Studying the Effect of Different Parameters on Photocatalytic Degradation of Commercial Safranin-T Dye by Using ZnO/V_2O_5 Nanocomposite

Ameerah S. Jawad[1*], Hazim Y. Al-gubury[2]

Abstract

Photocatalytic-degradation process of Safranin-T dye in this article has been investigated by using prepared nanocomposite and solar lamp. Zinc oxide/vanadium pentoxide nanocomposite was prepared using "hydrothermal processes". The degradation of dye was performed by irradiated aqueous suspended solutions containing different concentrations of dye using 0.2g/100ml of nanocomposite. The effect of various factors on the photocatalytic-degradation process of Safranin-T dye was tested to reach an optimal state, where they involve the effect of the nanocomposite mass and the effect of Safranin-T dye concentration the effect of light intensity and effect of temperature. The activation energy has been calculated equal 28.84 kJ.mole-1 The irradiated solutions were studied using UV-Vis spectrophotometer.

Key Words: Photocatalytic, Degradation, Safranin-T Dye, Zinc Oxide, Vanadium Pentoxide, Nanocomposite.

DOI Number: 10.14704/nq.2021.19.8.NQ21113 **NeuroQuantology 2021; 19(8):59-65**

Introduction

One of the most important causes of pollution of water sources is throwing factory waste directly into water sources without treating them, knowing that these materials contain many high-risk dyes, that cause many diseases dangerous to human health (Misriyani et al., 2015), (Gaya and Abdullah, 2008), (Liao et al., 2010). There are many methods used to treat these harmful wastes, the most important of which is the advanced oxidation processes (AOP) which is used for the photo-degradation of harmful wastes (Pereira et al., 2011). AOPs are depends primarily on the formation of the reactive-species such as "hydroxyl radicals" Capable of oxidizing many organic pollutants quickly and non-selectively (Yuliati et al., 2017), (Syafei et al., 2017), (Mallakpour and Khadem, 2016). When a nanocomposite is irradiated with a UV lamp with an energy equal to or greater than the band gap energy of the prepared composite, electrons in the valence band of the semiconducting oxide are excited (promoted) from the valence band to the conduction band, forming electron-hole pairs. The excitons created by the photo can be retained in aqueous solution by dissolved oxygen, forming reactive hydroxyl radicals that can attack and mineralize the adsorbed organic dye molecules. (Akhavan et al., 2011), (Olajire and Olajide, 2014), (Chijioke-Okere et al., 2019).

"Safranine T dye" a cationic dye derived from an aromatic amine with molecular formula:$C_{20}H_{19}ClN_4$. Safranin T typically has the chemical structure shown below:

Corresponding author: Ameerah S. Jawad
Address: [1*,2]Department of Chemistry, College of Science for Women, University of Babylon, Hilla, Iraq.
[2]E-mail: h.yahya40@yahoo.com

Relevant conflicts of interest/financial disclosures: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.
Received: 03 June 2021 **Accepted:** 08 July 2021

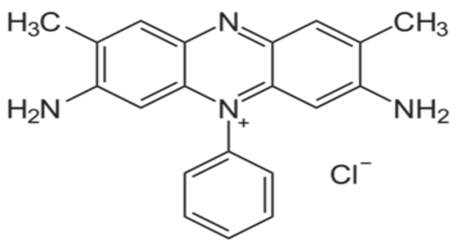

Fig. 1. Chemical structure of Safranine T dye

Safranine T dye has been widely utilized in the synthetic fiber, leather, paper dyeing, and food coloring sectors, among others. On the other hand, in the biological field, it works as a staining agent and photosensitizer. Safranin is also used as redox indicator in analytical chemistry (Mostafa et al., 2018) (Bhavani et al., 2018), (Malik, 2004).

Experimental Section

1- Chemicals

a- Zinc acetate dehydrate, were supplied by Fluka.
b- Oxalic acid, were supplied by Fluka (Buchs, Switzerl and)
c- Zinc oxide, (100) mesh particle size, purity (99 %), supplied by Fluka AG.
d- Vanadium pentoxide, was obtained from Sigma-Aldrich (St. Louis, USA)
e- Safranine T dye, e supplied by sigma – Aldrich.
f- Ethanol, were sourced from Fluka.

No further purification was performed on any of the compounds.

2- Synthesis of ZnO/V_2O_5 Nanocomposite

The nanocomposite ZnO/V_2O_5 was synthesized using the hydrothermal process, which is a technique for growing single crystals from aqueous solutions in an autoclave (a thick-walled and sealed vessel) at elevated temperatures and pressures. Firstly zinc acetate dehydrate (5 g) were dissolved in 50ml distilled water with continuous stirring for 15 min, in the same time 3 g of oxalic acid were dissolved in in 50ml distilled water with string for 15 min after that mixing two solution with string to prepared zinc oxide nanoparticle. 1g of V_2O_5 were dissolved in in 70ml distilled water and added to the mixture of zinc oxide nanoparticle with continuous stirring until get homogeneous solution. The final mixture was transferred into the stainless steel autoclave (a thick-walled and sealed vessel). The hydrothermal synthesis was maintained at 180 C for 12 h. The precipitate was taken out from the autoclaves at room temperature and washed several times with deionized water and ethanol to remove all the impurities, after that all the final products were filtered and dried at 60 C overnight in a vacuum oven. Finally, the mixture powders were calcined at 200, 300,500C in the air for 2 h to obtain ZnO / V_2O_5 composites.

3- Photocatalytic decomposition of safranin T dye using ZnO/V_2O_5 composites. We conducted photocatalytic degradation tests on safranin T dye in aqueous solution using a ZnO/V_2O_5 nanocomposite as the photo catalyst. A specially developed photo reactor was employed to conduct the entire experiment, which is divided into two halves. The first was employed to chill the suspension solution by the passage of cooling water. The second component contains a suspension solution with a capacity of (100 ml) for degraded dye. Using distilled water, a 100ppm stock solution of safranin T dye solutions was created. Through stirring, a suspension solution mixture for each dye concentration was obtained. By adding 0.2 g of ZnO/V_2O_5 nanocomposite to 100 ml of each color and stirring, a suspension mixture was formed. The respective suspension solution mixtures have been irradiated with an ultraviolet light source mounted on a bench top. Approximately 2-3 ml of each sample was obtained using a syringe at 10-minute intervals, spun at 3000 rpm for 10 minutes, and the absorption of all samples was determined using a UV-Vis spectrophotometer.

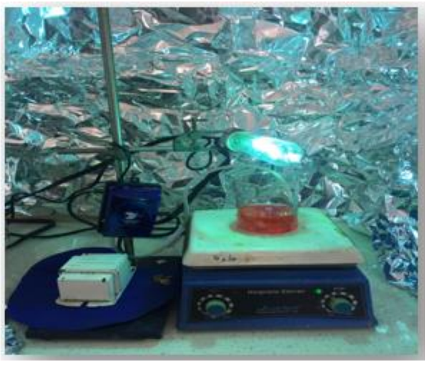

Fig. 2. Main parts of the photocatalytic-cell used in Photcatalytic-degradation of Safranin-T dye

Result and Discussion

1- Mass Effect of ZnO /V_2O_5 Nanocomposite on Photocatalytic-degradation of the Safranin-T dye

The mass effect of ZnO/ V_2O_5 nanocomposite on Photocatalytic-degradation of Safranin-T dye, has been studied using 20ppm of dye, airflow rate 10ml / min, at room temperature. When the mass of vanadium pentoxide is increased until it reaches 0.2g/100ml, the photocatalytic degradation of Safranin-T dye increases gradually and subsequently drops gradually. When the ZnO/V_2O_5 nanocomposite mass is 0.2g/100ml, the semiconductor can achieve the greatest light absorption. The decline in photo degradation efficiency associated with mass concentrations of ZnO/V_2O_5 nanocomposite more than 0.2 g/100 ml is due to "light absorption" in the first layers of Safranin-T dye; the remaining layers of solution don't receive "light photons". Additionally, "light scattering" occurs with high ZnO/V_2O_5 nanocomposite loading, resulting in a drop in photon intensity and substantial absorption of light through the first successive layers of solution, effectively blocking light from passing through all subsequent layers in the reaction vessel. Numerous researchers have examined this impact. (Ashwin et al., 2017), (Hu et al., 2010), (Chakrabarti and Dutta, 2004), (Hazim et al., 2014) When the loading mass of ZnO/V_2O_5 nanocomposite is less than the optimal value of 0.2 g/100 ml, the rate of photo degradation of Safranin-T dye also decreases. This is because the mass of ZnO/ V_2O_5 nanocomposite decreases, which results in a decrease in the surface area of ZnO/ V_2O_5 nanocomposite, which results in a decrease in light absorption by ZnO/ V_2O_5.

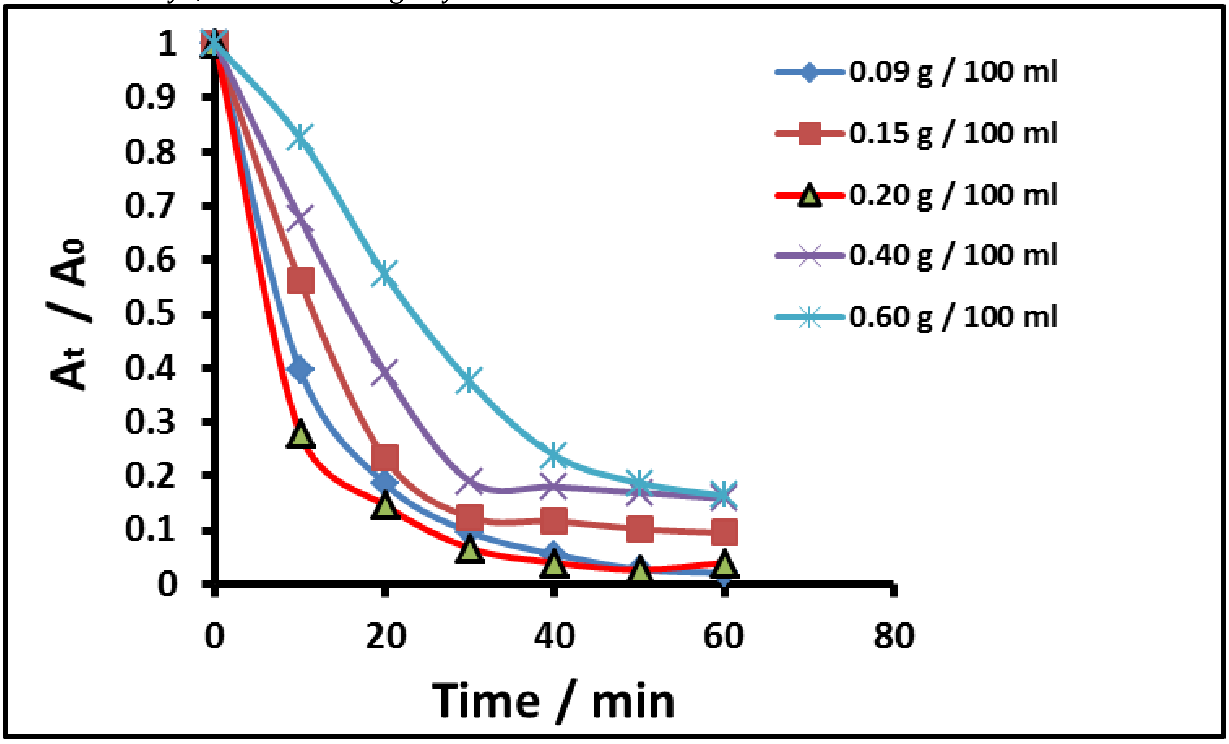

Fig. 3. Variation in (A_t/A_0) with time of irradiation at 20 ppm of the prepared dye

2- Effect of Initial Dye Concentration of Safranin-T on the Photocatalytic-Degradation Process

The effect of Safranin-T dye solution concentration in the photocatalytic-degradation processes in the range (20-90 ppm) was tested by keeping all the other experimental conditions constant.

The results are plotted in figure (4). These results indicate that the rate of photocatalytic degradation decreased as the original dye concentration increased. As the initial Safranin-T dye concentration falls, the path length of the photon entering the solution reduces, increasing the number of photons reaching the catalyst surface and hence the rate of synthesis of hydroxyl radicals and super oxide ions. (Aseel et al., 2020), (Sadiq et al., 2019), (Rattan et al., 2008).

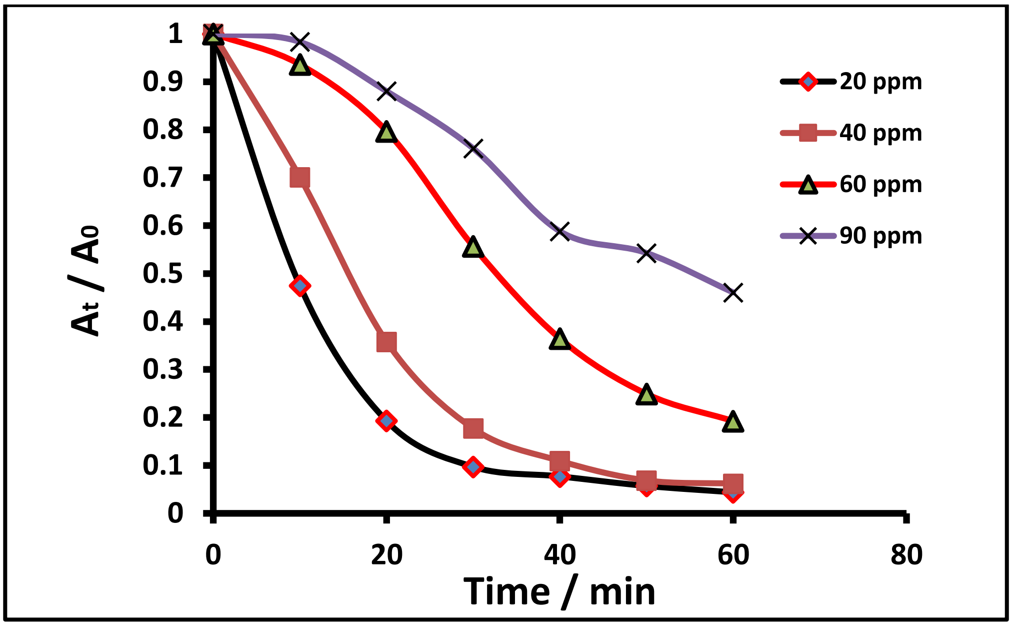

Fig. 4. Variation in (A_t/A_0) with time of irradiation at different concentrations of dye

3- The Effect of Light Intensity on Photodegradation of Safranin-T Dye Using ZnO/ V_2O_5 Nanocomposite

Numerous tests were conducted to investigate the effect of light intensity on photocatalytic degradation of Safranin-T dye at light intensities ranging from (3 to 9) mW/cm². Consistent with the original Safranin-T dye concentration of 20 ppm, the produced ZnO/V_2O_5 catalyst dose was 0.2 g/100cm³, 10cm³ /min flow rate of an air bubble at room temperature. The results in Figure (5) indicate that as the light intensity increased, the dye breakdown process accelerated. (Patil et al., 2014), (Al-gubury and Mohammed, 2016), (Qin et al., 2016). This could be explained by the enhanced photon production required for electron transport from the catalyst's valence band to its conduction band. The light intensity of 9 mW/cm² is sufficient to achieve a photo degradation efficiency of 95.61 percent.

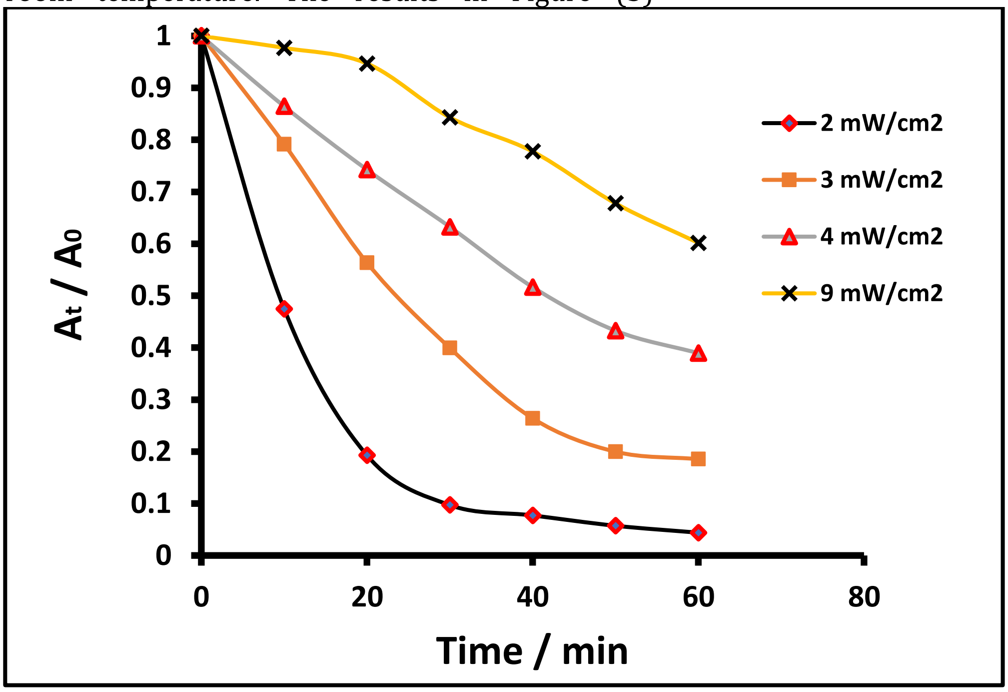

Fig. 5. Variation in (A_t/A_0) with irradiation time at different light intensity

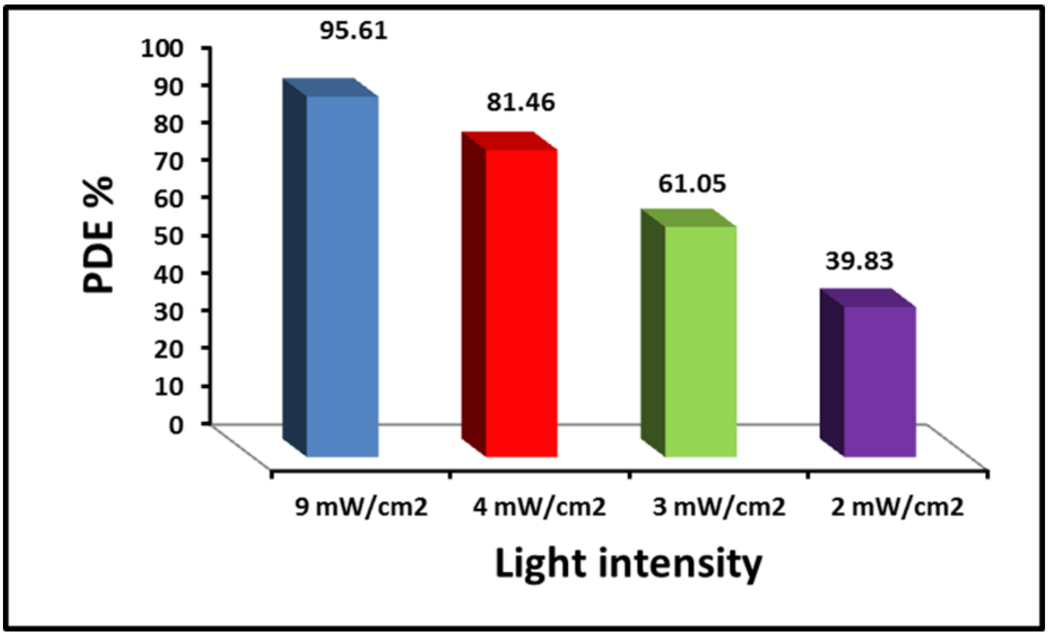

Fig. 6. Photocatalytic degradation efficiency using 0.2g / 100 ml ZnO / V_2O_5 nanocomposite and 20 ppm of safranine-T dye

4- Temperature Effect on Photocatalytic-degradation of Safranin-T Dye

A series of experiments were done for studding the influence of temperature on photocatalytic degradation of Safranin-T dye in range (298 – 313)k. By conservation other experimental conditions apply constant at initial Safranin-T dye concentration of 20 ppm, prepared ZnO/ V_2O_5 catalyst dosage was 0.2 g /100cm^3. The results in Figure(7) show that the degradation process of dye progressively increased with increase in the temperature, this may be due to the increased reactive hydroxyl radical obstetrics. (Algubury, 2016), (Chen et al., 2014), (Algubury, 2016).

The activation energy associated with the photodegrdation of dye was calculated according to the Arrhenius equation by plot of In k versus 1/T (Figure 8), which gives 28.83 ±1 kJ.mol-1.

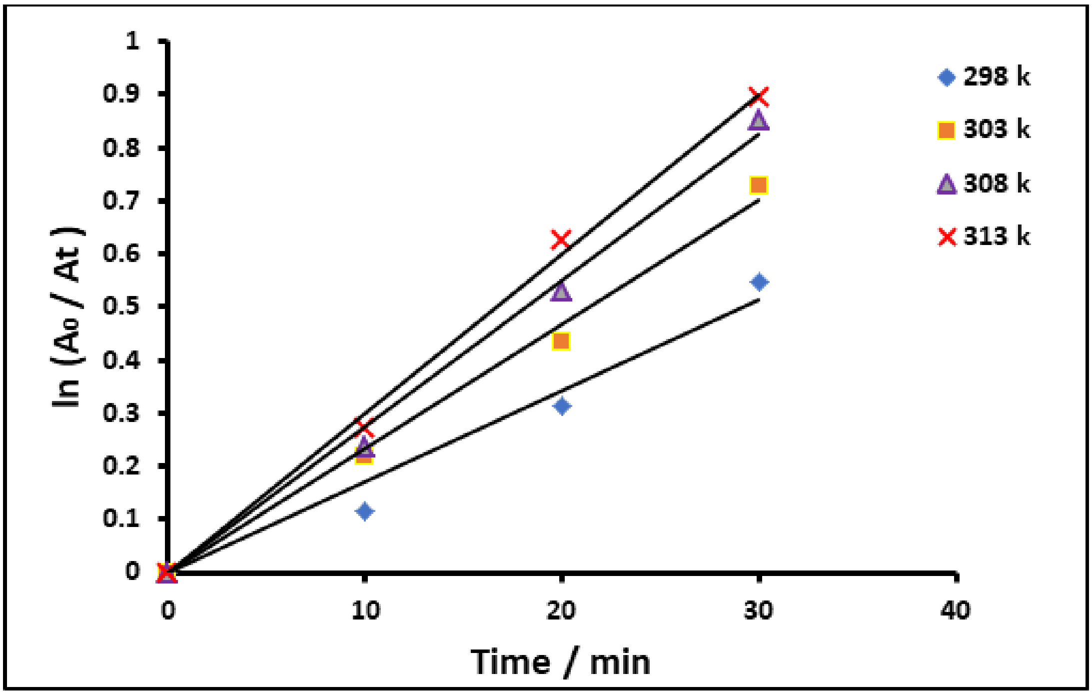

Figure 7. Change of "ln (A_0 / A_t)" with time of irradiation at different temperature using UV radiation, initial Safranin-T dye concentrations = 20 ppm, amount of photo catalyst = 0.20 g / 100 cm^3

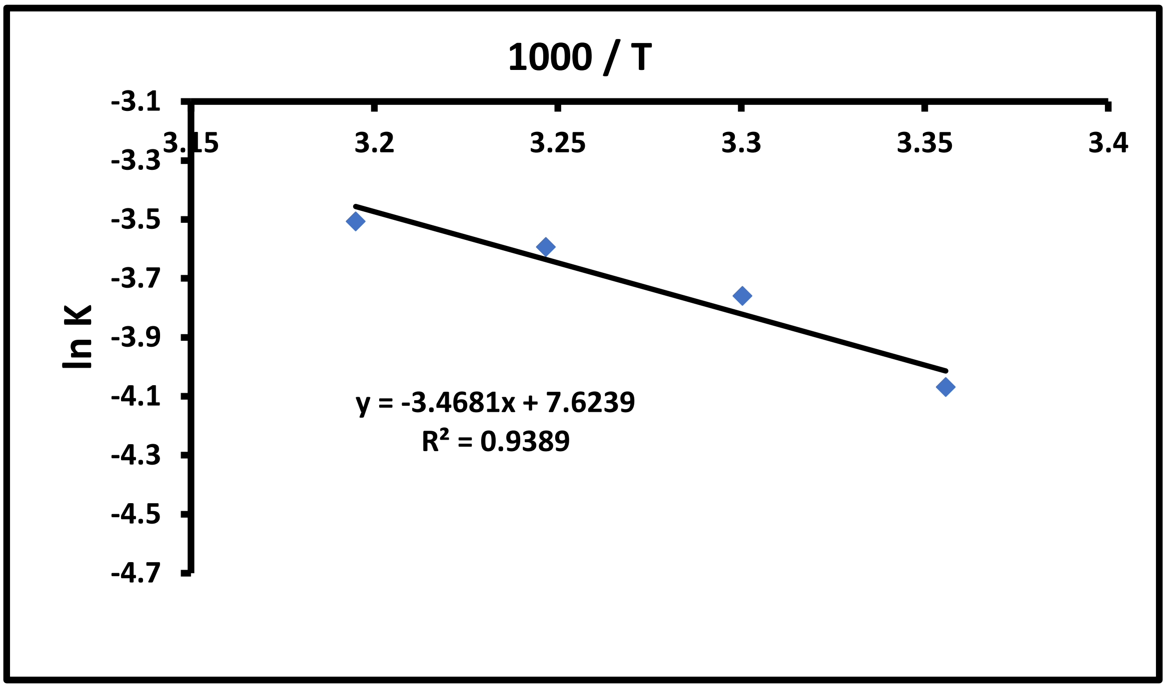

Fig. 8. Arrhenius plot of safranine-T dye

Conclusion

In this article zinc oxide/vanadium pentoxide nanocomposite was prepared using hydrothermal method. The photocatalytic degradation processes of safranine-T depended on the amount of "catalyst dosage" and the optimum value equal 0.2 gm / 100 cm^3 of ZnO/V_2O_5 nanocomposite. The effect of dye concentration has been studied the optimum value of safranine-T dye 20ppm.The light intensity $9mW/cm^2$. The photocatalytic-degradation "decrease" with "increase" concentration of safranine-T due to the decrease of the concentration OH- adsorbed on the catalyst surface. The photocatalytic-degradation of safranine-T increases with the increase of light intensity. The percentage efficiency of The photocatalytic-degradation safranine-T equals 95.61 %.The activation energy has been calculated $=28.84kJ.mol^{-1}$.

Acknowledgments

We would like to express our gratitude to the Chemistry Department of the College of Science for Women/University of Babylon for assisting us in completing this study.

References

Misriyani M, Kunarti ES, Yasuda M. Synthesis of Mn (II)-Loaded Ti x Si 1-x O 4 Composite Acting as a Visible-Light Driven Photocatalyst. *Indonesian Journal of Chemistry* 2015; 15(1): 43-49.

Gaya UI, Abdullah AH. Heterogeneous photocatalytic degradation of organic contaminants over titanium dioxide: a review of fundamentals, progress and problems. *Journal of photochemistry and photobiology C: Photochemistry reviews* 2008; 9(1): 1-12.

Liao W, Zheng T, Wang P, Tu S, Pan W. Efficient microwave-assisted photocatalytic degradation of endocrine disruptor dimethyl phthalate over composite catalyst ZrOx/ZnO. *Journal of Environmental Sciences* 2010; 22(11): 1800-1806.

Pereira JH, Vilar VJ, Borges MT, González O, Esplugas S, Boaventura RA. Photocatalytic degradation of oxytetracycline using TiO2 under natural and simulated solar radiation. *Solar Energy* 2011; 85(11): 2732-2740.

Yuliati L, Roslan NA, Siah WR, Lintang HO. Cobalt oxide-modified titanium dioxide nanoparticle photocatalyst for degradation of 2,4-dichlorophenoxyacetic acid. *Indonesian Journal of Chemistry* 2017; 17(2): 284–290.

Syafei D, Sugiarti S, Darmawan N, Khotib M. Synthesis of TiO2/carbon nanoparticle (C-dot) composites as active catalysts for photodegradation of persistent organic pollutant. *Indonesian Journal of Chemistry* 2017; 17(1): 37–42.

Mallakpour S, Khadem E. Carbon nanotube-metal oxide nanocomposites: Fabrication, properties and applications. *Chemical Engineering Journal* 2016; 302: 344–367.

Akhavan O, Azimirad R, Safa S, Hasani E. CuO/Cu (OH) 2 hierarchical nanostructures as bactericidal photocatalysts. *Journal of Materials Chemistry* 2011; 21(26): 9634-9640.

Olajire AA, Olajide AJ. Kinetic Study of Decolorization of Methylene Blue with Sodium Sulphite in Aqueous Media: Influence of Transition Metal Ions. *Journal of Physical Chemistry & Biophysics* 2014; 4(2): 2-7.

Maureen COO, Nnaemeka OJ, Basil AN, Emeka OE. Photocatalytic degradation of a basic dye using zinc oxide nanocatalyst. *International Letters of Chemistry, Physics and Astronomy* 2018; 81: 18-26.

Abukhadra MR, Shaban M, Abd El Samad MA. Enhanced photocatalytic removal of Safranin-T dye under sunlight within minute time intervals using heulandite/polyaniline@ nickel oxide composite as a novel photocatalyst. *Ecotoxicology and environmental safety* 2018; 162, 261-271.

Nenavathu BP, Kandula S, Verma S. Visible-light-driven photocatalytic degradation of safranin-T dye using functionalized graphene oxide nanosheet (FGS)/ZnO nanocomposites. *RSC advances* 2018; 8(35): 19659-19667.

Malik PK. Oxidation of safranine T in aqueous solution using Fenton's reagent: involvement of an Fe (III) chelate in the catalytic hydrogen peroxide oxidation of safranine T. *The Journal of Physical Chemistry A* 2004; 108(14): 2675-2681.

Ashwin BCMA, Vinothini A, Stalin T, Muthu Mareeswaran P. Synthesis of a Safranin T-p-Sulfonatocalix [4] arene Complex by Means of Supramolecular Complexation. *Chemistry Select*, 2017; (3): 931-936.

Hu Q, Liu B, Song M, Zhao X. Temperature effect on the photocatalytic degradation of methyl orange under UV-vis light irradiation. *Journal of Wuhan University of Technology-Mater. Sci. Ed.*, 2010; 25(2): 210-213.

Chakrabarti S, Dutta BK. Photocatalytic degradation of model textile dyes in wastewater using ZnO as semiconductor catalyst. *Journal of hazardous materials* 2004; 112(3): 269-278.

Al-Gubury HY, Hassan AF, Alteemi HS, Alqaragully MB, Bennecer A, Alkaim AF. Photo catalytic removal of paraquat dichloride herbicide in aqueous solutions by using TiO2 nanoparticle, 16. *Journal of Global Pharma Technology* 2017; 12(9): 290-295.

Aljeboree AM, Al-Gubury HY, Bader AT, Alkaim AF. Adsorption of Textile Dyes in the Presence Either Clay or Activated Carbon as a Technological Models: A Review. *Journal of Critical Reviews* 2020; 7(5): 620-626.

Karim SA, Al-Gubury HY, Abd Alrazzak N. The synthesis of a novel azo dyes and study of photocatalytic degradation. *In Journal of Physics: Conference Series* 2019; 1294(5): 052054.

Rattan VK, Purai A, Singh H, Manoochehri M. Adsorption of dyes from aqueous solution by cow dung ash. *Carbon Letters* 2008; 9(1): 1-7.

Patil PN, Bote SD, Gogate PR. Degradation of imidacloprid using combined advanced oxidation processes based on hydrodynamic cavitation. *Ultrasonics sonochemistry* 2014; 21(5): 1770-1777.

Al-gubury HY, Mohammed QY. Prepared coupled ZnO–Co2O3 then study the photocatalytic activities using crystal violet dye. *Journal of Chemical and Pharmaceutical Sciences* 2016; 9(3): 1161-1165.

Qin L, Liu M, Wu Y, Xu Z, Guo X, Zhang G. Bioinspired hollow and hierarchically porous MOx (M= Ti, Si)/carbon microellipsoids supported with Fe2O3 for heterogenous photochemical oxidation. *Applied Catalysis B: Environmental* 2016; 194: 50-60.

Algubury HY. Study the activity of titanium dioxide nanoparticle using orange G dye. *Malaysian Journal of Science* 2016; 35(2): 340-353.

Chen Y, Zhang C, Huang W, Yang C, Huang T, Situ Y, Huang H. Synthesis of porous ZnO/TiO2 thin films with superhydrophilicity and photocatalytic activity via a template-free sol–gel method. *Surface and Coatings Technology* 2014; 258: 531-538.

Algubury HY. Study the activity of titanium dioxide nanoparticle using orange G dye. *Malaysian Journal of Science* 2016; 35(2): 340-353.

Bayazit ZZ. The determination of brain localization in adult second language learning process. *NeuroQuantology* 2019; 17(2): 8-15.