h^+) + H^2O \rightarrow HO\bullet + H^+ + C^3N^4(e^-)\#(3)$$

$$C^3N^4(e^-, h^+) + O^2 \rightarrow O^2\bullet^- + C^3N^4(h^+)\#(4)$$

$$e^- + O^2 \rightarrow O^2\bullet^-\ \#(5)$$

$$h^+ + H^2O \rightarrow \bullet OH + H^+\#(6)$$

Further reactions leading to formation of oxidizing species:

$$2h^+ + H^2O \rightarrow H^2O^2 + 2H^+\#(7)$$

$$O^2\bullet^- + O^2\bullet^- + 2H^+ \rightarrow H^2O^2 + O^2\#(8)$$

$$H^2O^2 \rightarrow 2\bullet OH\#(9)$$

Reactions leading to degradation of NDEA:

$$C^3N^4(e^-, h^+) + NDEA \rightarrow NDEA\ oxidized\#(10)$$

$$HO\bullet + NDEA \rightarrow NDEA\ oxidized\#(11)$$

$$O^2\bullet^- + NDEA \rightarrow NDEA\ oxidized\#(12)$$

$$^1O^2 + NDEA \rightarrow NDEA\ oxidized\#(13)$$

In these reactions, •OH radicals attack and cleave the –N=O bond in NDEA forming diethylamine and NO_3^-. Two experimental segments were performed: photolysis of NDEA with amines (MEA + DEA) without catalyst, and photocatalysis of NDEA with carbon nitride without amines. Samples were collected at regular intervals using glass syringes and analyzed using UV-Vi's spectrophotometer. Aliquots of 05 mL were withdrawn at 0 to 120 minutes at a regular interval of 10 minutes for photolysis and 0 to 80 minutes for photocatalysis, and samples containing catalyst were centrifuged prior to analysis.

A calibration curve for NDEA was constructed using standard solutions of 5, 10, 20, 25 and 50 mg/L and absorbance was measured in the range of 325–350 nm using the relation:

$$y = mx + c\#(14)$$

Absorbance measurements were carried out in the spectral range of 325 nm to 1100 nm using quartz cuvettes. HPLC analysis was performed to confirm degradation and quantify NDEA using HPLC-UV system with C18 column, flow rate of 1 mL/min, detection wavelengths of 230 nm and 340 nm, and acetonitrile as mobile phase with a total run time of 20 minutes.

3. Results and Discussion

The results obtained from the photocatalytic degradation of N-nitrosodiethylamine (NDEA) are presented and discussed in this section. Data acquired through UV–Vis spectroscopy and High-Performance Liquid Chromatography (HPLC) is systematically analyzed to elucidate the reaction pathway and evaluate the degradation behavior. Initial UV–Vis screening revealed kinetic profiles indicative of a complex reaction, which necessitated further investigation using HPLC for accurate quantification.

3.1 Calibration Curve

A five-point calibration curve was constructed for NDEA using standard solutions (05, 10, 20 & 25 mg/L prepared from a 50 mg/L stock) analyzed by UV-Vi's spectrophotometer. The absorbance was measured at 325 to 350 nm. The curve is exhibited as follows in Fig. 2.

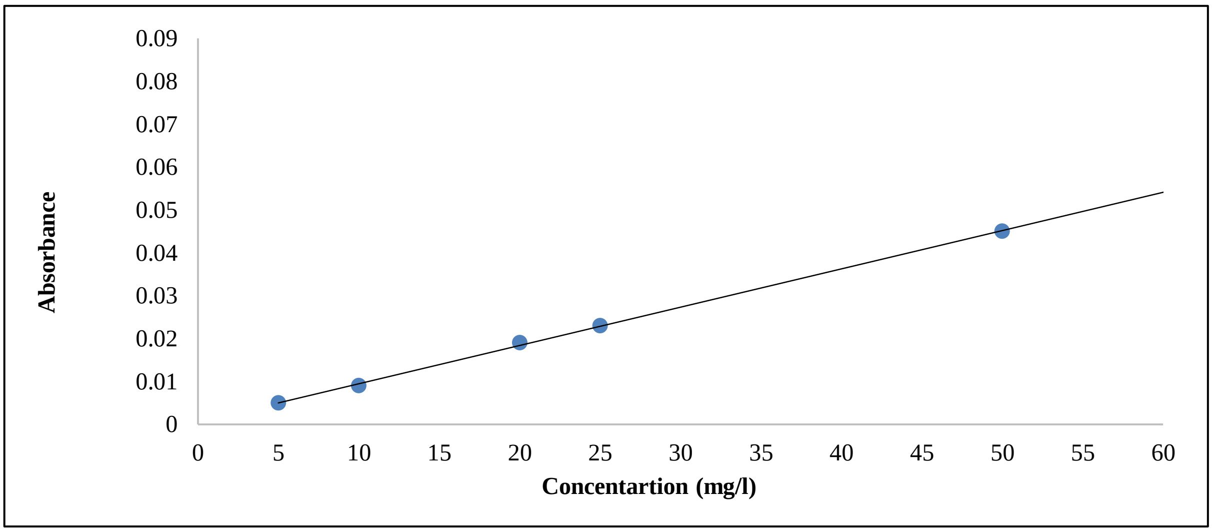

Figure 2 Calibration curve of N-nitrosodiethylamine (NDEA) at a concentration of 50 mg/L.

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3.2 Photocatalytic Degradation Behavior

The maximum peak intensity was observed at various wavelengths i.e. 336 to 348 nm, whereas weak and minimum peaks were observed at larger wavelengths such as 1076 nm. The weak absorption bands arise due to transitions and become responsible for the degradation of nitrosamines in the natural environment.

Without the use of catalysts, a quick decrease was observed in the first ten minutes; however, later the rise and fall was due to the absorbance of the intermediates. A similar kind of behavior was observed when no catalyst was used, where various elevated signals in the degradation were observed. The very cause of those variations was due to the formation of byproducts which are difficult for the UV-Vis spectrophotometer to segregate and define their absorbance separately. As shown in Fig. 3, the degradation trend of NDEA at wavelengths without catalyst highlights these fluctuations.

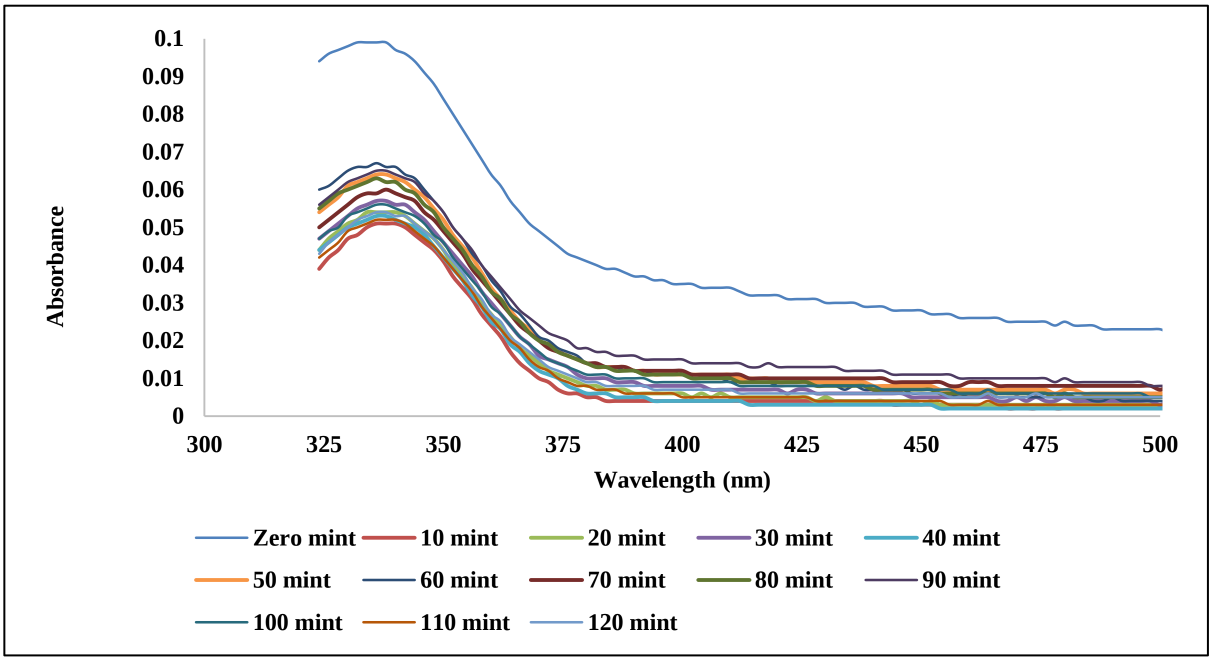

Figure 3 Degradation profile of N-nitrosodiethylamine (NDEA) at selected wavelengths in the absence of catalyst

Photodegradation took place when the catalyst was added. Firstly, NDEA was broken and byproducts were formed due to which a decrease was seen, but later it showed rise because of the absorbance of the byproducts that were formed due to the breakdown of the targeted pollutant (NDEA). Formation of products involves the successive attack of either HO•, CN(h^+) or O_2 on different parts of the molecule. The carbon nitride was able to oxidize and reduce NDEA in the solution. It was also able to reduce molecular oxygen to $O_2^{\bullet-}$ and oxidize water to hydroxyl radical.

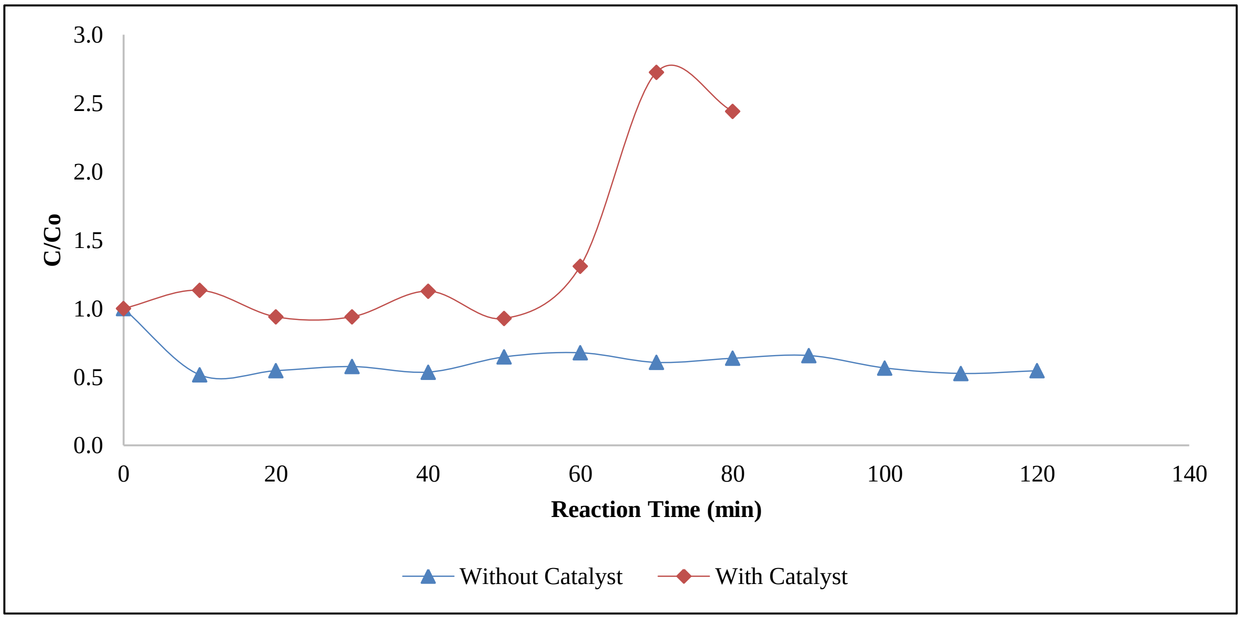

Figure 4 Degradation profile of N-nitrosodiethylamine (NDEA) concentration as a function of reaction time.

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Due to the absorbance of byproducts, the UV-Vis showed an upward trajectory which was later verified by HPLC analysis to get the true reason behind this surge as illustrated in Fig. 4.

HPLC Analysis

Chromatographic analysis revealed a significant increase in absorbance which was an accurate representation of the reaction composition. The very reason behind this is the formation of byproducts or intermediates. Furthermore, the sum of the absorbance from the remaining NDEA with addition of the absorbance from the newly made byproducts is larger than that absorbance of the earlier NDEA that was present initially.

To get specific and selective data, the HPLC technique is the most effective method to adopt which provides the constituent compounds in that mixture. Moreover, clear evidence of NDEA's depletion was targeted to be obtained which was obscured in the UV-Vis data. Hence, utilizing HPLC was an essential step towards knowing the true picture of the scenario of rise in the absorbance as depicted in Fig.5 and 6 and in Table 2 and Table 3 respectively.

These samples were analyzed by HPLC for quantification of the NDEA. HPLC analysis at 340 nm successfully quantified the definitive degradation of the targeted analyte which was free from the interference of byproducts that confounded the UV analysis. The reduction in an absolute area confirmed the consumption of the parent compound i.e. NDEA.

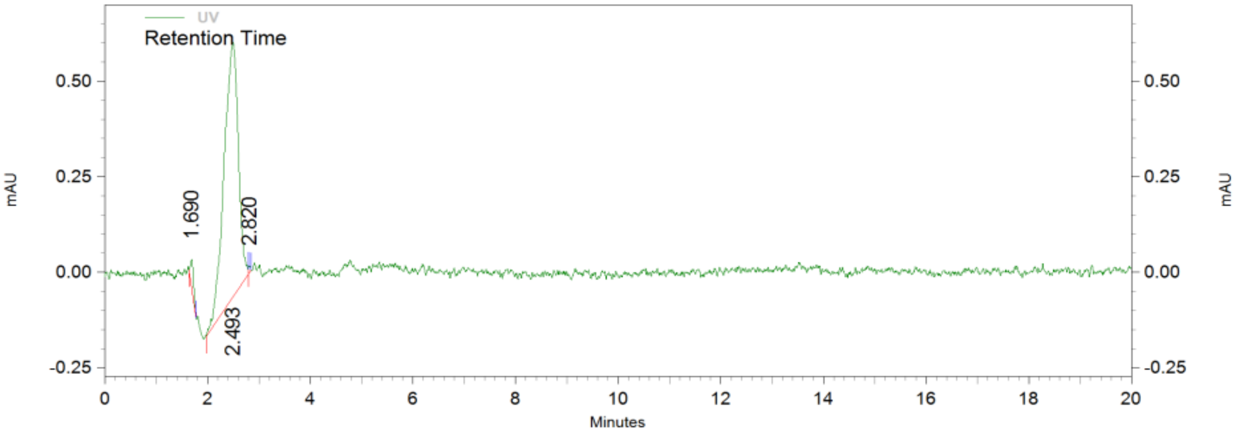

Figure 5 HPLC chromatogram of N-nitrosodiethylamine (NDEA) at 0 min measured at 340 nm.

Table 2 HPLC analysis of N-nitrosodiethylamine (NDEA) at 0 min measured at 340 nm.

Name	Retention Time	Area	Area %	Integration Codes	
	1.69	1287	2.424	BB	
	2.493	51627	97.23	BV	
	2.82	184	0.347	VI	
Total		53098	100		

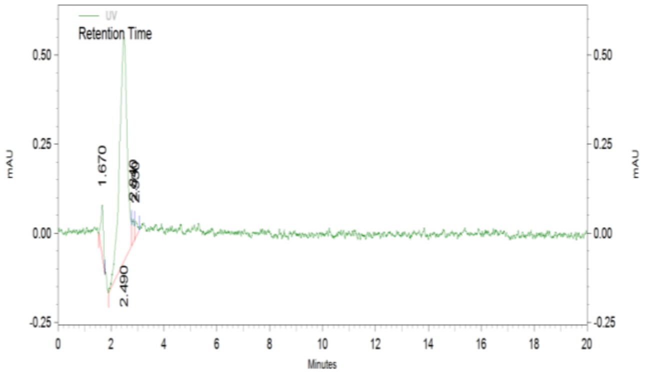

Figure 6 HPLC chromatogram of N-nitrosodiethylamine (NDEA) at 60 min measured at 340 nm.

Table 3 HPLC analysis of N-nitrosodiethylamine (NDEA) after 60 min measured at 340 nm.

Name	Retention Time	Area	Area %	Integration Codes
	1.67	3787	6.727	BB
	2.49	49756	88.378	BV
	2.84	1538	2.732	VV
	2.93	1218	2.163	VB
Total		56299	100	

The HPLC provides a clear and quantifiable narrative of the reaction. While the data conclusively demonstrates the consumption of the starting material (NDEA peak area decreased from 51,627 to 49,756) it also reveals the formation of the reaction products. This is proven by emergence and growth of new chromatographic peaks whose collective area contributes to the net increase in total absorbance observed in UV-Vi's spectroscopy. Therefore, the observed surge in peaks is a measurable signal from newly formed compounds.

It has been learned from this experimentation that C_3N_4 under visible light range not only degrades NDEA but also forms intermediates which surge the absorbance level in UV-Vi's spectroscopy. HPLC proved that the catalyst does degrade NDEA, but it creates byproducts which explain the UV-Vis data. These findings highlight a critical consideration for photocatalytic water treatment, where catalyst efficiency must be evaluated not only by the removal of the parent pollutant but also by the minimization of potentially persistent and harmful transformation products.

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4. Conclusion

The effective mitigation of carcinogenic nitrosamines remains a critical concern in amine-based CO_2 capture. N-Nitrosamines are recognized as carcinogenic compounds with varying degrees of impact, whereas nitramines are comparatively less potent in terms of mutagenicity and carcinogenicity. Nitrosamines, including NDEA, are classified in group 2B by IARC, which emphasizes the need for further investigation and development of effective mitigation strategies. This study provides a baseline for the use of carbon nitride as a catalyst for the degradation of NDEA under visible light. The use of amines (MEA and DEA) was intended to simulate real-time industrial conditions, and it was observed that their presence did not hinder the degradation process. It was further observed that most of the degradation occurred within the initial 10 to 50 minutes, followed by a relatively stable trend in both major segments of the experiment. The catalyst was found to be convenient to synthesize from urea and easy to apply. In the first segment of the study, noticeable degradation was achieved even in the absence of the catalyst; however, upon the introduction of the catalyst, approximately 50% degradation was achieved within the first 10 minutes. The photocatalytic degradation of NDEA at 340 nm demonstrated effective performance. The involvement of photogenerated holes (h^+) and electrons (e^-) enhanced the activity of reactive species such as HO• and O_2, thereby improving the degradation process. A robust HPLC method was utilized and validated for the quantification of NDEA, particularly for samples at zero and 60 minutes at 340 nm, where variations in peak intensity were observed. High resolution was achieved through optimized gradient elution (10–90% ACN) using a C18 column. Validation confirmed linearity, precision, and sensitivity in accordance with ICH guidelines. This study can be extended in future work to other N-Nitrosamines. It is also recommended that, when using C_3N_4, the UV range should be maintained between 200 and 500 nm to obtain optimal results.

References

1. Y. Wang, L. Zhao, A. Otto, M. Robinius, and D. Stolten, “A review of post-combustion CO2 capture technologies from coal-fired power plants,” *Energy Procedia*, vol. 114, pp. 650–665, 2017.
2. J. Coker, *Mass Transfer and Emission Studies on a Catalyset-Aided CO2 Absorption and Desorption in a Post Combustion CO2 Capture*. The University of Regina (Canada), 2018.
3. J. B. Domingo, *Biological Treatment of Reclamation of Industrial Wasterwater From Post-Combustion Carbon Capture*. The University of Regina (Canada), 2020.
4. L. Więcław-Solny, A. Tatarczuk, A. Krótki, and A. Wilk, “Przegląd technologii ograniczenia emisji CO 2 z sektora energetycznego,” *Karbo*, 2012.
5. L. Dai, D. W. Chang, J. Baek, and W. Lu, “Carbon nanomaterials for advanced energy conversion and storage,” *small*, vol. 8, no. 8, pp. 1130–1166, 2012.
6. J. Liu *et al.*, “Oriented nanostructures for energy conversion and storage,” *ChemSusChem Chem. Sustain. Energy Mater.*, vol. 1, no. 8-9, pp. 676–697, 2008.
7. J. Low, B. Cheng, and J. Yu, “Surface modification and enhanced photocatalytic CO2 reduction performance of TiO2: a review,” *Appl. Surf. Sci.*, vol. 392, pp. 658–686, 2017.
8. A. Akhundi, A. Habibi-Yangjeh, M. Abitorabi, and S. Rahim Pouran, “Review on photocatalytic conversion of carbon dioxide to value-added compounds and renewable fuels by graphitic carbon nitride-based photocatalysts,” *Catal. Rev.*, vol. 61, no. 4, pp. 595–628, 2019.
9. S. P. Pattnaik, A. Behera, S. Martha, R. Acharya, and K. Parida, “Synthesis, photoelectrochemical properties and solar light-induced photocatalytic activity of bismuth ferrite nanoparticles,” *J. Nanoparticle Res.*, vol. 20, no. 1, p. 10, 2018.
10. S. Nayak and K. M. Parida, “Deciphering Z-scheme charge transfer dynamics in heterostructure NiFe-LDH/N-rGO/g-C3N4 nanocomposite for photocatalytic pollutant removal and water splitting reactions,” *Sci. Rep.*, vol. 9, no. 1, p. 2458, 2019.
11. S. Nayak, G. Swain, and K. Parida, “Enhanced photocatalytic activities of RhB degradation and H2 evolution from in situ formation of the electrostatic heterostructure MoS2/NiFe LDH nanocomposite through the Z-scheme mechanism via p–n heterojunctions,” *ACS Appl. Mater. Interfaces*, vol. 11, no. 23, pp. 20923–20942, 2019.
12. N. Dai and W. A. Mitch, “Controlling nitrosamines, nitramines, and amines in amine-based CO2 capture systems with continuous ultraviolet and ozone treatment of washwater,” *Environ. Sci. Technol.*, vol. 49, no. 14, pp. 8878–8886, 2015.
13. A. K. Voice, A. Hill, N. A. Fine, and G. T. Rochelle, “Nitrosamine formation and mitigation in blended amines for CO2 capture,” *Int. J. Greenh. gas Control*, vol. 39, pp. 329–334, 2015.
14. K. Yu, M. C. Reichard, and N. Dai, “Nitrosamine formation in the desorber of tertiary alkanolamine-based carbon dioxide capture systems,” *Ind. Eng. Chem. Res.*, vol. 55, no. 9, pp. 2604–2614, 2016.
15. N. Dai and W. A. Mitch, “Influence of amine structural characteristics on N-nitrosamine formation potential relevant to postcombustion CO2 capture systems,” *Environ. Sci. Technol.*, vol. 47, no. 22, pp. 13175–13183, 2013.
16. A. J. Sexton and G. T. Rochelle, “Reaction products from the oxidative degradation of monoethanolamine,” *Ind. Eng. Chem. Res.*, vol. 50, no. 2, pp. 667–673, 2011.
17. T. Spietz, S. Dobras, L. Więcław-Solny, and A. Krótki, “Nitrosamines and nitramines in Carbon Capture plants,” *Group*, vol. 2, no. 4.6, pp. 10–13, 2017.
18. N. J. Farren, N. Ramírez, J. D. Lee, E. Finessi, A. C. Lewis, and J. F. Hamilton, “Estimated exposure risks from carcinogenic nitrosamines in urban airborne particulate matter,” *Environ. Sci. Technol.*, vol. 49, no. 16, pp. 9648–9656, 2015.
19. A. Aqeel, C.-J. Kim, and H.-J. Lim, “Influence of pH on the UV photolysis of N-nitrosamines in water: kinetics and products,” *Int. J. Greenh. Gas Control*, vol. 64, pp. 194–203, 2017.
20. A. Andersson, “Dynamic behaviour of soil-steel composite bridges for high-speed railways,” 2020.
21. Z. Liang, K. Fu, R. Idem, and P. Tontiwachwuthikul, “Review on current advances, future challenges and consideration issues for post-combustion CO2 capture using amine-based absorbents,” *Chinese J. Chem. Eng.*, vol. 24, no. 2, pp. 278–288, 2016.
22. B. R. Strazisar, R. R. Anderson, and C. M. White,

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DOI: 10.5281/zenodo.20251168

"Degradation pathways for monoethanolamine in a CO2 capture facility," *Energy & fuels*, vol. 17, no. 4, pp. 1034–1039, 2003.

23. M. Karl, R. F. Wright, T. F. Berglen, and B. Denby, "Worst case scenario study to assess the environmental impact of amine emissions from a CO2 capture plant," *Int. J. Greenh. Gas Control*, vol. 5, no. 3, pp. 439–447, 2011.
24. F. de Miguel Mercader, A. K. Voice, H. Trap, and E. L. V Goetheer, "Nitrosamine degradation by UV light in post-combustion CO2 capture: Effect of solvent matrix," *Energy Procedia*, vol. 37, pp. 701–716, 2013.
25. J. Nawrocki and P. Andrzejewski, "Nitrosamines and water," *J. Hazard. Mater.*, vol. 189, no. 1–2, pp. 1–18, 2011.
26. M. I. Stefan and J. R. Bolton, "UV direct photolysis of N-nitrosodimethylamine (NDMA): Kinetic and product study," *Helv. Chim. Acta*, vol. 85, no. 5, pp. 1416–1426, 2002.
27. M. H. Plumlee and M. Reinhard, "Photochemical attenuation of N-nitrosodimethylamine (NDMA) and other nitrosamines in surface water," *Environ. Sci. Technol.*, vol. 41, no. 17, pp. 6170–6176, 2007.
28. K. R. R. Mahanama and J. M. Daisey, "Volatile N-nitrosamines in environmental tobacco smoke: Sampling, analysis, emission factors, and indoor air exposures," *Environ. Sci. Technol.*, vol. 30, no. 5, pp. 1477–1484, 1996.
29. C. Lee, W. Choi, and J. Yoon, "UV photolytic mechanism of N-nitrosodimethylamine in water: roles of dissolved oxygen and solution pH," *Environ. Sci. Technol.*, vol. 39, no. 24, pp. 9702–9709, 2005.
30. J.-G. Shim, A. Aqeel, B.-M. Choi, J.-H. Lee, N.-S. Kwak, and H.-J. Lim, "Effect of pH on UV Photodegradation of N-Nitrosamines in Water," *J. Korean Soc. Water Environ.*, vol. 32, no. 4, pp. 357–366, 2016.
31. A. Aqeel and H.-J. Lim, "Role of various factors affecting the photochemical treatment of N-nitrosamines related to CO2 capture," *Environ. Technol.*, 2020.
32. P. Singh, M. M. Abdullah, M. Ahmed, and S. Ikram, *Photocatalysis: perspective, mechanism, and applications*. Nova Science, 2019.
33. D. Masekela, S. A. Balogun, T. L. Yusuf, S. Makgato, and K. D. Modibane, "Advancements in piezo-photocatalysts for sustainable hydrogen generation and pollutant degradation: A comprehensive overview of piezo-photocatalysis," *J. Water Process Eng.*, vol. 71, p. 107172, 2025.
34. C. V. Reddy *et al.*, "Metal-organic frameworks (MOFs)-based efficient heterogeneous photocatalysts: synthesis, properties and its applications in photocatalytic hydrogen generation, CO2 reduction and photodegradation of organic dyes," *Int. J. Hydrogen Energy*, vol. 45, no. 13, pp. 7656–7679, 2020.
35. S. N. Tan, M. L. Yuen, and R. A. Ramli, "Photocatalysis of Dyes: Operational Parameters, Mechanisms, and Degradation Pathway," *Green Anal. Chem.*, p. 100230, 2025.
36. K. Ancy, M. R. Bindhu, J. S. Bai, M. K. Gatasheh, A. A. Hatamleh, and S. Ilavenil, "Photocatalytic degradation of organic synthetic dyes and textile dyeing waste water by Al and F co-doped TiO2 nanoparticles," *Environ. Res.*, vol. 206, p. 112492, 2022.
37. Z. Wang, Y. Li, and X. Chen, "Recent advances in graphitic carbon nitride-based photocatalysts for environmental remediation," *RSC Advances*, vol. 15, pp. 12345–12360, 2025.
38. M. A. Rahman, S. Gupta, and T. Nguyen, "Recent progress in carbon nitride photocatalysts for energy and environmental applications," *AIP Advances*, vol. 15, no. 1, 2025.
39. H. Zhang, L. Liu, and J. Wang, "Silver-modified graphitic carbon nitride for enhanced photocatalytic degradation of organic pollutants," *Scientific Reports*, vol. 14, 2024.
40. Y. Chen, X. Zhao, and M. Liu, "Advanced crystalline carbon nitride materials for photocatalytic applications," *Chemical Engineering Journal*, vol. 482, 2025.

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