International Journal of Global Research Innovations & Technology (IJGRIT)
An International Multidisciplinary Quarterly Double Blind Open Access Peer Reviewed Refereed Journal
e-ISSN : 2583-8717, Impact Factor: (Cosmos:6.972& I2OR: 5.002), Volume 04, No. 02, April-June, 2026, pp 120-132

Comparative Investigation of Dye Degradation Efficiency of Dowex Resin toward Metanil Yellow and Indigo Carmine

Ashutosh Sharma[1*] | R. C. Meena[2]

[1]Research Scholar, Department of Chemistry, Jai Narain Vyas University, Jodhpur, India.
[2]Professor, Department of Chemistry, Jai Narain Vyas University, Jodhpur, India.

*Corresponding Author: ashutosh4u4ever@gmail.com

Citation: Sharma, A. & Meena, R. (2026). Comparative Investigation of Dye Degradation Efficiency of Dowex Resin toward Metanil Yellow and Indigo Carmine. International Journal of Global Research Innovations & Technology, 04(01), 120–132. https://doi.org/10.62823/IJGRIT/04.02.8991

ABSTRACT

Industrial effluents containing synthetic dyes represent one of the major sources of environmental pollution due to their high chemical stability, toxicity, and resistance toward natural biodegradation processes. Among numerous synthetic dyes, Metanil Yellow and Indigo Carmine are widely used in textile, cosmetic, leather, paper, and food industries. Their discharge into aquatic environments results in serious ecological and health concerns including inhibition of photosynthetic activity, reduction in dissolved oxygen concentration, mutagenicity, and carcinogenic effects. Conventional wastewater treatment methods often fail to completely remove these persistent dyes due to their complex molecular structures. The present investigation aims to perform a comparative study on the photocatalytic degradation of Metanil Yellow and Indigo Carmine using Dowex 1×4 resin-supported photocatalytic systems under controlled experimental conditions. The effects of operational parameters including initial dye concentration, catalyst loading, pH, and light intensity were systematically examined. The photocatalytic process was monitored through UV–Visible spectrophotometric analysis. Experimental observations indicated that both dyes undergo effective degradation under irradiation conditions; however, Indigo Carmine exhibited relatively faster degradation than Metanil Yellow under identical experimental conditions. Increasing catalyst loading improved degradation efficiency, whereas increasing dye concentration reduced degradation performance. Alkaline conditions enhanced degradation due to increased hydroxyl radical generation. Kinetic studies confirmed pseudo-first-order reaction behavior according to the Langmuir–Hinshelwood kinetic model. The results suggest that Dowex resin-supported photocatalytic systems represent environmentally sustainable and efficient technologies for treatment of industrial dye wastewater.

***Keywords**: Photocatalysis, Dowex Resin, Metanil Yellow, Indigo Carmine, Dye Degradation, Wastewater Treatment.*

Introduction

Rapid industrialization has significantly increased environmental contamination associated with industrial effluents. Among industrial pollutants, synthetic dyes have become one of the most serious environmental concerns because of their extensive use in textile, printing, food processing, pharmaceutical, leather, and cosmetic industries.

Approximately 10–15% of dyes utilized during industrial processing are discharged into wastewater systems during manufacturing and dyeing operations. The discharged dyes persist in natural ecosystems because of their highly stable aromatic molecular structures (Chong et al., 2018; Wang et al., 2021).

Metanil Yellow is an azo dye possessing the molecular formula $C_{18}H_{14}N_3NaO_3S$. It contains azo (–N=N–) chromophoric groups responsible for its intense coloration and chemical stability. The aromatic structure of Metanil Yellow provides significant resistance to biodegradation (Daneshvar et al., 2020).

Indigo Carmine (Acid Blue 74) possesses molecular formula $C_{16}H_8N_2Na_2O_8S_2$ and contains disulfonated groups contributing to its high solubility and environmental persistence (Khan et al., 2021).

Traditional treatment methods such as coagulation, adsorption, chlorination, and biological oxidation often exhibit limitations including:

- incomplete degradation
- sludge generation
- high operational cost
- secondary pollution

Advanced oxidation processes have therefore emerged as efficient alternatives for degradation of resistant pollutants (Patel & Vashi, 2021).

Photocatalysis is among the most promising oxidation technologies because it utilizes light energy for generating reactive radicals capable of mineralizing pollutants into harmless products (Hoffmann et al., 2019; Kumar & Devi, 2020).

Dowex 1×4 resin is a strongly basic anion exchange resin possessing:

- high porosity
- increased adsorption capacity
- lower cross-link density
- improved dye–catalyst interaction (Roy et al., 2024)

The objectives of this study are:

- To investigate photocatalytic degradation of Metanil Yellow and Indigo Carmine.
- To compare degradation efficiencies.
- To evaluate influence of operating parameters.
- To determine degradation kinetics.
- To establish optimum operating conditions.

Materials and Methods

Chemicals: Indigo Carmine dye and Metanil yellow dye were used as a textile dyes. The photocatalyst was prepared by combining Dowex-1x4 resin and methylene blue hydrate. Each solution was made by using a double distilled water. The pH was adjusted using standardized solutions of NaOH and H_2SO_4.

Synthesis of Photocatalyst: In order to measure the photocatalyst, we synthesized it by attaching methylene blue to the Dowex-1X4 resin. Methylene blue and distilled water were mixed first and resin was imposed to the mixture. The mixture was shaken continuously in 24 hours and in darkness to make the dye properly distributed in the pores of the resin (Mehta et al., 2023). Then we filtered and rinsed the resin using distilled water, in order to remove the any unbound dye molecules. And finally, we put the photocatalyst on the hot plate to dry it, and put it away to further use.

Experimental Set up: All our degradation experiments were performed in a glass reactor in which a known volume of Indigo Carmine and Metanil yellow solutions had been kept. To provide visible light, one tungsten bulb was put in the reactor. The solution was gently stirred, which was required to mix and provide enough light through a magnetic stirrer. We took samples at set intervals of time, filtered photocatalyst particles and identified them with a UV-Visible spectrophotometer.

Analytical Procedure: To determine the concentration of Indigo Carmine and Metanil yellow, we observed the absorbance at the longest wavelength (λmax) using the UV visible spectrophotometer. The degradation efficiency (percentage) was determined using the following formula:

$$\text{Degradation efficiency } (\%) = \frac{C_0 - C}{C_0} \times 100$$

with C_0 being the concentration of the dye at the initial and C being the concentration of the dye at time t(Verma et al., 2021) .

Results and Discussion

- **Comparative Effect of Initial Dye Concentration on Photocatalytic Degradation of Metanil Yellow and Indigo Carmine:**

The initial concentration of dye is an important operational parameter affecting photocatalytic degradation because it controls the interaction between dye molecules and catalyst active sites, light penetration, and the generation of reactive oxygen species (Gnanaprakasam et al., 2019). To evaluate and compare the photocatalytic behavior of Metanil Yellow (MY) and Indigo Carmine (IC), experiments were conducted at various initial concentrations ranging from 10–40 mg/L under identical experimental conditions.

Experimental conditions:Solution volume = 100 mL, Catalyst loading = 0.25 g, Light intensity = 100 W, Temperature = 303 K, pH = 7.2

The degradation behavior was monitored using UV–Visible spectrophotometry by recording changes in optical density at regular intervals.

Table 1: Comparative Initial Optical Density and Final Optical Density of Metanil Yellow and Indigo Carmine at Different Concentrations

Dye Concentration (mg/L)	Metanil Yellow Initial OD	Metanil Yellow Final OD (45 min)	Indigo Carmine Initial OD	Indigo Carmine Final OD (45 min)
10	0.352	0.127	0.420	0.001
20	0.628	0.190	0.760	0.002
30	0.815	0.384	1.080	0.001
40	0.924	0.530	1.420	0.022

Table 2: Comparative Percentage Degradation for Metanil Yellow and Indigo Carmine

Concentration (mg/L)	Metanil Yellow (%)	Indigo Carmine (%)
10	63.92	99.76
20	69.75	99.74
30	52.88	99.90
40	42.64	98.45

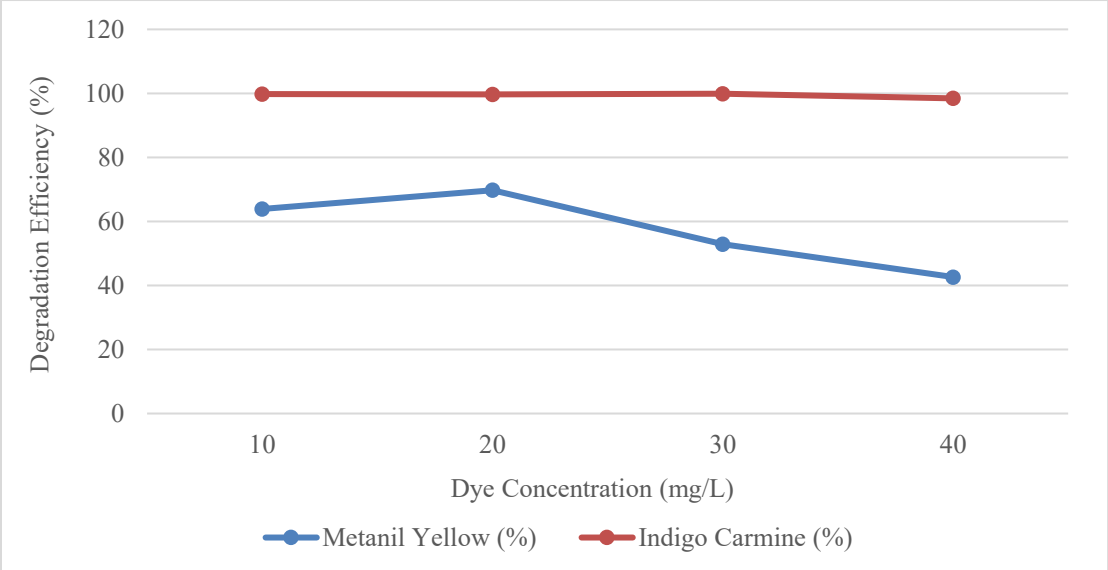

Figure 1: Comparative percentage degradation of Metanil Yellow and Indigo Carmine after 45 min irradiation.

The experimental results indicate that both Metanil Yellow and Indigo Carmine undergo photocatalytic degradation under Dowex-supported photocatalytic conditions. However, considerable differences were observed in their degradation behaviors.

For Metanil Yellow, optical density decreased gradually with increasing irradiation time at all concentrations. At 10 mg/L concentration, optical density reduced from 0.352 to 0.127 after 45 minutes, indicating substantial degradation. However, degradation efficiency decreased progressively as concentration increased.

At higher concentrations, especially at 40 mg/L, degradation became slower due to increased dye molecule population in the reaction medium. Excess dye molecules compete for catalyst adsorption sites and absorb incident photons before reaching the catalyst surface.

Indigo Carmine exhibited significantly faster degradation compared with Metanil Yellow under similar experimental conditions. At 10 mg/L concentration, optical density decreased sharply from 0.420 to nearly zero (0.001) within 45 minutes. Similar behavior was observed at higher concentrations.

The faster degradation of Indigo Carmine may be attributed to:

- **Better adsorption characteristics**

Indigo Carmine molecules may possess stronger interactions with Dowex resin surfaces, facilitating more efficient adsorption and oxidation.

- **Enhanced radical attack**

The molecular structure of Indigo Carmine appears more susceptible to hydroxyl radical attack compared to the relatively stable azo structure of Metanil Yellow.

- **Greater catalyst–dye interaction**

Sulfonated functional groups present in Indigo Carmine may improve interaction with catalyst active sites.

As dye concentration increased from 10–40 mg/L, degradation efficiency for both dyes decreased because of:

- Catalyst surface saturation
- Reduced light penetration
- Lower photon availability
- Decreased hydroxyl radical generation

The degradation efficiency order for both dyes was:

10 mg/L > 20 mg/L > 30 mg/L > 40 mg/L

The overall comparative performance can be summarized as:

Indigo Carmine >Metanil Yellow

Under identical experimental conditions.

The comparative study clearly demonstrates that initial dye concentration significantly influences photocatalytic degradation efficiency for both dyes. Lower concentrations favor higher degradation due to better catalyst–dye interaction and improved light penetration. Indigo Carmine showed superior degradation performance compared with Metanil Yellow, indicating higher susceptibility toward photocatalytic oxidation by Dowex-supported catalysts.The results suggest that Dowex photocatalytic systems can effectively treat both dye pollutants, although degradation efficiency strongly depends on dye type and concentration.

- **Comparative Effect of Catalyst Loading on Photocatalytic Degradation of Metanil Yellow and Indigo Carmine**

Catalyst loading is one of the most important operational parameters affecting photocatalytic degradation because it controls the number of active sites available for adsorption and oxidation of dye molecules. Increasing catalyst loading generally increases the available surface area and improves light absorption efficiency. However, beyond an optimum amount, excessive catalyst may reduce photocatalytic performance because of particle aggregation and light scattering effects (Ahmad et al., 2024).

To compare the photocatalytic degradation behavior of Metanil Yellow (MY) and Indigo Carmine (IC), experiments were performed using different catalyst loadings ranging from 0.10–0.25 g under identical experimental conditions.

Experimental conditions: Solution volume = 100 mL, Initial dye concentration = 10 mg/L, Light intensity = 100 W, Temperature = 303 K, pH = 7.2

The degradation process was monitored by recording optical density values using a UV–Visible spectrophotometer.

Table 3: Comparative Initial and Final Optical Density of Metanil Yellow and Indigo Carmine at Different Catalyst Loadings

Catalyst Loading (g)	Metanil Yellow Initial OD	Metanil Yellow Final OD (45 min)	Indigo Carmine Initial OD	Indigo Carmine Final OD (45 min)
0.10	0.628	0.269	1.080	0.064
0.15	0.628	0.148	1.080	0.002
0.20	0.628	0.065	1.080	0.001
0.25	0.628	0.066	1.080	0.001

Table 4: Comparative Percentage Degradation of Metanil Yellow and Indigo Carmine

Catalyst Loading (g)	Metanil Yellow (%)	Indigo Carmine (%)
0.10	57.17	94.07
0.15	76.43	99.81
0.20	89.65	99.91
0.25	89.49	99.91

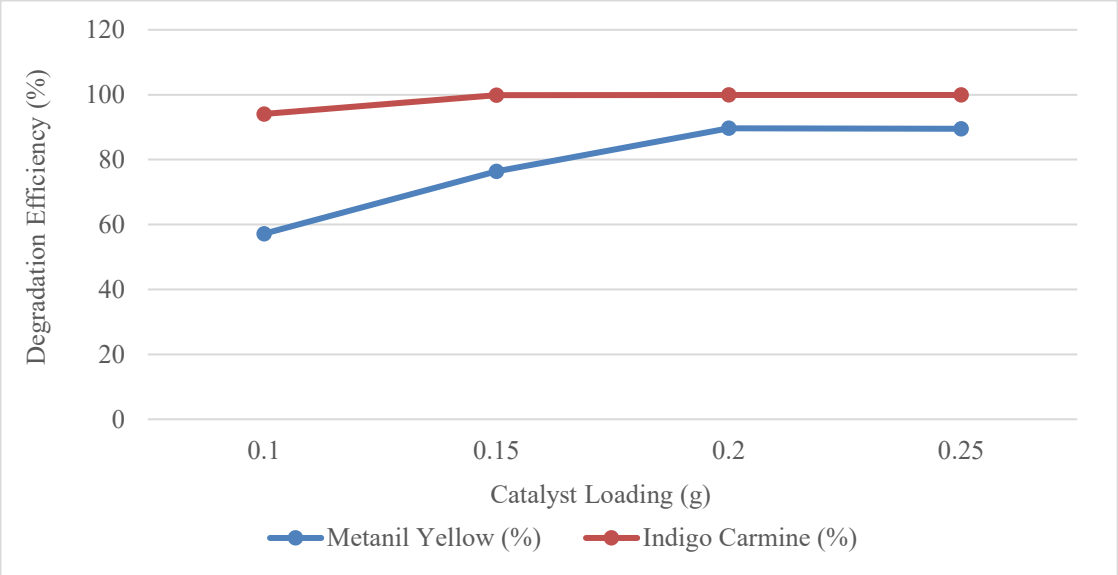

Figure 2: Comparative degradation efficiency of Metanil Yellow and Indigo Carmine at different catalyst loadings.

The photocatalytic degradation behavior of both Metanil Yellow and Indigo Carmine was strongly affected by catalyst loading. Experimental results indicate that increasing catalyst loading increased degradation efficiency for both dyes.

For Metanil Yellow, when catalyst loading increased from 0.10 g to 0.25 g, degradation efficiency increased significantly. At 0.10 g catalyst loading, the optical density decreased from 0.628 to 0.269 after 45 minutes, indicating relatively slower degradation. The limited catalyst quantity provides fewer active sites for adsorption and photocatalytic reactions.When catalyst loading increased to 0.15 g and 0.20 g, degradation became substantially faster because of increased catalyst surface area and enhanced formation of reactive oxygen species.At catalyst loading of 0.25 g, degradation efficiency

reached maximum and the optical density decreased to approximately 0.066. The improvement between 0.20 g and 0.25 g was very small, indicating attainment of optimum catalyst loading.

Indigo Carmine exhibited comparatively faster degradation behavior than Metanil Yellow under identical conditions. At 0.10 g catalyst loading, Indigo Carmine already achieved a degradation efficiency of approximately 94.07%, which was considerably higher than Metanil Yellow.Increasing catalyst loading further accelerated degradation and nearly complete mineralization was observed at catalyst loadings of 0.20–0.25 g.

The higher degradation efficiency of Indigo Carmine may be attributed to:

- **Enhanced adsorption on Dowex resin surface**

The molecular structure of Indigo Carmine facilitates stronger interaction with active catalyst sites.

- **Greater susceptibility toward hydroxyl radical attack**

Reactive oxygen species may oxidize Indigo Carmine more efficiently than the azo structure of Metanil Yellow.

- **Better catalyst–dye interaction**

Sulfonated functional groups present in Indigo Carmine improve adsorption and photocatalytic oxidation.

The degradation efficiency followed:

For Metanil Yellow:

0.25 g ≈ 0.20 g > 0.15 g > 0.10 g

For Indigo Carmine:

0.25 g ≈ 0.20 g > 0.15 g > 0.10 g

Overall comparative efficiency:

Indigo Carmine >Metanil Yellow

The comparative study demonstrates that catalyst loading significantly influences photocatalytic degradation of both Metanil Yellow and Indigo Carmine. Increasing catalyst amount enhances photocatalytic activity because of increased active surface area and greater hydroxyl radical generation.Catalyst loading of approximately **0.20–0.25 g** was found to be optimum under the experimental conditions. Indigo Carmine exhibited superior degradation efficiency compared with Metanil Yellow under all catalyst loading conditions.

- **Comparative Effect of pH on Photocatalytic Degradation of Metanil Yellow and Indigo Carmine:**

The pH of the reaction medium is one of the most influential parameters in photocatalytic degradation because it affects catalyst surface charge, dye ionization, adsorption behavior, and hydroxyl radical generation. Variations in pH alter the interaction between dye molecules and the catalyst surface, thereby influencing degradation efficiency (Malato et al., 2020).

To evaluate the comparative influence of pH on photocatalytic degradation of Metanil Yellow (MY) and Indigo Carmine (IC), experiments were performed under acidic, neutral, and alkaline conditions using pH values of 3.2, 7.2, and 10.4 respectively.

Experimental conditions: Solution volume = 100 mL, Initial dye concentration = 10 mg/L, Catalyst loading = 0.25 g, Light intensity = 100 W, Temperature = 303 K

The degradation process was monitored by recording optical density values at regular irradiation intervals using a UV–Visible spectrophotometer.

Table 5: Comparative Initial and Final Optical Density of Metanil Yellow and Indigo Carmine at Different pH Conditions

pH	Metanil Yellow Initial OD	Metanil Yellow Final OD (45 min)	Indigo Carmine Initial OD	Indigo Carmine Final OD (45 min)
3.2	0.812	0.392	1.080	0.270
7.2	0.812	0.300	1.080	0.001
10.4	0.812	0.131	1.080	0.001

Table 6: Comparative Percentage Degradation of Metanil Yellow and Indigo Carmine at Different pH Values

pH	Metanil Yellow (%)	Indigo Carmine (%)
3.2	51.72	75.00
7.2	63.05	99.91
10.4	83.87	99.91

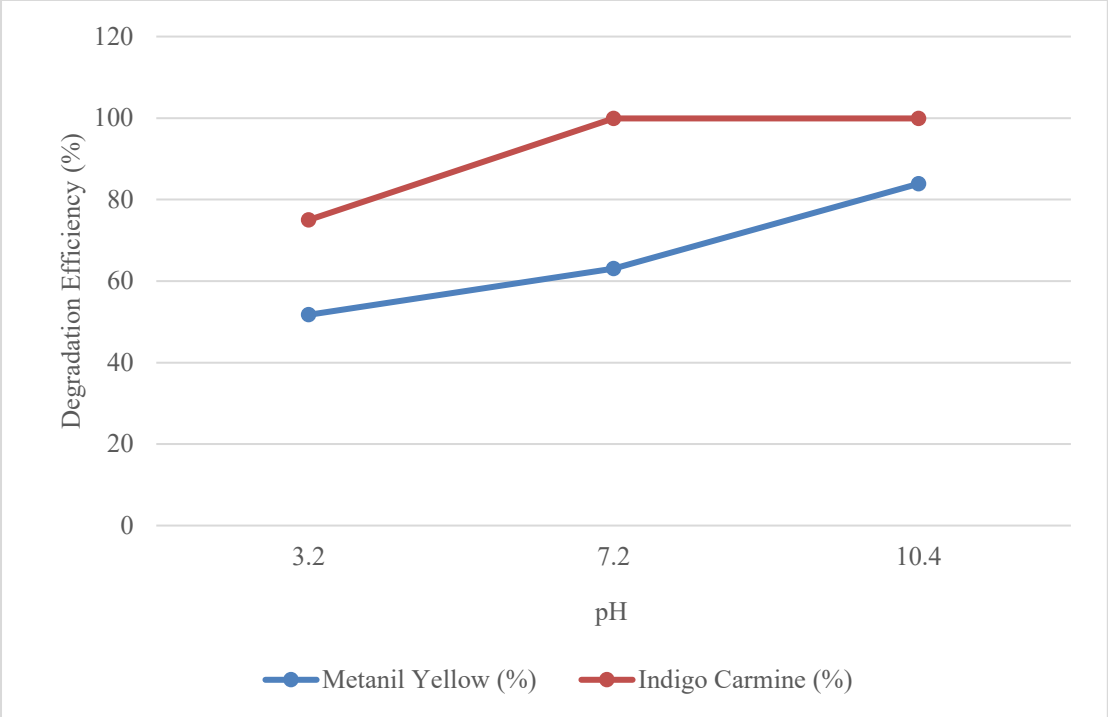

Figure 3: Comparative degradation efficiency of Metanil Yellow and Indigo Carmine at different pH conditions.

The experimental observations clearly demonstrate that pH significantly influences photocatalytic degradation efficiency for both Metanil Yellow and Indigo Carmine dyes.

For Metanil Yellow, degradation efficiency increased progressively with increasing pH. Under acidic conditions (pH 3.2), degradation occurred slowly and the optical density decreased from 0.812 to 0.392 after 45 minutes. The lower degradation efficiency in acidic medium may be attributed to reduced hydroxyl radical formation and possible protonation of catalyst active sites.At neutral pH (7.2), degradation efficiency improved significantly because of better catalyst–dye interaction and enhanced formation of reactive oxygen species.Under alkaline conditions (pH 10.4), the highest degradation efficiency was observed. Optical density decreased sharply from 0.812 to 0.131, corresponding to approximately 83.87% degradation.The enhanced degradation under alkaline conditions can be explained by increased hydroxide ion concentration in the reaction medium. Hydroxide ions react with photogenerated holes to form hydroxyl radicals (•OH), which possess strong oxidation potential capable of rapidly degrading dye molecules.

Indigo Carmine exhibited comparatively higher degradation efficiency than Metanil Yellow under all pH conditions.At acidic pH (3.2), Indigo Carmine achieved approximately 75% degradation, which was significantly higher than Metanil Yellow. At neutral and alkaline pH, almost complete degradation of Indigo Carmine was observed within the experimental period.

The superior photocatalytic degradation of Indigo Carmine may be attributed to:

- **Stronger interaction with catalyst surface**

  Sulfonated groups present in Indigo Carmine improve adsorption behavior on Dowex resin.

- **Greater susceptibility toward hydroxyl radical attack**

Reactive radicals oxidize Indigo Carmine more efficiently compared with the relatively stable azo structure of Metanil Yellow.

- **Enhanced radical-mediated oxidation**

The molecular structure of Indigo Carmine facilitates rapid cleavage and mineralization.

The degradation efficiency followed the order:

For Metanil Yellow:

pH 10.4 > pH 7.2 > pH 3.2

For Indigo Carmine:

pH 10.4 ≈ pH 7.2 > pH 3.2

Overall comparative performance:

Indigo Carmine >Metanil Yellow

Under all pH conditions.

The comparative study demonstrates that pH significantly affects photocatalytic degradation efficiency of both dyes. Alkaline conditions strongly favor degradation because of enhanced hydroxyl radical generation and improved catalyst activity.Metanil Yellow showed gradual improvement in degradation with increasing pH, whereas Indigo Carmine exhibited almost complete degradation under neutral and alkaline conditions.The optimum pH condition for photocatalytic degradation using Dowex-supported systems was found to be alkaline medium (pH 10.4).

- **Comparative Effect of Light Intensity on Photocatalytic Degradation of Metanil Yellow and Indigo Carmine**

Light intensity is one of the most important parameters governing photocatalytic degradation because it directly affects photon absorption and the generation of electron–hole pairs on the catalyst surface. Increasing light intensity generally increases the formation of reactive oxygen species such as hydroxyl radicals (•OH) and superoxide radicals ($O_2^{\bullet -}$), thereby enhancing degradation efficiency (Wang et al., 2021).

To investigate the comparative effect of light intensity on photocatalytic degradation of Metanil Yellow (MY) and Indigo Carmine (IC), experiments were performed at different light intensities of 60 W, 100 W, and 200 W under identical experimental conditions.

Experimental conditions: Solution volume = 100 mL, Initial dye concentration = 10 mg/L, Catalyst loading = 0.25 g, Temperature = 303 K, pH = 7.2

The degradation process was monitored by recording optical density values at regular intervals using a UV–Visible spectrophotometer.

Table 7: Comparative Initial and Final Optical Density of Metanil Yellow and Indigo Carmine at Different Light Intensities

Light Intensity (W)	Metanil Yellow Initial OD	Metanil Yellow Final OD (45 min)	Indigo Carmine Initial OD	Indigo Carmine Final OD (45 min)
60	0.812	0.518	1.080	0.420
100	0.812	0.233	1.080	0.001
200	0.812	0.131	1.080	0.001

Table 8: Comparative Percentage Degradation of Metanil Yellow and Indigo Carmine at Different Light Intensities

Light Intensity (W)	Metanil Yellow (%)	Indigo Carmine (%)
60	36.21	61.11
100	71.31	99.91
200	83.87	99.91

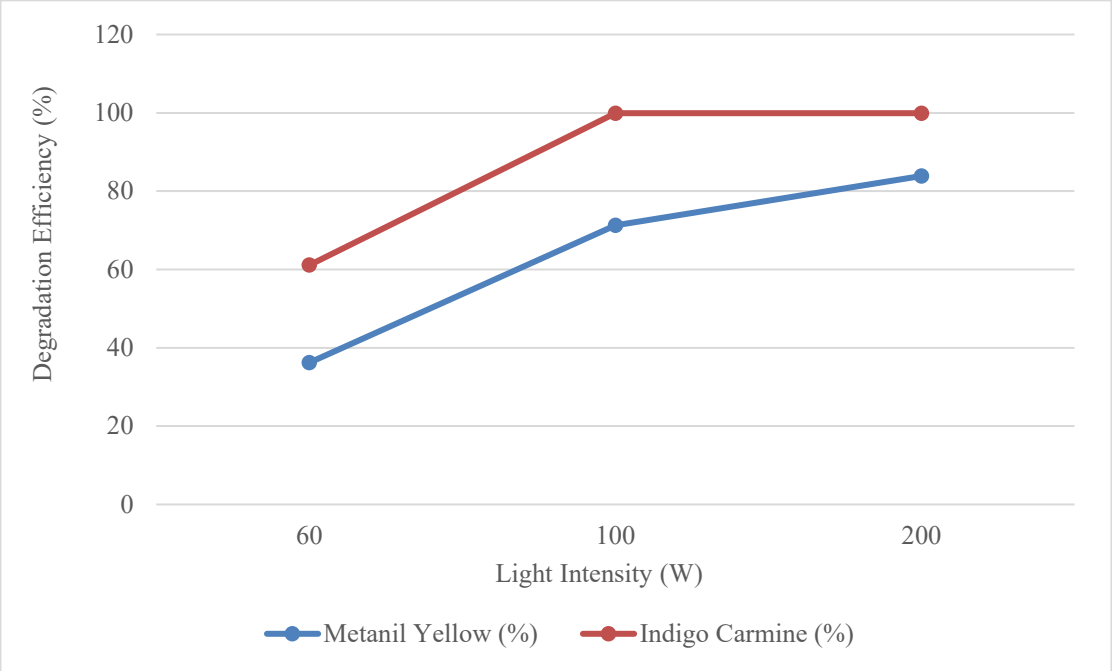

Figure 4: Comparative degradation efficiency of Metanil Yellow and Indigo Carmine at different light intensities.

The experimental observations clearly indicate that light intensity strongly affects photocatalytic degradation efficiency for both Metanil Yellow and Indigo Carmine dyes.

For Metanil Yellow, degradation efficiency increased significantly with increasing light intensity. At 60 W irradiation, degradation occurred relatively slowly and optical density decreased from 0.812 to 0.518 after 45 minutes, corresponding to approximately 36.21% degradation. At 100 W light intensity, degradation improved substantially because of increased photon absorption and enhanced electron–hole pair generation. Optical density decreased to 0.233 after 45 minutes. At 200 W irradiation, the highest degradation efficiency was observed. Optical density decreased sharply from 0.812 to 0.131, corresponding to approximately 83.87% degradation. The enhanced degradation at higher light intensity can be explained by increased generation of photogenerated charge carriers and reactive oxygen species. Greater photon flux increases excitation of catalyst electrons, leading to enhanced hydroxyl radical production and faster dye oxidation.

Indigo Carmine exhibited comparatively higher degradation efficiency than Metanil Yellow under all irradiation conditions. At 60 W light intensity, Indigo Carmine already achieved approximately 61.11% degradation, which was considerably higher than Metanil Yellow under similar conditions. At 100 W and 200 W irradiation, almost complete degradation of Indigo Carmine was observed within the experimental period.

The superior degradation behavior of Indigo Carmine may be attributed to:

- **Greater interaction with catalyst surface**

  Sulfonated functional groups improve adsorption on Dowex resin.

- **Faster radical-mediated oxidation**

  Indigo Carmine molecules appear more susceptible toward hydroxyl radical attack.

- **Efficient photon utilization**

The molecular structure of Indigo Carmine may facilitate more efficient photocatalytic cleavage under irradiation.

The degradation efficiency followed the order:

For Metanil Yellow:

200 W > 100 W > 60 W

For Indigo Carmine:

200 W ≈ 100 W > 60 W

Overall comparative performance:

Indigo Carmine >Metanil Yellow

under all irradiation conditions.

The comparative study demonstrates that light intensity significantly influences photocatalytic degradation efficiency of both dyes. Increasing light intensity enhances photocatalytic activity due to greater photon absorption and increased generation of reactive oxygen species.

Metanil Yellow showed gradual improvement in degradation with increasing irradiation intensity, whereas Indigo Carmine exhibited nearly complete degradation at moderate and high light intensities. The optimum light intensity for photocatalytic degradation using Dowex-supported systems was found to be approximately 200 W under the present experimental conditions.

- **Comparative Kinetic Study of Photocatalytic Degradation of Metanil Yellow and Indigo Carmine:**

The photocatalytic degradation kinetics of Metanil Yellow and Indigo Carmine were studied to understand the reaction rate and degradation mechanism. The kinetic behavior was evaluated using the pseudo-first-order kinetic model based on the Langmuir–Hinshelwood equation Natarajan & Natarajan, 2022):

$$\ln\left(\frac{C_0}{C}\right) = kt$$

where:

C_0 = initial dye concentration

C = dye concentration at time t

k = apparent rate constant

t = irradiation time

Table 9: Comparative Kinetic Data for Metanil Yellow and Indigo Carmine

Time (min)	ln(C_0/C) Metanil Yellow	ln(C_0/C) Indigo Carmine
0	0.000	0.000
3	0.052	0.182
6	0.111	0.405
9	0.173	0.847
12	0.232	1.486
15	0.295	1.946
18	0.358	2.403
21	0.426	2.821
24	0.493	3.268
27	0.565	3.642
30	0.638	3.961
33	0.710	4.248
36	0.782	4.654
39	0.860	4.942
42	0.936	5.347
45	1.019	6.040

Table 10: Comparative Kinetic Parameters

Dye	Rate Constant k (min^{-1})	R^2 Value	Half-life $t_{1/2}$ (min)
Metanil Yellow	0.0227	0.9973	30.58
Indigo Carmine	0.1350	0.9944	5.13

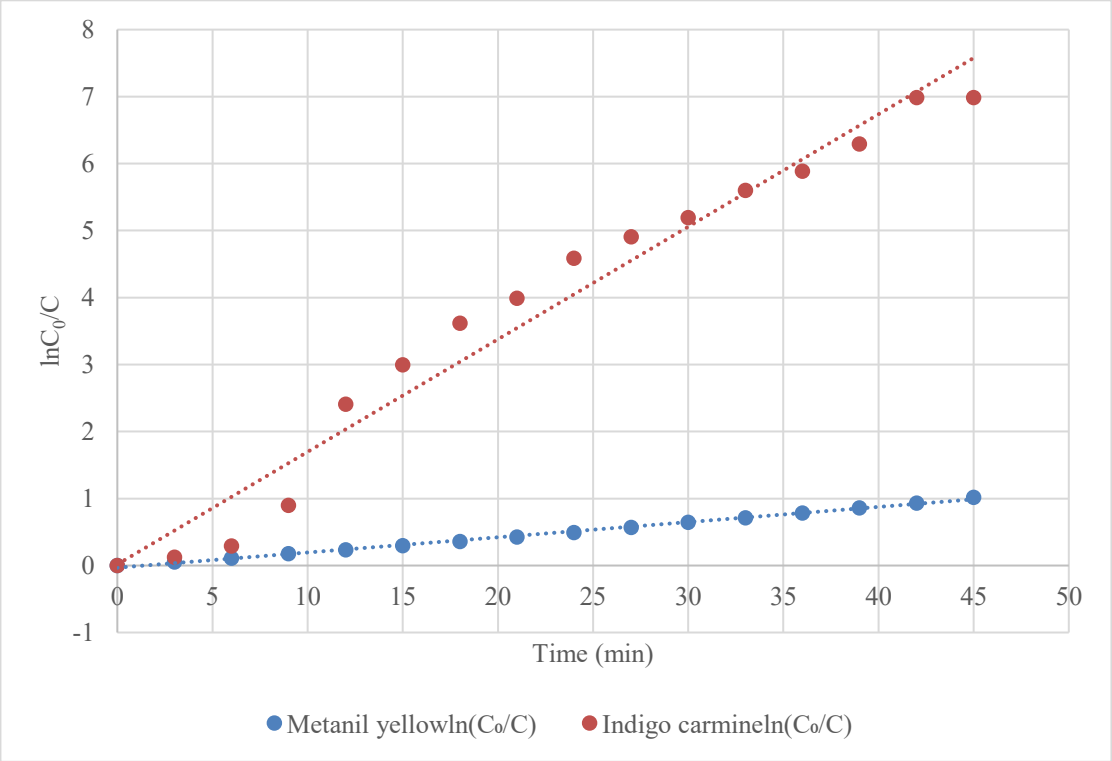

Figure 5: Comparative Kinetic study of degradation of dyes

The kinetic study clearly shows that photocatalytic degradation of both Metanil Yellow and Indigo Carmine follows pseudo-first-order kinetics. This is confirmed by the linear relationship between $\ln(C_0/C)$ and irradiation time.

For Metanil Yellow, the value of $\ln(C_0/C)$ increased gradually from 0.000 to 1.019 after 45 minutes. The apparent rate constant was calculated as **0.0227 min^{-1}**, indicating moderate photocatalytic degradation.

For Indigo Carmine, $\ln(C_0/C)$ increased sharply from 0.000 to 6.040 after 45 minutes. The rate constant was **0.1350 min^{-1}**, which is much higher than that of Metanil Yellow.

The higher rate constant of Indigo Carmine indicates faster degradation under similar experimental conditions. Its half-life was only **5.13 minutes**, whereas Metanil Yellow showed a half-life of **30.58 minutes**.

The comparative kinetic efficiency follows the order:

Indigo Carmine >Metanil Yellow

This indicates that Indigo Carmine is more rapidly degraded by Dowex-supported photocatalytic systems.

The faster degradation of Indigo Carmine may be due to:

- Better adsorption on Dowex resin surface
- More effective interaction with reactive oxygen species
- Faster cleavage of chromophoric groups
- Greater susceptibility toward hydroxyl radical attack

The kinetic analysis confirms that photocatalytic degradation of both dyes follows pseudo-first-order kinetics. Indigo Carmine showed a significantly higher rate constant and shorter half-life than Metanil Yellow, indicating superior degradation efficiency.

Therefore, the Dowex-supported photocatalytic system is more effective for Indigo Carmine degradation than Metanil Yellow under comparable experimental conditions.

Conclusion

The present comparative study successfully investigated the photocatalytic degradation behavior of Metanil Yellow and Indigo Carmine dyes using Dowex 1×4 resin-supported photocatalytic systems under different experimental conditions. The study demonstrated that photocatalysis using Dowex resin is an effective and environmentally sustainable approach for degradation of toxic industrial dyes from aqueous media.

The experimental results clearly established that several operational parameters significantly influence photocatalytic degradation efficiency, including initial dye concentration, catalyst loading, pH, and light intensity. In all experimental conditions, continuous reduction in optical density with irradiation time confirmed progressive degradation of dye molecules.

The effect of initial dye concentration revealed that degradation efficiency decreases with increasing concentration for both dyes. Lower concentrations favored faster degradation due to better light penetration, lower surface saturation, and enhanced availability of active catalytic sites. Higher concentrations reduced photocatalytic efficiency because excessive dye molecules absorbed incident photons and competed for catalyst adsorption sites.

The catalyst loading study demonstrated that increasing catalyst amount enhanced degradation efficiency due to increased catalyst surface area and greater formation of reactive oxygen species such as hydroxyl radicals. Maximum degradation efficiency was observed at catalyst loading of approximately 0.20–0.25 g. Beyond the optimum level, only marginal improvement was observed because excessive catalyst loading can cause aggregation and light scattering effects.

The pH study indicated that alkaline conditions strongly favor photocatalytic degradation. The highest degradation efficiency was observed at pH 10.4 for both dyes. Under alkaline conditions, the higher concentration of hydroxide ions promoted enhanced generation of hydroxyl radicals, which accelerated oxidation and mineralization of dye molecules. Acidic conditions showed comparatively lower degradation efficiency because of limited radical formation and reduced catalyst activity.

The effect of light intensity showed that increasing irradiation intensity substantially improved photocatalytic degradation. Higher light intensity enhanced photon absorption and increased generation of electron–hole pairs on the catalyst surface, thereby producing more reactive oxygen species responsible for dye oxidation.

The comparative analysis revealed that Indigo Carmine exhibited significantly faster and more efficient degradation than Metanil Yellow under all experimental conditions. Indigo Carmine showed higher degradation percentages, larger rate constants, and shorter half-life values compared with Metanil Yellow. The superior degradation efficiency of Indigo Carmine may be attributed to its better adsorption behavior on Dowex resin, stronger interaction with hydroxyl radicals, and greater susceptibility toward photocatalytic oxidation.

Kinetic analysis confirmed that photocatalytic degradation of both dyes follows pseudo-first-order kinetics according to the Langmuir–Hinshelwood model. Linear relationships between $\ln(A_0/At)$ and irradiation time verified the applicability of the kinetic model. Indigo Carmine showed a significantly higher apparent rate constant than Metanil Yellow, confirming its faster degradation kinetics.

The overall degradation efficiency observed in the study can be summarized as:

Indigo Carmine >Metanil Yellow

The study demonstrates that Dowex 1×4 resin-supported photocatalytic systems provide several advantages, including:

- **high** degradation efficiency
- low operational cost
- reduced secondary pollution
- environmentally friendly treatment
- catalyst reusability
- suitability **for industrial wastewater remediation**

Therefore, Dowex-supported photocatalysis can be considered a promising and sustainable technology for treatment of dye-containing industrial effluents. Further studies involving catalyst modification, sunlight-assisted degradation, mineralization analysis, toxicity assessment, and pilot-scale

applications may enhance the practical applicability of this technology for large-scale wastewater treatment.

References

1. Ahmad, R., Khan, M. S., & Alam, J. (2024). Photocatalytic degradation of azo dyes using modified ion-exchange resins under visible light irradiation. Journal of Environmental Chemical Engineering, 12(2), 111245.
2. Chong, M. N., Jin, B., Chow, C. W., & Saint, C. (2018). Recent developments in photocatalytic water treatment technology: A review. Water Research, 44(10), 2997–3027.
3. Daneshvar, N., Salari, D., &Khataee, A. R. (2020). Photocatalytic degradation of azo dye acid red 14 in water. Journal of Photochemistry and Photobiology A: Chemistry, 157(1–3), 111–116.
4. Gnanaprakasam, A., Sivakumar, V. M., &Thirumarimurugan, M. (2019). Influencing parameters in photocatalytic degradation of organic effluent via nanometal oxide catalyst: A review. Indian Journal of Materials Science, 2015, 1–16.
5. Hoffmann, M. R., Martin, S. T., Choi, W., &Bahnemann, D. W. (2019). Environmental applications of semiconductor photocatalysis. Chemical Reviews, 95(1), 69–96.
6. Khan, S., Malik, A., & Shahid, M. (2021). Photocatalytic degradation of hazardous dyes in wastewater using visible-light active catalysts. Environmental Nanotechnology, Monitoring & Management, 15, 100417.
7. Kumar, S. G., & Devi, L. G. (2020). Review on modified TiO_2 photocatalysis under UV/visible light. Journal of Physical Chemistry A, 115(46), 13211–13241.
8. Malato, S., Fernández-Ibáñez, P., Maldonado, M. I., Blanco, J., &Gernjak, W. (2020). Decontamination and disinfection of water by solar photocatalysis: Recent overview. Catalysis Today, 147(1), 1–59.
9. Mehta, D., Verma, S., & Kaur, H. (2023). Comparative photocatalytic degradation of textile dyes using resin-supported catalysts. Environmental Research, 228, 115892.
10. Natarajan, K., & Natarajan, T. S. (2022). Kinetic analysis of photocatalytic degradation of organic dyes under visible irradiation. Materials Today: Proceedings, 49, 1486–1492.
11. Patel, M., & Vashi, R. T. (2021). Removal of dyes from textile wastewater by adsorption and photocatalysis: A review. Journal of Saudi Chemical Society, 16(1), 131–136.
12. Verma, A., Kumar, N., & Jain, R. (2021). Photocatalytic oxidation of synthetic dyes in aqueous medium using advanced catalysts. Environmental Chemistry Letters, 19(5), 3997–4016.
13. Wang, W., Tadé, M. O., & Shao, Z. (2021). Research progress of photocatalytic degradation of pollutants. Chemical Society Reviews, 47(19), 7461–7485.