g EB irradiation. For samples saturated with nitrogen and samples without any aeration, the degradation curves were almost coincided, it indicated that small amount of oxygen did not stop the abundant amount of e_{aq}^- to react with TCS. On the contrary, the existence of N_2O strongly inhibited the reaction, N_2O was used here as the scavenger of e_{aq}^- (Eq. (5)), so this result proved the great contribution of e_{aq}^- in the degradation of TCS, however, there was still apparent degradation of TCS even with saturated N_2O, it might be ascribed to topical overdose of EB irradiation which caused transient high concentration of e_{aq}^- and led to the TCS degradation.

$$e_{aq}^- + N_2O + H_2O \rightarrow {}^{\bullet}OH + OH^- + N_2 \qquad (5)$$

3.2 Effect of typical anions

Anions existed everywhere in WWTPs and natural aquatic environment with considerable concentrations, so their effect on TCS degradation by EB irradiation was considered in this part.

Typical anions such as sulfate ion (SO_4^{2-}), nitrate ion (NO_3^-) and Bicarbonate ions (HCO_3^-) were studied, the obtained results were exhibited in Fig. 3.

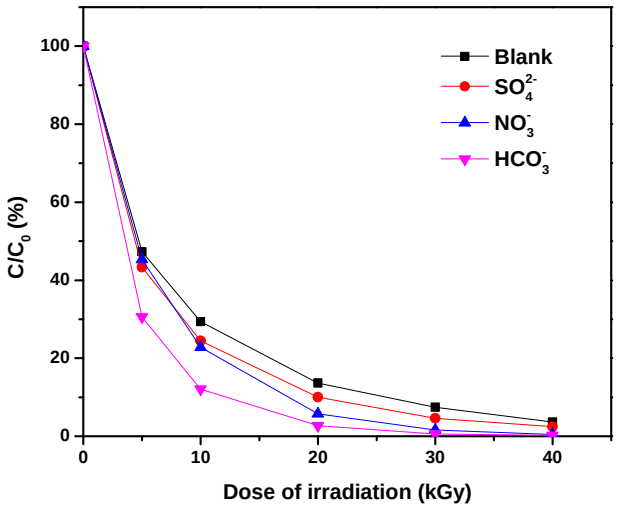

Fig. 3 Effect of dissolved gas on the degradation of TCS

It can be obviously seen in Fig. 3 that all the investigated anions accelerated the degradation of TCS, Huang et al (2007) investigated the the reactivity of hydrated electron toward perfluorinated carboxylates and found that the second-order rate constant is highly dependent on the ionic strength (adding $NaClO_4$) of the medium, higher ionic strength caused better rate constant. In this study, as analyzed before, e_{aq}^- is the primary active radical, so these results correspond well with the former reports.

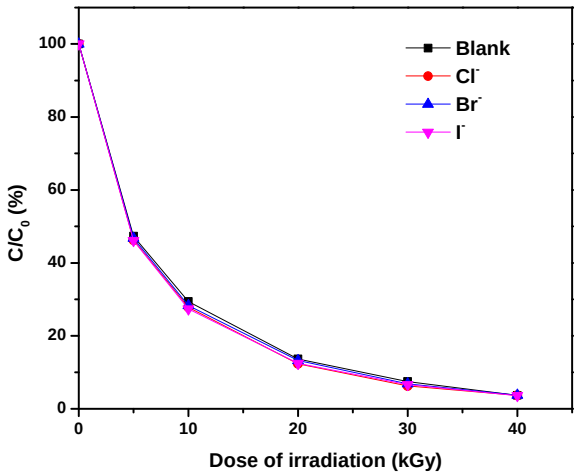

Fig. 4 Effect of halide ion on the degradation of TCS

Effect of halide ions was studied using chloridion (Cl^-), bromide ion (Br^-) and iodide ions (I^-), the results are depicted in Fig. 4, as shown in Fig. 4, all the degradation curves were almost the same as the blank control group, in which no halide ions were added, it indicates that halide ions has no effect on TCS degradation, this result is reasonable because halide ions are all electronic saturated and can not react with e_{aq}^- by any means, unfortunately, the only active radical in the solution is e_{aq}^-.

3.3 Effect of oxidizing species

During the process of e_{aq}^- reduction, the effect of oxidizing species can be of great importance, as studied in 3.1, the existence of oxygen did not make any difference on the degradation of TCS, then other oxidizing species were added and the obtained results were illustrated in Fig. 5.

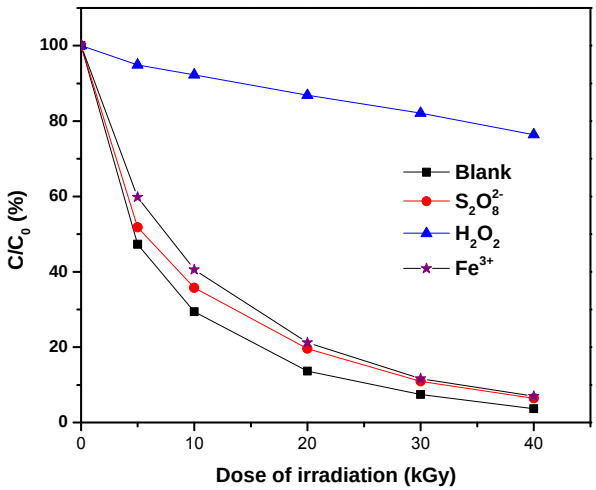

Fig. 5 Effect of oxidizing species on the degradation of TCS

As shown, all the oxidizing species inhibited the degradation procedure, especially for H_2O_2, this result can be explained by Eq. (6), H_2O_2 could react rapidly with e_{aq}^- and form $^{\bullet}OH$ ($k=1.1\times10^{10}$ L $mol^{-1}s^{-1}$), but $^{\bullet}OH$ was quenched by ethanol in Eq. (2), leading to the great loss of e_{aq}^- and thus slowed down the reaction rate.

$$H_2O_2 + e_{aq}^- \rightarrow {}^{\bullet}OH + OH^- \quad (6)$$

Fe (III) commonly exists in the aquatic environment, its reaction reaction equation is similar (Eq. (7)):

$$Fe^{3+} + e_{aq}^- \rightarrow Fe^{2+} \quad (7)$$

In this study, the solution pH was 6.4, in this condition, Fe (III) usually existed in the form of $Fe(OH)^{2+}$, $Fe(OH)_2^+$ or even precipitated (Wu 2000), so the inhibiting effect was not as strong as H_2O_2.
In the case of $S_2O_8^{2-}$, it also react with e_{aq}^- in Eq. (8):

$$S_2O_8^{2-} + e_{aq}^- \rightarrow SO_4^{\bullet-} + SO_4^{2-} \quad (8)$$

Alcohols that contain an α-hydrogen, such as ethanol, can react with both $SO_4^{\bullet-}$ and $^{\bullet}OH$ (Anipsitakis 2004), so the $SO_4^{\bullet-}$ generated is supposed to be quenched by ethanol, causing the inhibition of TCS degradation rate.

4. CONCLUSIONS

The higher degradation efficiency of TCS in aqueous solution under EB irradiation was observed, the analysis of different dissolved gas proved the great contribution of e_{aq}^- in the irradiation process. The addition of different acid radical accelerated the degradation rate by increasing acid radical ion strength and then accelerating the second-order rate constant of e_{aq}^- and TCS, on the contrary, adding halide ion made no difference in the degradation process of TCS. oxidizing species could consume e_{aq}^- and thus slow down the degradation process.

REFERENCES

AlSheikhly, M., Poster, D.L., An, J.C., Neta, P., Silverman, J. and Huie R.E. (2006), "Ionizing radiation-induced destruction of benzene and dienes in aqueous media", *Environ. Sci. Technol*., **40**, 3082-3088.

Anipsitakis, G.P., and Dionysiou, D.D. (2004), "Radical generation by the interaction of transition metals with common oxidants", *Environ. Sci. Technol*., **38**, 3705-3712.

Bergman, A., Heindel, J.J., Jobling, S., Kidd, K.A. and Thomas Zoeller, A. (2012), "State-of-the-science of endocrine disrupting chemicals"

Binelli, A., Cogni, D., Parolini, M., Riva, C. and Provini, A., (2009), "In vivo experiments for the evaluation of genotoxic and cytotoxic effects of Triclosan in Zebra mussel

hemocytes", *Aquat. Toxicol.*, **91**, 238-244.
Chen, X., Richard, J., Liu, Y., Dopp, E., Tuerk, J. and Bester, K. (2012), "Ozonation products of triclosan in advanced wastewater treatment", *Water Res.* **46**, 2247-2256.
Dann, A.B. and Hontela, A. (2011), "Triclosan: environmental exposure, toxicity and mechanisms of action", *J. Appl. Toxicol.*, **31**, 285-311.
Daughton, C.G. and Ternes, T.A. (1999) "Pharmaceuticals and personal care products in the environment: agents of subtle change?", *Environ. Health Perspect.,* **107**(6), 907-938.
Heidler, J. and Halden, R.U. (2007), "Mass balance assessment of triclosan removal during conventional sewage treatment", *Chemosphere*, **66**, 362-369.
Huang, L., Dong, W. and Hou, H. (2007), "Investigation of the reactivity of hydrated electron toward perfluorinated carboxylates by laser flash photolysis", *Chem. Phys. Lett.*, **436**, 124-128.
Knust, K.N., Foley, M.P., Mubarak, M.S., Skljarevski, S., Raghavachari, K. and Peters, D.G., (2010), "Electrochemical reduction of 5-chloro-2-(2,4- dichlorophenoxy) phenol (triclosan) in dimethylformamide", J. Electroanal. Chem., **638**, 100-108.
Kolpin, D., Furlong, E., Meyer, M., Thurman, E.M., Zaugg, S. (2002), "Pharmaceuticals, hormones, and other organic wastewater contaminants in U.S. Streams", *Environ. Sci. Technol*. **36**, 1202-1211.
Onesios, K.M., Yu, J.T. and Bouwer, E.J. (2009), "Biodegradation and removal of pharmaceuticals and personal care products in treatment systems: a review", *Biodegradation*, **20**, 441-466.
Savage, J.H., Matsui. E.C., Wood, R.A. and Keet, C.A. (2012), "Urinary levels of triclosan and parabens are associated with aeroallergen and food sensitization", *J. Allergy. Clin. Immunol*. 130(2), 453-460.
Slater, G.F., Sherwood Lollar, B., Allen King, R. and O'Hannesin, S. (2002), "Isotopic fractionation during reductive dechlorination of trichloroethene by zero-valent iron: influence of surface treatment", *Chemosphere*, **49**, 587-596.
Song, Z, Wang, N, Zhu, L., Huang, A., Zhao, X. and Tang, H. (2012), "Efficient oxidative degradation of triclosan by using an enhanced Fenton-like process", *Chem. Eng. J.*, **198-199**, 379-387.
Suarez, S., Dodd, M.C., Omil, F. and Gunten, U.V. (2007), "Kinetics of triclosan oxidation by aqueous ozone and consequent loss of antibacterial activity: Relevance to municipal wastewater ozonation", *Water Res.* **41**, 2281-2290.
Wu, F. and Deng, N. (2000), "Photochemistry of hydrolytic iron (III) species and photoinduced degradation of organic compounds: A minireview", *Chemosphere*, **41**, 1137-1147.
Xavier, M.G., Timothy, A. and Stephen, H.Z. (1999), "Reductive Dechlorination of Chlorinated Ethenes and 1,2-Dichloroethane by 'Dehalococcoides ethenogenes' 195", Appl. *Environ. Microbiol.,* **65**(7), 3108-3113.
Yang, B., Ying, G, Zhao, J., Zhang, L., Fang, Y. and Nghiem, L.D. (2011), "Oxidation of triclosan by ferrate: Reaction kinetics, products identification and toxicity evaluation", *J. Hazard. Mater.*, **186**, 227-235.
Yazdankhah, S.P., Scheie, A.A., Hoiby, E.A., Lunestad, B.T., Heir, E., Fotland, T.O., Naterstad, K. and KRUSE, H. (2006), "Triclosan and antimicrobial resistance in bacteria: An overview", *Microbial Drug Resistance*, **12**(2), 83-90.