

Z-Scheme Heterojunction Of ZnO/MoS₂ For Photocatalytic Degradation Of Rose Bengal

Danech Sanket S.^{1*}, Seema Kothari¹, Sandip T Gadge¹

¹Department of Chemistry, PAHER University, Udaipur-313003 (Raj.), INDIA

*sanketdanech@gmail.com

ABSTRACT

The Z-scheme mechanism is a green approach for the photocatalytic degradation of Rose Bengal. This Z-scheme consists of ZnO-MoS₂ semiconductors coupled to form a Z-scheme heterojunction photocatalyst, which well separated hole and electron, possesses a strong ability of oxidation and reduction and improve the degradation of Rose Bengal under visible light. In the scavenger study observed, the Hydroxyl radical was responsible for its degradation of the Rose Bengal. They observed that degradation efficiency for Rose Bengal was 90.55% in the presence of sunlight irradiation for 210 min., and this reaction was monitored spectrophotometrically at 540 nm

Keywords: ZnO-MoS₂, Rose Bengal, degradation.

How to cite this article: Sanket DS, Kothari S, Gadge ST.. Z-Scheme Heterojunction Of ZnO/MoS₂ For Photocatalytic Degradation Of Rose Bengal Int J Drug Deliv Technol. 2026;16(6s): 9-15; DOI: 10.25258/ijddt.16.6s.2

Source of support: Nil.

Conflict of interest: None

INTRODUCTION

Many toxic organic and inorganic compounds are released into the environment through industrial and municipal wastewaters. Different types of organic pollutants from dyeing, agro, pharma industries, etc., are daily discharged into water resources, adversely affecting human beings as well as the animal and plant kingdom. Some of the dyes pose severe issues in biological eco-systems due to their resistance to biodegradation. The presence of dyes and pigments in the wastewater is clearly indicated by their colours. As a result, when these compounds are released into the aquatic system untreated, they are extremely toxic. Some technologies are used for waste treatment, such as membrane filtration, adsorption, bio- electrochemical degradation, etc. Recently, advanced oxidation processes have been advocated for the treatment of wastewater, as these are eco-friendly in nature, of which photocatalysis has much potential. The development of Z-scheme photocatalyst by coupling semiconductors seems to be an effective method for achieving high degradation efficiency.

ZnO is a good photocatalyst, while MoS₂ has a 1.8 eV bandgap with strong absorption of visible light. The MoS₂ may suffer from limited charge separation efficiency to couple with ZnO to form a Z-scheme heterojunction to increase photocatalytic performance by promoting charge separation and a high degradation rate of dye.

MATERIALS AND METHODS

The materials used are zinc acetate (99% SRL-India), molybdenum disulfide (99% SRL-India) and Rose Bengal dye (99.5% Sigma-India).

The 5.0 g of molybdenum disulfide, 10.8 g zinc acetate and 400 mL of distilled water were taken in a beaker. Then 4.77% of NaOH solution was added dropwise in this mixture at 40°C and magnetically stirred. The fine black

particles were filtered and washed with distilled water and ethanol. The product was isolated and dried at 150°C for 3-4 h in an oven. The colour of the product was black, and the particles were fine.

Characterization of zinc oxide- molybdenum disulfide

X-ray diffraction (XRD) was observed crystalline nature and synthesised nanoparticle. The morphology and element composition were analysed using Field emission scanning electron microscopy (FESEM) and Energy dispersive X-ray spectroscopy (EDX)

X-ray Diffraction (XRD):

The X-ray diffraction (XRD) pattern of the ZnO-MoS₂ is shown in Fig. 1,

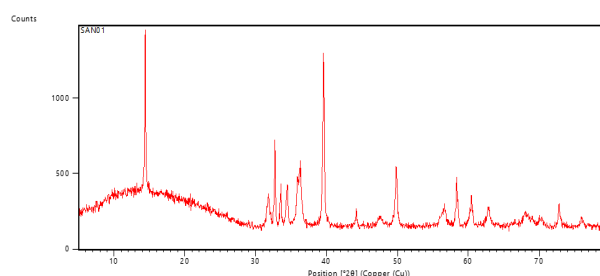


Fig. 1: XRD pattern of ZnO-MoS₂

It indicated its crystalline nature, as there are sharp peaks. The XRD pattern of the synthesized ZnO-MoS₂ showed many peaks in a wide range of 2θ angle. The average crystalline size of ZnO-MoS₂ was measured using Debye Scherrer's equation, and the value was found to be 67.37 nm, which is in the nano-scale.

Field Emission Scanning Electron Microscopy (FESEM):

The FESEM image was recorded with the help of the FESEM instrument. The image is presented in Fig. 2

*Author for Correspondence: Danech Sanket S

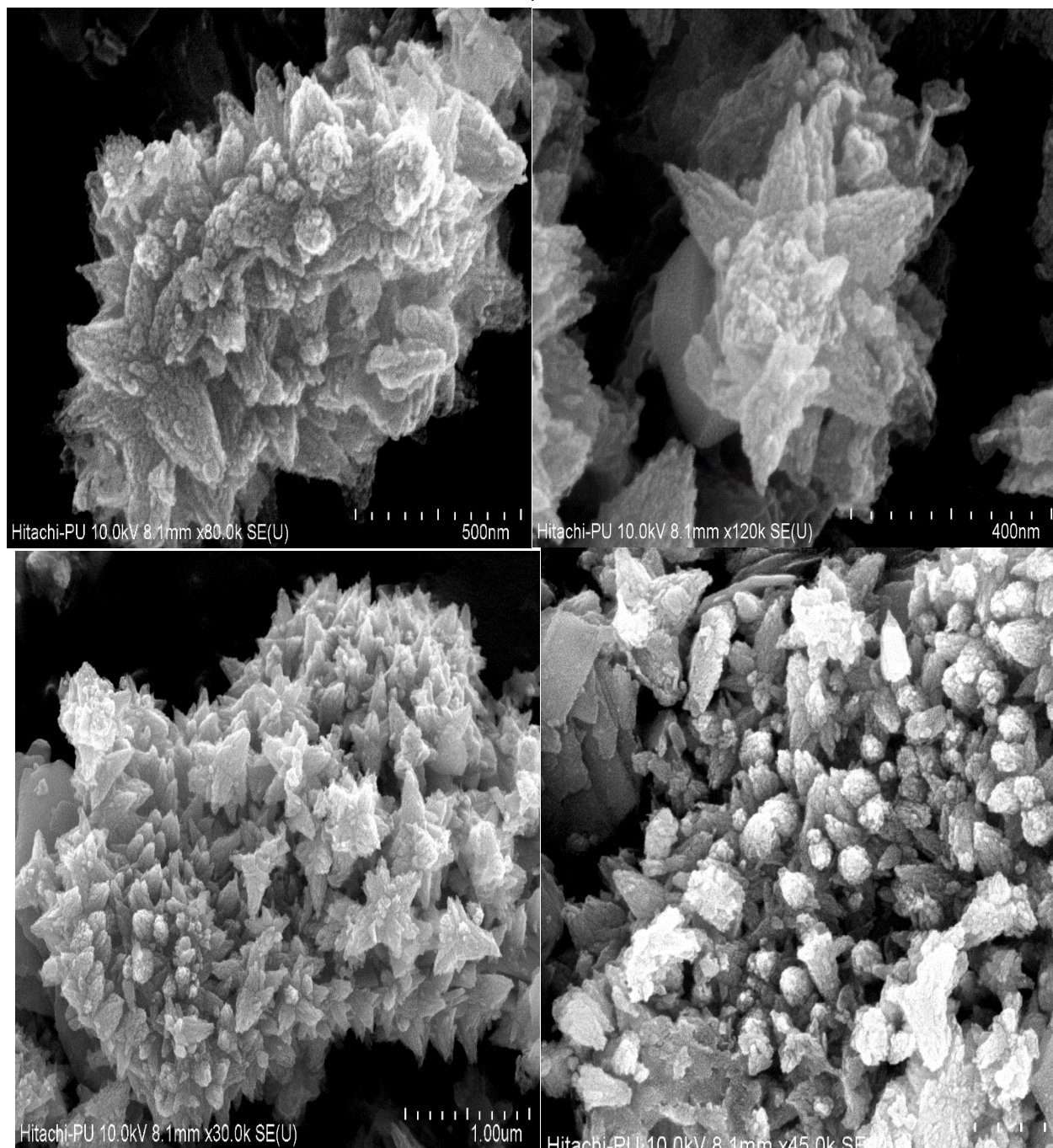


Fig. 2: FESEM image of ZnO-MoS₂

Energy Dispersive Spectroscopy (EDS):

The ZnO-MoS₂ sample was also analysed for its elemental composition using energy dispersive spectroscopy (EDS) (EDX – Oxford INCA Energy 250 EDS). The results are reported in Fig. 3. It was observed that the ZnO-MoS₂ sample contains only zinc, molybdenum, sulphur and oxygen. Therefore, it may be concluded that it does not have any impurity.

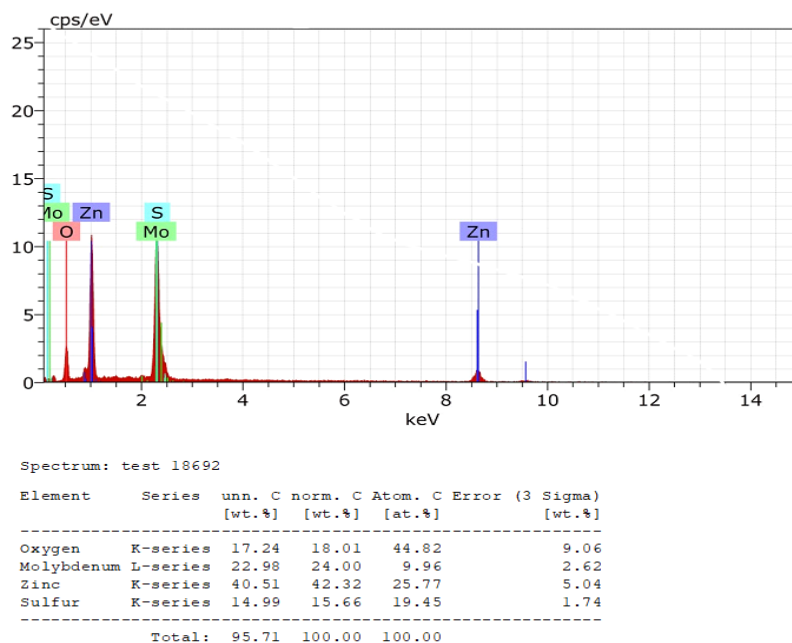


Fig. 3: EDS data of ZnO-MoS₂

Results and Discussion

Effect of pH

The degradation of dye was studied at various pH levels in the range of 4.0 – 9.0. The effect of pH variation on the rate is given in Fig. 4

pH	Rate constant (k) × 10 ⁴ (s ⁻¹)
4.0	1.15
5.0	1.54
6.0	1.87
7.0	1.77
8.0	1.45
9.0	1.03

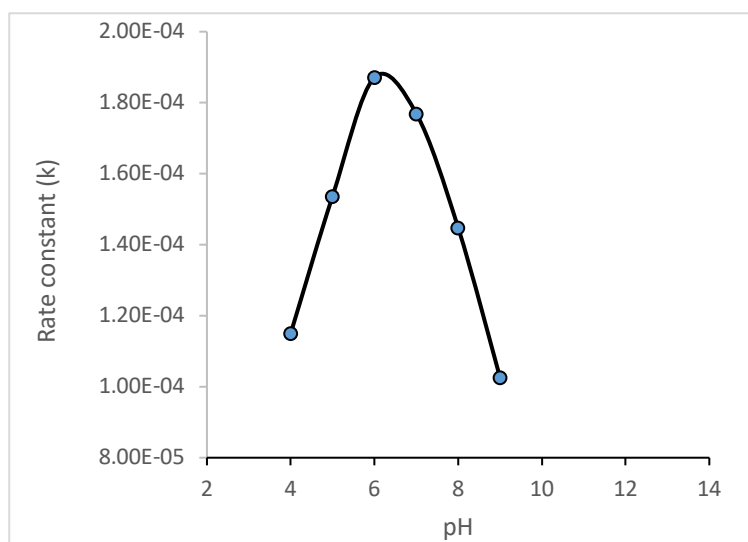


Fig. 4: Effect of pH

It was found that as the pH of the dye solution was raised, the rate of photocatalytic degradation increased. The degradation attains maximum value at pH 6.0 and other parameter constant as a 6.0×10^{-6} M concentration of Rose Bengal solution, 0.08 g catalyst of ZnO-MoS₂ and 70.0 mWcm⁻² of Light intensity.

Effect of dye concentration

The concentration of was varied from 4.0×10^{-6} to 14.0×10^{-6} M, keeping all other factors constant. The results are represented in Fig 5.

[Rose Bengal] x 10 ⁻⁶ M	Rate constant(K) × 10 ⁵ (s ⁻¹)
4.0	1.86
6.0	2.21
8.0	1.52
10.0	1.06
12.0	0.90
14.0	0.82

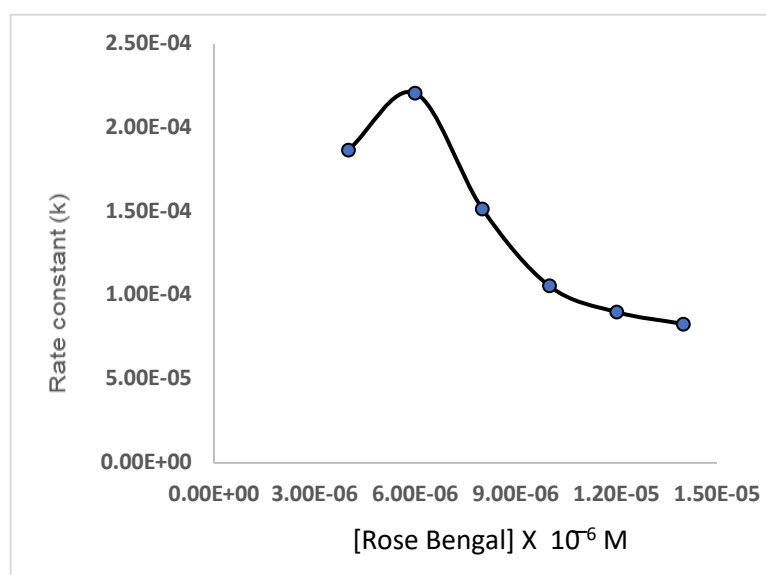


Fig. 5: Effect of Rose Bengal concentration

The rate of photocatalytic degradation was found to increase with an increase in the concentration of Rose Bengal. The rate of degradation of dye started declining after optimum concentration (6.0×10^{-6} M) and other parameters constant, as a 0.08 g catalyst of ZnO-MoS₂ and 70.0 mWcm⁻² of Light intensity at pH 6.00. At higher concentrations of dye, the dye will act as a filter to the incident light reaching the surface of the composite, and due to this, the rate of photocatalytic degradation of the dye decreases.

Effect of ZnO-MoS₂ amount catalyst

The dependence of the degradation of Rose Bengal on the amount of ZnO-MoS₂ catalyst was also studied. The results are represented in Fig. 6

Amount of catalyst (g)	Rate constant (k) × 10 ⁵ (s ⁻¹)
0.02	6.50
0.04	8.28
0.06	9.00
0.08	12.1
0.10	9.32
0.12	8.26
0.14	7.83

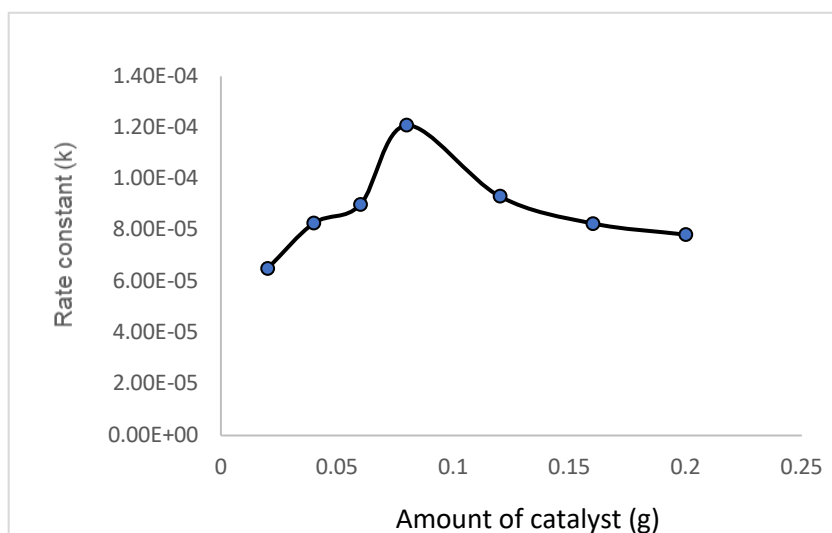


Fig. 6: Effect of the amount of catalyst

It was observed that the rate of degradation increases with the increase in the amount of composite as more active sites and availability increase, but it becomes virtually constant at 0.08 g. other parameters constant as a 6.0×10^{-6} M concentration of Rose Bengal solution and 70.0 mWcm^{-2} of Light intensity at pH 6. Then there was a slight decrease, this is a saturation point. It is due to the fact that there is no increase in the exposed surface area of the catalyst after 0.08 g of composite, there only multilayers are formed.

Effect of light intensity

The dependence of the degradation of Rose Bengal on the intensity of light was studied and represented in Fig. 7.

Light intensity (mWcm^{-2})	Rate constant ($k) \times 10^5 \text{ (s}^{-1}\text{)}$
20.0	4.43
30.0	5.3
40.0	6.50
50.0	7.10
60.0	13.00
70.0	18.00

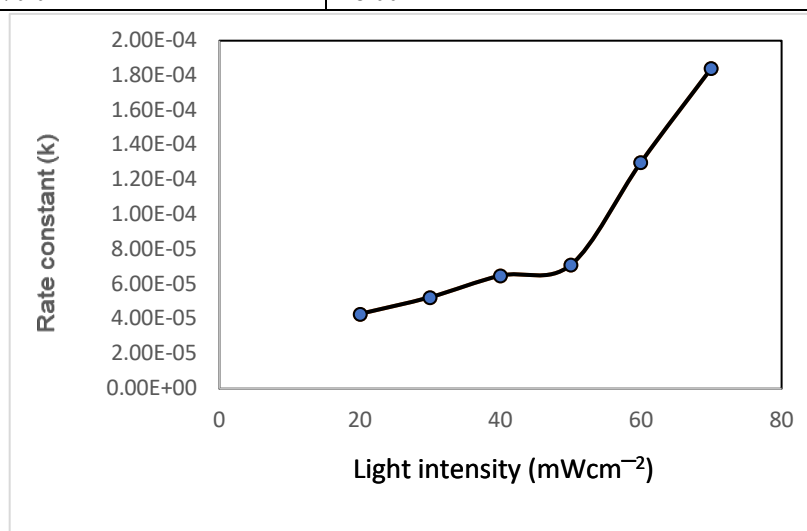


Fig 7: Effect of Light intensity

The results indicated that an increase in light intensity to increases the degradation of Rose Bengal. The maximum degradation rate of Rose Bengal was observed at 70.0 mWcm^{-2} other parameters constant as a 6.0×10^{-6} M

concentration of Rose Bengal solution and 0.08 g catalyst of ZnO-MoS₂ at pH 6.0. It was attributed to the fact that the number of photons per unit time per unit area increases on increasing light intensity, resulting in a higher rate of degradation.

Scavenger study:

Different types of scavengers were used for the scavenger study, such as Isopropyl alcohol was a specific scavenger for hydroxyl radical. The photodegradation efficiency of Rose Bengal by the ZnO-MoS₂ composite was investigated under visible light, with a control experiment without a scavenger and with a scavenger. It was indicated that h⁺ and [•]OH played a major role in the degradation process.

Mechanism:

The Rose Bengal is excited from the ground state to its first excited state by absorbing incident radiation of a suitable wavelength, which undergoes intersystem crossing (ISC) to generate the triplet excited state of the dye. The electrons are transferred from the valence band to the conduction band under visible irradiation of the photocatalyst, thereby generating electrons (e⁻) in the conduction band and holes (h⁺) in the valence band. The photo-generated holes could either directly oxidize adsorbed Rose Bengal or react with hydroxyl ion (⁻OH) or H₂O to generate hydroxyl radicals ([•]OH). Rose Bengal dye was degraded by these generated [•]OH and h⁺.

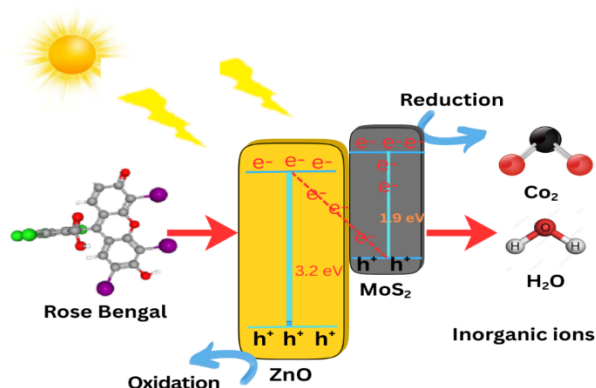


Fig. 8: Z-scheme Mechanism

CONCLUSIONS

This composite photocatalyst followed the Z-Scheme and provided better degradation. The reusability of this composite was also confirmed. The ZnO/MoS₂ heterostructures were prepared and used successfully for the degradation of Rose Bengal. The optimum conditions were obtained as:

- pH = 6.0,
- Rose Bengal concentration = 6.0×10^{-6} M,
- ZnO-MoS₂ amount 0.08 g

Intensity of light = 70.0 mWcm⁻². The Rose Bengal was degraded 90.55% over this composite

REFERENCE

1. Liu L., Chen P., Kovarik L., Yoreo J., D., Liu J. and Sushko M. L., Solution synthesis of two-dimensional ZnO / MoS₂ heterostructure through reactive templating for enhanced visible-light degradation of Rhodamine B (RB), *Adv. Compos. Hybrid Mater.*, <https://doi.org/10.21203/rs.3.rs-3343676/v1> (2023)

2. Kao L., Chuang K., Catherine H. N., Huang J., Hsu H., Shen Y. and Hu C., MoS₂-coupled coniferous ZnO for photocatalytic degradation of dyes, *Taiwan Inst. Chem. Eng.*, **142**, <https://doi.org/10.1016/j.jtice.2022.104638> (2023)
3. Krishnan U., Kaur M., Kaur G., Singh K., Dogra A. R., Kumar M., and Kumar A., MoS₂/ZnO nanocomposites for efficient photocatalytic degradation of industrial pollutants. *Mate. Res. Bull.*, **111**, 212-221 (2019)
4. Tama A. M., Das S., Dutta S., Bhuyan M. D. I., Islam M. N., and Basith, M. A., MoS₂ nanosheet incorporated α -Fe₂O₃/ZnO nanocomposite with enhanced photocatalytic dye degradation and hydrogen production ability, *RSC Adv.*, **9(69)**, 40357–40367 (2019)
5. Tian Q., Wu W., Yang S., Liu J., Yao W. Ren F., and Jiang C., Zinc Oxide Coating Effect for the Dye Removal and Photocatalytic Mechanisms of Flower-Like MoS₂ Nanoparticles. *Nanoscale Res. Lett.*, **12**, <https://doi.org/10.1186/s11671-017-2005-0> (2017)
6. Jia M., Yu S., Li D., Liu C., Bao Y. and Yu X., Chen K., Preparation and Photocatalytic Performance of MoS₂/ZnS/ZnO-T Heterojunction Photocatalyst for Dye Degradation in Water, **39 (10)**, <https://doi.org/10.1002/ppsc.202200034> (2022)
7. Y. Fu, Z. Ren, J. Wu, Y. Li, W. Liu, P. Li, L. Xing, J. Ma, H. Wang and X. Xue, Direct Z-scheme heterojunction of ZnO/MoS₂ nanoarrays realized by flowing induced piezoelectric field for enhanced sunlight photocatalytic performances, *Appl. Catal. Environ.*, **285**, 119785 (2021).
8. K. Gayathri, Y. N. Teja, R. Prakash, M. Hossain, A. Alsalmeh, E. Sundaravadivel and M. Sakar, In situ-grown ZnO particles on g-C₃N₄ layers: a direct Z-scheme-driven photocatalyst for the degradation of dye and pharmaceutical pollutants under solar irradiation, *J. Mater Sci: Mater Electron.*, **33**, 9774–9784 (2022).
9. Hezam, K. Namratha, D. Ponnammam, Q. A. Drmish, A. Morshed, N. Saeed, C. Cheng and K. Byrappa, Direct Z-Scheme Cs₂O–Bi₂O₃–ZnO heterostructures as efficient sunlight-driven photocatalysts, *ACS Omega*, **3**, 12260–12269 (2018).
10. S. Balu, S. Velmurugan, S. Palanisamy, S. W. Chen, V. Velusamy, T. C. K. Yang and E. S. E. Shafey, Synthesis of α -Fe₂O₃ decorated g
11. C₃N₄/ZnO ternary Z-scheme photocatalyst for degradation of tartrazine dye in aqueous media, *J. Taiwan Inst. Chem. Eng.*, **99**, 258-267 (2019).
12. Kapatel S. and Sumesh, C. K., Two-Step Facile Preparation of MoS₂·ZnO Nanocomposite as Efficient Photocatalyst for Methylene Blue (Dye) Degradation. *Electron. Mater. Lett.*, **15**, 119-132 (2019)
13. Alharthi F. A., Alghamdi A., Alanazi H. S., Alsyahi

- A. A. and Naushad A, Photocatalytic Degradation of the Light Sensitive Organic Dyes: Methylene Blue and Rose Bengal by Using Urea Derived g-C₃N₄/ZnO Nanocomposites. *Catalysts*, **10(12)**, 1457 (2020)
14. Khatri A., Jangra V. and Rana P., Efficient photocatalytic degradation of Rose Bengal dye by Cu doped zinc oxide nanoparticles, *AIP Conf. Proc.* 2265, 030186 (2020) <https://doi.org/10.1063/5.0017150>.