



The influence of Operational Parameters on the Photocatalytic Decolorization of Tubantin blue BRR-HC dye in pure aqueous TiO₂ Suspensions

Yasmin A.A^{1*}, S. Hamdo², Adil A. E³, Elmugdad A.A¹.

1. Chemistry Department, College of science, Sudan University of Science and Technology

2. Solar Energy Equipment Co. Khartoum- Sudan

3. Department of Chemistry, College of Science and Arts (Al-Khafji), University of Hafr Al Batin, Saudi Arabia

* Corresponding author: yasabao01@gmail.com

Received: April 2017

Accepted: May 2017

Abstract

Photo-catalytic decolorization of Tubantin blue BRR-HC dye was investigated using pure TiO₂ anatase in aqueous suspension under solar radiation. The influence of pH solution, amount of catalyst, dye concentration, volume of 30% hydrogen peroxide and irradiation time was studied. Temperature of solution and photon flux were calculated during the experiments. Results show that the employment of efficient photo-catalyst and selection of optimal operational parameters might lead to complete decolorization

المستخلص

تمت التحقق من التحفيز الضوئي لإزالة لون صبغة التوبنتان الزرقاء باستخدام محلول مائي لثاني أكسيد التيتانيوم النقي تحت أشعة الشمس وتمت دراسة تأثير الأس الهيدروجيني، وكمية محفز، وتركيز الصبغة، وحجم محلول فوق أكسيد الهيدروجين تركيزه 0.0% و زمن التعرض للأشعة على التفاعل. تم حساب درجة حرارة المحلول وتدفق الفوتونات أثناء التجارب. وضحت النتائج أن تطبيق العوامل الفعالة ربما قادت لإزالة كامله للون الصبغة.

KEYWORD: Tubantin blue BRR-HC, Advance Oxidation processes titanium dioxide photo-catalyst.

© 2017 Sudan University of Science and Technology, All rights reserved

Introduction

Dyes are organic compounds that colorized materials. Dyes can be classified as anionic (direct, acid, and reactive dyes), cationic (basic dyes), non-ionic (disperse dyes), azo, diazo, anthroquinone based and metal complex dyes. (Mall et al., 2006). Large amounts of synthetic dyes are produced and used in many different industries; textiles, paper, cosmetic, printing, leather, rubber and plastics. (Seyyedi and Jahromi, 2014; Kerkez-Kuyumcu et al., 2015). About 1–20% of the total global production of dyes

is lost during the dyeing process and is released into the environment as textile effluent (Han et al.; 2009, Kerkez-Kuyumcu et al., 2015). The release of those colored waters in the environment is a considerable source of non-aesthetic pollution and eutrophication and it can originate dangerous byproducts through oxidation, hydrolysis or other chemical reactions taking place in the wastewater phase (Habibi et al., 2005, Mahmood and Arami, 2006, Kordouli et al., 2015). It inhibits sunlight penetration into the stream

and reduces the photosynthetic reaction. Some dyes are also toxic and even carcinogenic. (Shakir *et al.*, 2010). Removing color from wastes is often more important than other colorless organic substances, because the presence of small amounts of dyes (over 1 ppm) is clearly visible and influences the water environment considerably (Verma *et al.*, 2012). Highly substituted aromatic rings, joined by one or more azo groups, characterize their chemical structures. These substituted ring structures make the molecules recalcitrant which the conventional wastewater treatment, such as Biological, physical, chemical and physico-chemical methods, which include coagulation and flocculation (Aleboye *et al.*; 2008, Harrelkas *et al.*, 2009; Zonoozi *et al.*, 2009), membrane separation (Sachdeva and Kumar, 2009; Amini *et al.*, 2011) sonochemical degradation (Abbasi and Asl, 2008), electrochemical (Gupta *et al.*, 2007; Fan *et al.*, 2008), activated carbon adsorption (Xu *et al.*, 2008; Tan *et al.*, 2008; Foo and Hameed, 2010) and adsorption (Crini, 2005, Crini and Badot, 2008) processes do not degrade (Soutsas *et al.*, 2010; Ajma *et al.*, 2016). These methods only succeed in transferring organic compounds from water to another phase, thus creating secondary pollution. This will require a further treatment of solid-wastes and regeneration of the adsorbent which will add more cost and expensive operations to the process (Mall *et al.*, 2006;

Mittal *et al.*, 2014; Lima *et al.*, 2015). In recent years an alternative to conventional methods, that is “Advanced Oxidation Processes” (AOPs), which includes ozonation (Akpan and Hameed, 2009), H₂O₂/UV processes (Saqib *et al.*, 2008), Fenton and photo-Fenton catalytic reactions (Zangeneh *et al.*, 2015) and heterogeneous photocatalysis based on the generation of very reactive species such as hydroxyl radicals that quickly and nonselectively, oxidizes a broad range of organic pollutants, was been applied. This technology leads to the total mineralization of most of the organic pollutants (Konstantinou and Albanis, 2004; Akpan and Hameed, 2009; Verma *et al.*, 2012). Heterogeneous nanophotocatalysis has several advantages over competing processes are; complete mineralization, no waste-solids disposal problem and only mild temperature and pressure conditions are necessary (Seyyedi and Jahromi, 2014). TiO₂ semiconductor photo-catalyst, has received increasing attention because of its low cost, non-toxicity, relatively high chemical stability of the catalyst, and the possibility of using sunlight as a source of irradiation. The aim of the present work is to investigate the influence of various parameters on photo-catalytic decolorization of Tubantin dye (fig 1), in the presence of pure TiO₂ irradiated by the Solar light. And also to determine solution temperature and photon flux during the reactions.

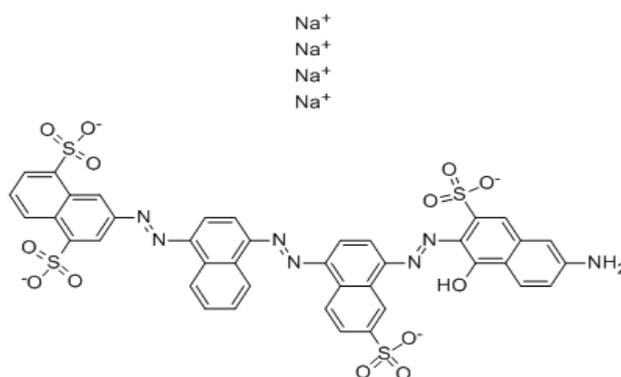


Fig (1): Chemical structure of Tubantin blue BRR-HC dye⁽³⁹⁾

Materials & Methods

Materials

Chemicals

Pure titanium dioxide (particle size 49nm, specific surface area 46.962 m²/g) from Aldrich, tubantin blue BRR-HC dye (colour index C.I DrB71) from Bezema, ferrioxalate actinometry (0.006M) was prepared, distilled water, sodium hydroxide 1%, sulphuric acid 0.5M, 1-10phenanthroline, Sodium acetate and all other chemicals of analytical grade.

Apparatus

Sensitive balance, magnetic stirrer, spectrophotometer (Jenway Aquanova), compound parabolic collector (CPC) solar collector (built by Dr. Saleh Hamdo at

Solar Energy Equipment Co), borosilicate tube (length 50cm, d 5cm, with slot on end to outlet the product.) built by technician Ahmed at physics Department – Faculty of science – Khartoum University

Method

Photo-reactor setup

All experiments were performed under the air and natural solar radiation. The solar CPC. was constituted by one CPC unit (0.2m²) and tilted 15° N local latitude. The cylindrical photochemical reactor 800cm³ capacity was made-up of borosilicate glass (length 50cm, d 5cm) (fig 2). The slot was opened during experimentation.



Fig (2):1 Photo-reactor setup

Determination of photon flux

2.947g of ferrioxalate actinometry (0.006M) solution was prepared in 100cm³ of H₂SO₄(0.5 M) and diluted with distilled water to 1 dm³. 450 cm³ (V₁) of solution irradiated under solar light using photo-reactor in (fig 2) for 30 min. 10cm³ (V₂) of irradiated solution was transferred into 50

cm³ volumetric flask (V₃) containing a mixture of 5cm³ of 0.1% 1.10-phenanthroline solution and 2.5 cm³ buffer pH 5, and then diluted to the mark with distilled water. A reference is prepared in the same way except that it has not been irradiated. Both solutions were kept in the dark (about 30 min) until full colour

development is achieved, and the absorbance difference between the two samples were measured at 510nm [optical path length $l=2.5\text{cm}$, $\epsilon(510\text{nm}) = 11100 \text{ dm}^3\text{mol}^{-1}\text{cm}^{-1}$, $\Phi(510 \text{ nm}) = 1.26 (0.006\text{M})$]. The photon flux amount $q_{n,p}$ einstein s^{-1} was calculated by (Kuhn et al., 2004)

$$q_{n,p} = \frac{\Delta AV_1 V_3}{\Phi(\lambda) \epsilon(510\text{nm}) V_2 l t} \quad - (1)$$

Photodecolorization of dye

500 cm^3 of dye solution was taken for all experiment, desired initial concentration for the different experiment (12.5, 25, 50, 100 and 200ppm) were prepared from a stock solution of 1000ppm. The pH was adjusted in (1.7, 3.3, 7.4, 9.4 and 10.6) using H_2SO_4 1% or NH_4OH 1%. Desired amount of

catalyst (0.1, 0.125, 0.25, 1, 2 and 3g). Repeat the experiments using H_2O_2 (30%) in different volumes (12.5, 20, 25, 37.5, 50 cm^3). In all experiments the reactor was washed with distilled water. Then the mixture was stirred for 30min. and exposed to solar radiation for two hours. The effect of irradiation time (1-6 hours) under optimum parameters. Then the absorbance was read at 436,525 and 620nm and the average were taken and were studied the percentage removal colour was determined using equation (2):

$$\text{decolorization \%} = \frac{A_i}{A_f} \times 100 \quad - (2)$$

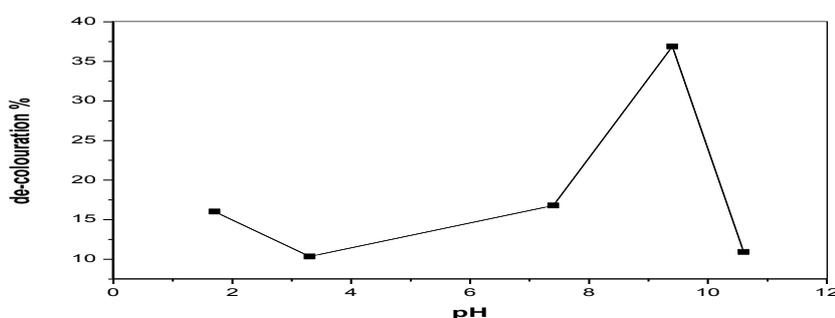
Where A_i is initial absorbance and A_f is final absorbance. The decolorization percentage versus irradiation time records using origin 8.6 computer programmer

Result and Discussion

Influence of pH

Table (1): Effect of pH on decolorization of tubantin blue dye at 50ppm concentration and 1g of catalyst

pH		Absorbance at 436nm	Absorbance at 525nm	Absorbance at 620nm	Average	De-coloration %
1.7	before	0.911	2.183	2.331	1.8083	16.03
	after	1.501	1.946	1.090	1.5183	
3.3	before	0.563	1.486	1.812	1.1930	10.34
	after	1.174	1.308	0.846	1.4512	
7.4	before	0.662	1.823	2.264	1.5830	16.80
	after	0.984	1.649	1.889	1.5123	
9.4	before	0.550	1.564	2.086	1.4000	36.90
	after	0.775	1.046	0.829	0.8833	
10.6	before	0.441	1.223	1.735	1.1330	10.94
	after	0.999	1.168	1.131	1.0090	



Fig(3) : Effect of pH on decoloration of Tubantin blue dye at 50ppm concentration and 1g of catalyst

The pH of the solution that achieved maximum removal was very effective, indicating that changes in pH of solution had a significant impact on the decolorization process. Table 1 summarizes the influence of pH solution in photo-decolorization and Fig (3) demonstrates the photo-catalytic decolorization of tubantin blue BRR-HC. The best results of Tubantin blue BRR-HC were obtained in alkaline pH 9.4, owing its molecular weight and structure causing hindrance. Very high pH

value was found to be favorable even when anionic azo dyes should hamper adsorption on the negatively charged surface. In alkaline solution OH⁻ radicals catalytic enhancement are easier to be generated by oxidation as more hydroxide ions are available on TiO₂ surface, thus the efficiency of the process is logically enhanced. (Habibi, et al., 2005; Konstantinou and Albanis, 2004; Akpan and Hameed, 2009; Qamar et al., 2005; Saquib et al., 2008)

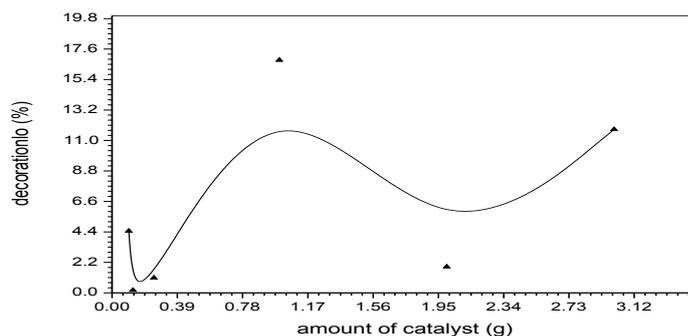
Influence of Amount of Catalyst

Table (2): effect of amount of catalyst on decolorization of Tubantin blue dye at pH 7.4 dye at 50ppm concentration

Amount of catalyst g/dm ³		Absorbance at 436nm	Absorbance at 525nm	Absorbance at 620nm	Average	Decoloration %
0.1	before	0.662	1.823	2.264	1.58300	4.466
	after	0.928	1.720	1.889	1.51230	
0.125	before	0.675	1.798	2.242	1.57167	0.191
	after	0.996	1.786	1.924	1.56867	
0.25	before	1.046	2.480	2.500	2.00900	1.082
	after	1.304	2.041	2.249	1.74700	
1	before	0.662	1.823	2.264	1.583	16.8
	after	0.984	1.649	1.318	1.317	
2	before	0.521	1.552	2.120	1.4177	1.88
	after	1.341	1.693	1.342	1.391	
3	before	0.521	1.552	2.120	1.4177	11.8
	after	1.104	1.421	1.224	1.2497	

Table 2 demonstrates the effect of amount of catalyst on the photo-decolorization of Tubantin blue BRR-HC. Fig (4) show the effect of amount of TiO₂ on photo-decolorization of Tubantin blue BRR-HC. Decolorization was observed to increase the photocatalyst amount. (Akpan and Hameed, 2009; Seyyedi and Jahromi, 2014; Sun et al., 2008) The increase in the amount of

catalyst increased the number of active sites, on the photocatalyst surface, that in turn increase the number of hydroxyl and superoxide radicals causing an increasing the percentage of decolorization. (Huang et al., 2008). On the other hand when the concentration of TiO₂ was decreased, the catalyst surface and its effect on absorption of light were limited.

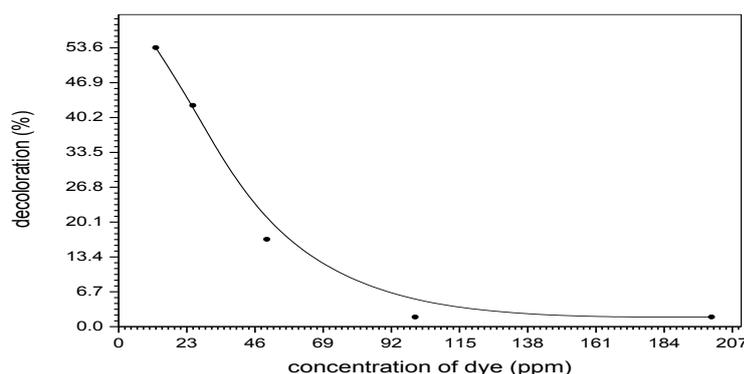


Fig(4) : effect of amount of catalyst(1/dm³TiO₂ pure) on decoloration of Tubantin blue dye at 50ppm concentration at pH 7.4

Influence of Initial Concentration of Dyes

Table (3) : concentration of dye on decoloration of tubantin blue dye at pH 7.4, catalyst (1g/dm³ TiO₂ pure)

Concentration of dye ppm		Absorbance at 436nm	Absorbance at 525nm	Absorbance at 620nm	Average	Decoloration %
12.5	before	0.176	0.425	0.635	0.412	53.46
	after	0.222	0.180	0.170	0.191	
25	before	0.343	0.825	1.226	0.807	42,54
	after	0.505	0.510	0.376	0.463	
50	before	0.662	1.823	2.264	1.583	16.80
	after	0.984	1.649	1.318	1.317	
100	before	1.070	2.406	2.485	1.987	1.857
	after	1.352	2.031	2.190	1.858	
200	before	1.046	2.480	2.500	2.009	1.875
	after	1.304	2.041	2.249	1.875	



Fig(5) : Concentration of dye on decoloration of tubantin blue dye at pH 7.4, catalyst (1g/dm³ TiO₂ pure)

The effect of initial concentration of dye on photo-decolorization of dye was summarized in Table (3). Fig (5) shows that

percentage declorization of tubantin blue BRR-HC decreases as the initial concentration of the dye increased. The decolorization was related not only to the

probability of OH[•] radicals formation on the catalyst surface but also to the probability their reaction with dye molecules. It was postulated that when the initial concentration of dye is increased, more and more dye molecules are adsorbed on the surface of TiO₂. whereas less number of photons are available to reach the catalyst surface and therefore less OH[•]

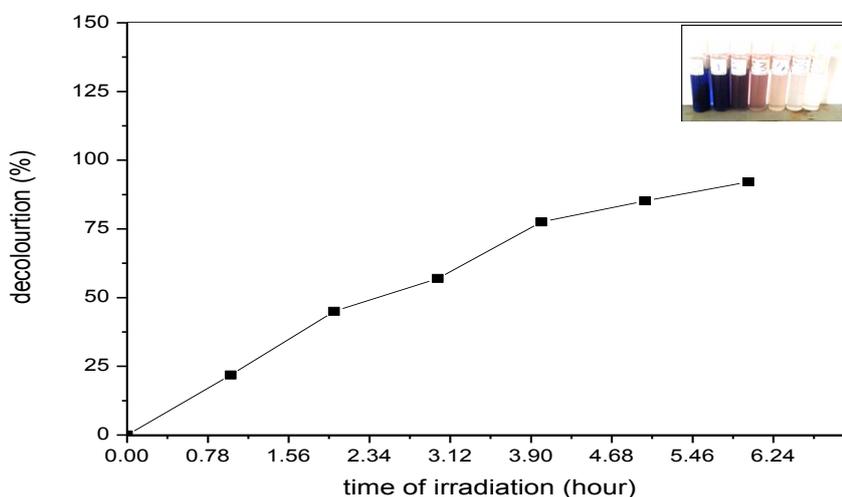
radicals are formed.(Konstantinou and Albanis, 2004; Daneshvar et al., 2003)

Influence of Time of Irradiation:

It can be seen from Table 5 and fig 6 percentage decolorization increased as function of irradiation time . due to hydroxyl radical(OH[•]) has short half life time.

Table (4): effect of irradiation time on decoloration of Tubantin blue dye at 50 ppm at pH 9.4, catalyst (1g/dm³) under air

Time of irradiation hour	Absorbance at 436nm	Absorbance at 525nm	Absorbance at 620nm	Average	Decoloration %
0	0.515	1.394	1.929	1.2793	0
1	0.730	1.148	1.124	1.00067	21.80
2	0.675	0.790	0.647	0.70400	45.00
3	0.679	0.567	0.402	0.54930	54.70
4	0.386	0.299	0.177	0.28730	77.50
5	0.272	0.179	0.116	0.15037	88.20
6	0.132	0.125	0.048	0.10167	92.01



Fig(6) : Effect of irradiation time on decoloration of tubantin blue dye at 50ppm, pH 9.4, catalyst (1g/dm³) under air

Temperature of solution:

Table (5) and fig (7) show the increase of temperature of solution during the decolorization of Tubantin blue BRR-HC. It was noticed that temperature was increased during experiment, owing the use

of CPC collector. Also related to daily period. However temperature is increased the decolorization uninfluenced. The best temperature range for the photo degradation is 20-80 °C. (Carp et al., 2004)

Table(5): The changing of temperature of solution against the irradiation time during decolorization of Tubantin blue dye at 50ppm, pH 7.4, catalyst (1g/dm³) under air

Irradiation time hour	Temperature °C
1	27
2	42
3	44
4	44
5	44

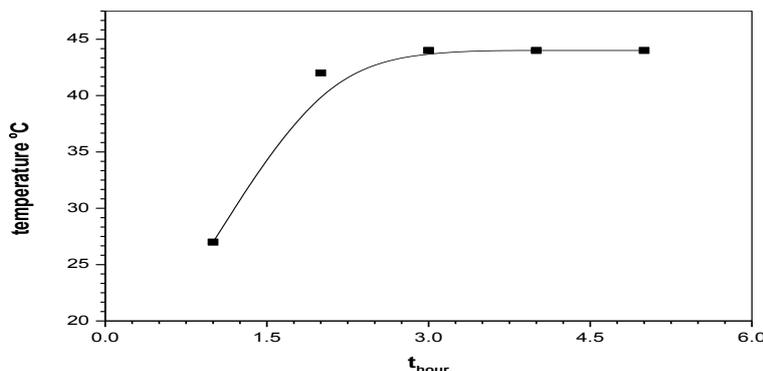


Fig (7): the various of temperature against the irradiation time during decolorization of Tubantin blue dye at pH 7.4, catalyst (1g/dm³) under air

variation in the values of photo flux Table((6) and Figure (8)) was quite consistent with the phenomenon of the daily change in solar light intensity.

Photon Flux

Solar light irradiation changed daily and even on the same day(Neppolian et al., 2002, Carp et al., 2004). Therefore, the

Table (6):photon flux during decolorization of tubantin blue dye at 50ppm, pH 9.4, catalyst (1g/dm³) under air

Irradiation time hour	Photon flux Enstien / second
First	7.615630E ⁻⁵
Second	5.212596E ⁻⁵
Third	3.643923E ⁻⁵
Fourth	2.494090E ⁻⁵
Fifth	3.671580E ⁻⁵

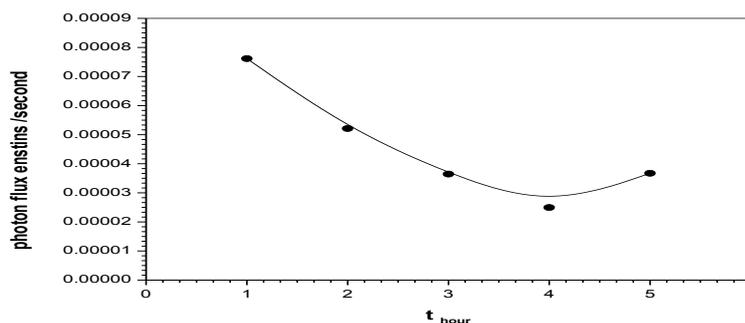


Fig (7): photon flux during decolorization of Tubantin blue dye at 50ppm, pH 9.4, catalyst (1g/dm³) under air

Influence of hydrogen peroxide H₂O₂

Oxidizing agents (hydrogen peroxide (H₂O₂), ammonium persulphate ((NH₄)₂S₂O₈) and potassium bromate (KBrO₃) and oxygen) have a great deal of influence on the photo-catalytic degradation of dyes. (Shakir et al., 2010; Seyyedi and Jahromi, 2014; Saquib *et al.*, 2008; Saquib et al., 2008). The effect of volume of 30% H₂O₂ on decolorization of tubantin blue

BRR-HC was performed by varying the volume of 30% H₂O₂ (12.5, 20, 25, 37.5 and 50 cm³). It can be seen from Table (7) and fig (9) the percentage of decolorization increased as volume of 30% H₂O₂ increased. This increase due to the effect of the additionally produced hydroxyl radicals. Fig (10) shows that TiO₂/H₂O₂ system gave high decolorization percentage.

Table (7):effect of volume of H₂O₂(30%) on decolorization of tubantin blue dye at 50ppm, pH 9.4, catalyst (1g/dm³)

Concentration of dye ppm		Absorbance at 436nm	Absorbance at 525nm	Absorbance at 620nm	Average	Decolorization %
12.5	before	0.560	1.992	2.008	1.5200	55.9211
	after	0.528	0.809	0.673	0.6730	
20	before	0.509	1.439	1.222	0.9923	34.5063
	after	0.6210	0.935	0.845	0.8003	
25	before	0.560	1.992	2.008	1.5200	84.4079
	after	0.270	0.289	0.152	0.2370	
37.5	before	0.727	1.238	1.302	1.0890	52.7090
	after	0.662	0.505	0.378	0.5150	
50	before	0.560	1.992	2.008	1.5233	91.35630
	after	0.179	0.130	0.086	0.1317	

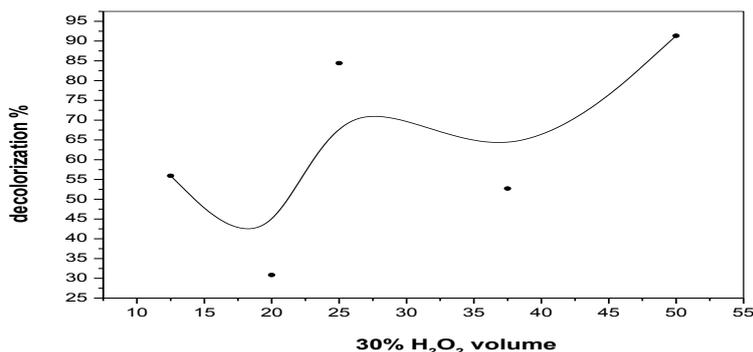


Fig (9):effect of volume of H₂O₂(30%) on decolorization of tubantin blue dye at 50ppm, pH 9.4, catalyst (1g/dm³)

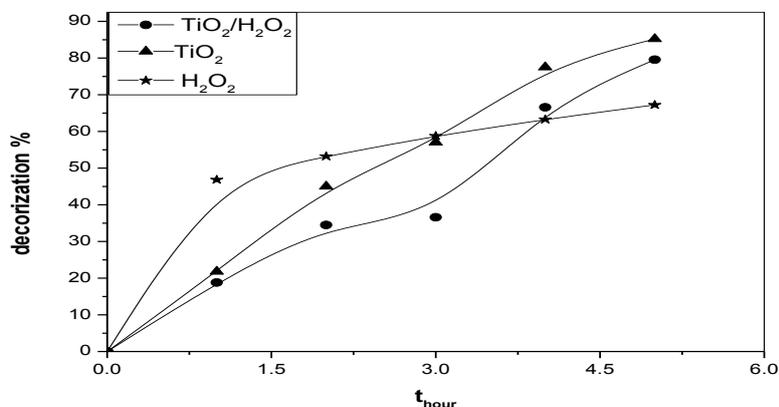


Fig (10): Decolorization % of Tubantin blue dye depending on H₂O₂/ TiO₂

Conclusion

The progress of photo-catalytic decolorization of Tubantin blue dye during changing the experimental parameters was monitored by measuring the absorbance in uv-visible spectrum 436, 525 and 620nm. Results indicate that the photo-catalytic decolorization of tubantin blue dye in water by TiO₂ catalyst were diverse and determined by the concentration of the dye, pH of the solution, amount of photo-catalyst, volume of 30% hydrogen peroxide and irradiation time. During these investigations the temperature of the solution had increased as the photon flux are vary during the experiment.

Acknowledgements

I thank College of Water and Environmental Engineering, Sudan University of Science and Technology where all these experiments were carried out at their laboratories and to help. I thank Ms Sara Yousif and all others for their hep and encouragement.

References:

1. Abbasi, M. and Asl, N.R., 2008. Sonochemical degradation of Basic Blue 41 dye assisted by nanoTiO₂ and H₂O₂. *Journal of hazardous materials*, 153(3), 942-947
2. Akpan, U.G. and Hameed, B.H., 2009. Parameters affecting the photocatalytic degradation of dyes using TiO₂-based

- photocatalysts: a review. *Journal of hazardous materials*, 170(2), 520-529..
- Aleboye, A., Daneshvar, N. and Kasiri, M.B., 2008. Optimization of CI Acid Red 14 azo dye removal by electrocoagulation batch process with response surface methodology. *Chemical Engineering and Processing: Process Intensification*, 47(5), 827-832
 - Amini, M., Arami, M., Mahmoodi, N.M. and Akbari, A., 2011. Dye removal from colored textile wastewater using acrylic grafted nanomembrane. *Desalination*, 267(1), 107-113.
 - Ajmal, A., Majeed, I., Malik, R.N., Iqbal, M., Nadeem, M.A., Hussain, I., Yousaf, S., Mustafa, G., Zafar, M.I. and Nadeem, M.A., 2016. Photocatalytic degradation of textile dyes on Cu₂O-CuO/TiO₂ anatase powders. *Journal of Environmental Chemical Engineering*, 4(2), 2138-2146
 - Carp, O., Huisman, C.L. and Reller, A., 2004. Photoinduced reactivity of titanium dioxide. *Progress in solid state chemistry*, 32(1), pp.33-177.
 - Crini, G., 2005. Recent developments in polysaccharide-based materials used as adsorbents in wastewater treatment. *Progress in polymer science*, 30(1), pp.38-70.
 - Crini, G. and Badot, P.M., 2008. Application of chitosan, a natural aminopolysaccharide, for dye removal from aqueous solutions by adsorption processes using batch studies: a review of recent literature. *Progress in polymer science*, 33(4), 399-447.
 - Daneshvar, N., Salari, D. and Khataee, A.R., 2003. Photocatalytic degradation of azo dye acid red 14 in water: investigation of the effect of operational parameters. *Journal of Photochemistry and Photobiology A: Chemistry*, 157(1), 111-116.
 - Fan, L., Zhou, Y., Yang, W., Chen, G. and Yang, F., 2008. Electrochemical degradation of aqueous solution of Amaranth azo dye on ACF under potentiostatic model. *Dyes and Pigments*, 76(2), 440-446.
 - Foo, K.Y. and Hameed, B.H., 2010. An overview of dye removal via activated carbon adsorption process. *Desalination and Water Treatment*, 19(1-3), 255-274.
 - Gupta, V.K., Jain, R. and Varshney, S., 2007. Electrochemical removal of the hazardous dye Reactofix Red 3 BFN from industrial effluents. *Journal of Colloid and Interface Science*, 312(2), 292-296.
 - Habibi, M.H., Hassanzadeh, A. and Mahdavi, S., 2005. The effect of operational parameters on the photocatalytic degradation of three textile azo dyes in aqueous TiO₂ suspensions. *Journal of Photochemistry and Photobiology A: Chemistry*, 172(1), 89-96.
 - Han, F., Kambala, V.S.R., Srinivasan, M., Rajarathnam, D. and Naidu, R., 2009. Tailored titanium dioxide photocatalysts for the degradation of organic dyes in wastewater treatment: a review. *Applied Catalysis A: General*, 359(1), 25-40.
 - Harrelkas, F., Azizi, A., Yaacoubi, A., Benhammou, A. and Pons, M.N., 2009. Treatment of textile dye effluents using coagulation–flocculation coupled with membrane processes or adsorption on powdered activated carbon. *Desalination*, 235(1-3), 330-339.
 - Huang, M., Xu, C., Wu, Z., Huang, Y., Lin, J. and Wu, J., 2008. Photocatalytic discolorization of methyl orange solution by Pt modified TiO₂ loaded on natural zeolite. *Dyes and Pigments*, 77(2), 327-334
 - Kerkez-Kuyumcu, Ö., Kibar, E., Dayıoğlu, K., Gedik, F., Akın, A.N. and Özkara-Aydınoglu, Ş., 2015. A comparative study for removal of different dyes over M/TiO₂ (M= Cu, Ni, Co, Fe, Mn and Cr) photocatalysts under visible light irradiation. *Journal of Photochemistry and Photobiology A: Chemistry*, 311, 176-185.
 - Konstantinou, I.K. and Albanis, T.A., 2004. TiO₂-assisted photocatalytic

- degradation of azo dyes in aqueous solution: kinetic and mechanistic investigations: a review. *Applied Catalysis B: Environmental*, 49(1), 1-14.
19. Kordouli, E., Bourikas, K., Lycourghiotis, A. and Kordulis, C., 2015. The mechanism of azo-dyes adsorption on the titanium dioxide surface and their photocatalytic degradation over samples with various anatase/rutile ratios. *Catalysis Today*, 252, 128-135.
 20. Kuhn, H.J., Braslavsky, S.E. and Schmidt, R., 2004. Chemical actinometry (IUPAC technical report). *Pure and Applied Chemistry*, 76(12), 2105-2146.
 21. Lima, C.S., Batista, K.A., Rodríguez, A.G., Souza, J.R. and Fernandes, K.F., 2015. Photodecomposition and color removal of a real sample of textile wastewater using heterogeneous photocatalysis with polypyrrole. *Solar Energy*, 114, 105-113.
 22. Mahmoodi, N.M. and Arami, M., 2006. Bulk phase degradation of Acid Red 14 by nanophotocatalysis using immobilized titanium (IV) oxide nanoparticles. *Journal of Photochemistry and Photobiology A: Chemistry*, 182(1), 60-66.
 23. Mall, I.D., Srivastava, V.C. and Agarwal, N.K., 2006. Removal of Orange-G and Methyl Violet dyes by adsorption onto bagasse fly ash—kinetic study and equilibrium isotherm analyses. *Dyes and pigments*, 69(3), 210-223.
 24. Mittal, M., Sharma, M. and Pandey, O.P., 2014. UV–Visible light induced photocatalytic studies of Cu doped ZnO nanoparticles prepared by coprecipitation method. *Solar Energy*, 110, 386-397.
 25. Neppolian, B., Choi, H.C., Sakthivel, S., Arabindoo, B. and Murugesan, V., 2002. Solar light induced and TiO₂ assisted degradation of textile dye reactive blue 4. *Chemosphere*, 46(8), 1173-1181.
 26. Qamar, M., Saquib, M. and Muneer, M., 2005. Photocatalytic degradation of two selected dye derivatives, chromotrope 2B and amido black 10B, in aqueous suspensions of titanium dioxide. *Dyes and Pigments*, 65(1), 1-9.
 27. Sachdeva, S. and Kumar, A., 2009. Preparation of nanoporous composite carbon membrane for separation of rhodamine B dye. *Journal of Membrane Science*, 329(1), 2-10.
 28. Saquib, M., Tariq, M.A., Haque, M.M. and Muneer, M., 2008. Photocatalytic degradation of disperse blue 1 using UV/TiO₂/H₂O₂ process. *Journal of environmental management*, 88(2), 300-306.
 29. Saquib, M., Tariq, M.A., Faisal, M. and Muneer, M., 2008. Photocatalytic degradation of two selected dye derivatives in aqueous suspensions of titanium dioxide. *Desalination*, 219(1-3), 301-311.
 30. Seyyedi, K. and Jahromi, M.A.F., 2014. Decolorization of Azo Dye CI Direct Black 38 by Photocatalytic Method Using TiO₂ and Optimizing of Process. *APCBEE Procedia*, 10, 115-119.
 31. Shakir, K., Elkafrawy, A.F., Ghoneimy, H.F., Beheir, S.G.E. and Refaat, M., 2010. Removal of rhodamine B (a basic dye) and thoron (an acidic dye) from dilute aqueous solutions and wastewater simulants by ion flotation. *Water research*, 44(5), 1449-1461.
 32. Soutsas, K., Karayannis, V., Poullos, I., Riga, A., Ntampeglitis, K., Spiliotis, X. and Papapolymerou, G., 2010. Decolorization and degradation of reactive azo dyes via heterogeneous photocatalytic processes. *Desalination*, 250(1), 345-350..
 33. Sun, J., Qiao, L., Sun, S. and Wang, G., 2008. Photocatalytic degradation of Orange G on nitrogen-doped TiO₂ catalysts under visible light and sunlight irradiation. *Journal of hazardous materials*, 155(1), 312-319.
 34. Tan, I.A.W., Ahmad, A.L. and Hameed, B.H., 2008. Adsorption of basic dye on

- high-surface-area activated carbon prepared from coconut husk: Equilibrium, kinetic and thermodynamic studies. *Journal of hazardous materials*, 154(1), 337-346.
35. Verma, A.K., Dash, R.R. and Bhunia, P., 2012. A review on chemical coagulation/flocculation technologies for removal of colour from textile wastewaters. *Journal of environmental management*, 93(1), 154-168.
36. Xu, L., Zhao, H., Shi, S., Zhang, G. and Ni, J., 2008. Electrolytic treatment of CI Acid Orange 7 in aqueous solution using a three-dimensional electrode reactor. *Dyes and Pigments*, 77(1), 158-164
37. Zangeneh, H., Zinatizadeh, A.A.L., Habibi, M., Akia, M. and Isa, M.H., 2015. Photocatalytic oxidation of organic dyes and pollutants in wastewater using different modified titanium dioxides: a comparative review. *Journal of Industrial and Engineering Chemistry*, 26,1-36.
38. Zonoozi, M.H., Moghaddam, M.A. and Arami, M., 2009. Coagulation/flocculation of dye-containing solutions using polyaluminium chloride and alum. *water science and technology*, 59(7), 1343-1351.
39. <https://pubchem.ncbi.nlm.nih.gov/compound/> (created 8 May 2005)