



## A Study of Chemiluminescence from Reaction of Bis(2,4,6-trichlorophenyl)oxalate–H<sub>2</sub>O<sub>2</sub> in the Presence of a Novel Blue Fluorescer, Furandicarboxylate Derivative

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**Abstract:** The chemiluminescence (CL) arising from the reaction of bis(2,4,6-trichlorophenyl)oxalate (TCPO) with H<sub>2</sub>O<sub>2</sub> in the presence of a novel blue fluorescer, furandicarboxylate derivative, has been studied. The relationship between the CL intensity and concentrations of peroxyoxalate, sodium salicylate, H<sub>2</sub>O<sub>2</sub> and furandicarboxylate derivative as fluorescer has been investigated. Kinetic parameters for the peroxyoxalate chemiluminescence (PO-CL) including intensity at maximum CL, time at maximum intensity, total light yield, theoretical maximum level of intensity and pseudo-first-order rate constants for the rise and fall of the CL burst ( $k_r$  and  $k_f$ ) were also calculated from the computer fitting of the corresponding CL intensity/time profiles. It was found that the furandicarboxylate derivative can be used as an efficient blue fluorescent emitter.

**Keywords:** Peroxyoxalate chemiluminescence, Furandicarboxylate derivative, Kinetic parameters, Bis(2,4,6-trichlorophenyl)oxalate, H<sub>2</sub>O<sub>2</sub>, Fluorescer.

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### 1. Introduction

Chemiluminescence (CL) is a phenomenon in which an electronically excited molecule is generated during the chemical reaction and emits light as a visual output. Owing to the advantages of high sensitivity, wide linear range, simple instrumentation, and fast dynamic response, CL has continually

received more and more attention in the last years [1-3]. CL has been used in various fields, including environmental, biological, clinical, food, and pharmaceutical analysis [4].

Of the numerous CL reactions known to date, peroxyoxalate chemiluminescence (PO-CL) is the most effective one (quantum yield up to 50%), which

has been extensively investigated since its discovery by Chandross [5]. A typical PO-CL consists of the reaction of the active oxalates, such as bis(2,4,6-trichlorophenyl)oxalate (TCPO),  $H_2O_2$  as oxidant and a catalyst, in which light emits from the excited states of various externally added fluorescent activators [6]. In the peroxyoxalate system, 1,2-dioxetanones [7] including a 1,2-dioxetanedione [8, 9] and some cyclic peroxides [10] have been suggested as the high energy key intermediates capable of producing an excited species by their thermal decomposition according to a chemically initiated electron exchange luminescence (CIEEL) process [11-13].

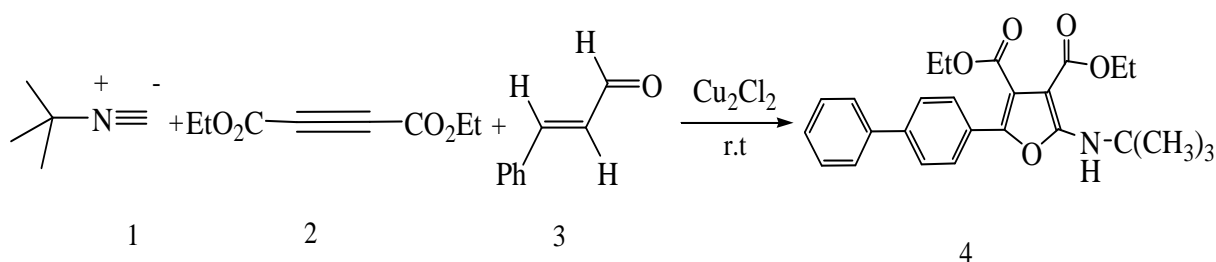
In this paper, we report the study of CL from the reaction of TCPO and  $H_2O_2$  with the laboratory-synthesized diethyl 2-(*tert*-butylamino)-5-biphenyl-3,4-furandicarboxylate (as shown in the scheme 1) as an efficient fluorescence brightener, in the presence of sodium salicylate as a base catalyst. The furan derivative is an intense and useful fluorescer compound containing an aromatic functional group with a low energy  $\pi \rightarrow \pi^*$  transition level and a rigid structure (blue light emission).

The influence of TCPO,  $H_2O_2$ , and sodium salicylate concentration on the intensity, decay and duration of CL emission systems in the presence of the fluorescer has been studied in a great detail. Kinetic parameters for the PO-CL were also calculated from the computer fitting of the corresponding CL intensity/time profiles.

## 2. Experimental

### 2.1. Chemicals and solutions

All chemical compounds were reagent-grade and purchased from Fluka chemical company (CH-9470, Buchs, Switzerland) and used as received without further purification. The furandicarboxylate derivative **4** was synthesized and purified in our laboratories, as described before [14]. We described in detail the preparation of polyfunctionalized furan ring by reaction of alkyl isocyanides **1** with dialkyl acetylenedicarboxylate **2** in the presence of trans-cinnamaldehyde **3**. This three component reaction produces highly functionalized furan **4** in fairly good yields. The yield of reaction for production of the furan derivative was about 65% (Scheme 1).



**Scheme 1.** Synthesis of di(ethyl)-2-(*tert*-butylamino)-5-biphenyl-3,4-furandicarboxylate.

## 2.2. Chemiluminescence measurements

Chemiluminescence detection was performed with a homemade apparatus equipped with a model BPY47 photocell (Leybold, Huerth, Germany). The apparatus was connected to a personal computer via a suitable interface (Micropars, Tehran, Iran). Experiments were carried out with magnetic stirring (500 rpm) in a light-tight flattened bottom glass cell of 15 mm diameter at room temperature. The fluorescence spectra were recorded with a Perkin Elmer, Ls50 spectrofluorimeter instrument.

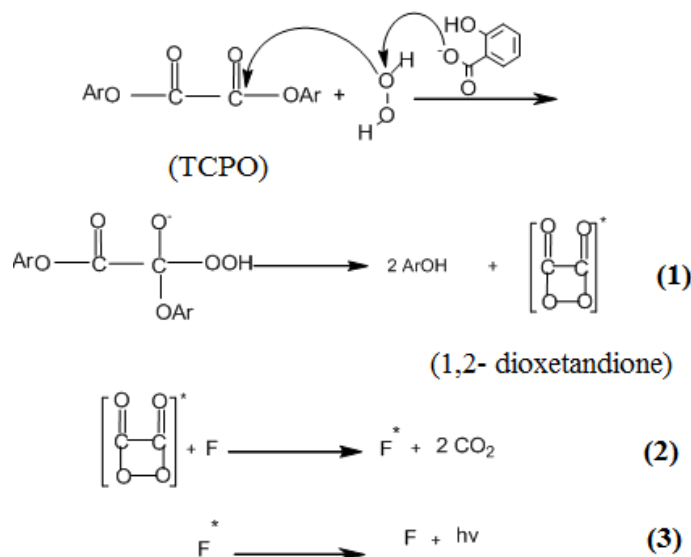
## 2.2. Procedures

Solution *I* was made by mixing 1.0 mL of TCPO (0.01 M) and 0.5 ml of fluorescer (various concentrations in ethyl acetate) and 1.5 mL of ethyl acetate. Solution *II* contained 2 mL of H<sub>2</sub>O<sub>2</sub> (4 M) and 1.0 mL of sodium salicylate (0.1 M) in methanol. Solution *I* was transferred into the instrument quartz

cuvette via polypropene syringes. Then 100 μL of solution *II* was injected into the quartz cuvette and the CL profile was recorded after mixing as soon as possible.

## 3. Results and discussion

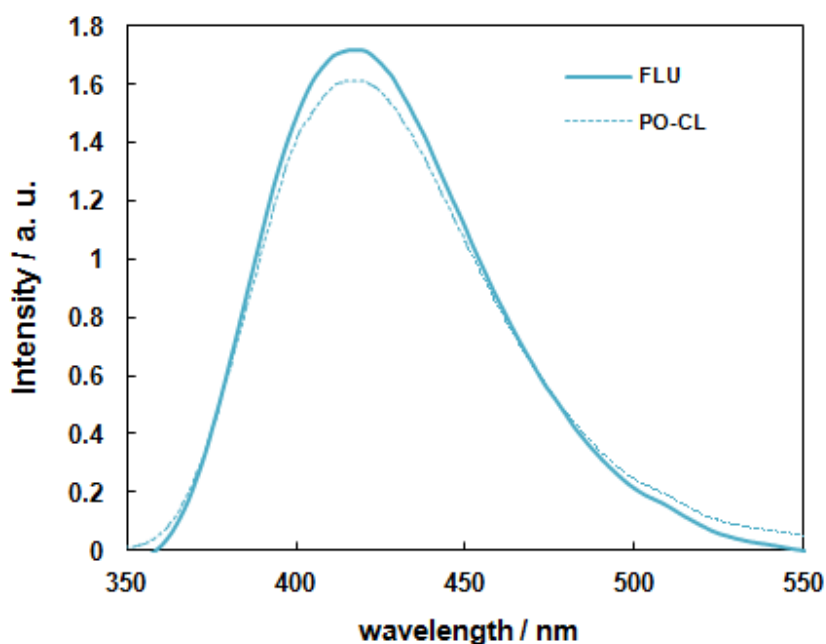
The peroxyoxalate system is the only chemiluminescent reaction supposed to involve an intermolecular CIEEL mechanism with proven high quantum yields [13, 15, 16]. This system consists of a base-catalysed reaction of activated oxalic phenylesters with H<sub>2</sub>O<sub>2</sub> in the presence of highly fluorescent aromatic hydrocarbons with low oxidation potentials as chemiluminescent activators. The mechanism of PO-CL process has been postulated to involve at least one highly energetic intermediate(s) (possibly a dioxetane species) capable of exciting a fluorescent receptor molecule [13, 17], as shown in scheme 2.



**Scheme 2.** Generally accepted understanding of the CIEEL mechanism in PO-CL.

It is well known that a base catalyst is needed to improve the reactivity of TCPO. The most frequently employed, imidazole and sodium salicylate act as a base catalyst for the deprotonation of  $\text{H}_2\text{O}_2$  [13, 15]. According to this mechanism, in the first step, sodium salicylate promotes the formation of the hydroperoxy anion ( $\text{HOO}^-$ ), a stronger nucleophile than  $\text{H}_2\text{O}_2$ , then TCPO reacts with  $\text{HOO}^-$  to produce

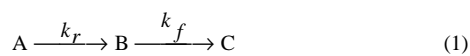
a key chemical intermediate of 1,2- dioxetandione ( $\text{C}_2\text{O}_4$ ) as an excitation source. The second step, excited cyclic  $\text{C}_2\text{O}_4$  intermediate transfer its energy to fluorescer (F, here furandicarboxylate derivative was used as fluorescer), resulting in an excited fluorescer ( $\text{F}^*$ ). The final step is the emission of light energy by returning the excited fluorescer molecule to the ground state.



**Fig. 1.** Steady state fluorescence (solid line), and chemiluminescence (dashed line) spectra of the furandicarboxylate derivative ( $1.0 \times 10^{-3} \text{ mol dm}^{-3}$ ).

The sensitized PO-CL spectrum of fluorescer together with its emission spectrum is shown in Fig. 1. As it is apparent, since the light emission steps for both CL and fluorescence are essentially analogous, the emission wavelength maxima in both processes are similar (*i.e.*, 420 nm).

In order to evaluate the kinetic data for the PO-CL system, a pooled intermediate model was used [10, 18]. According to this model, the CL reaction is simplified as:



where A, B and C represent pools of reactants, intermediates and products, respectively, and both reaction steps designated by the rate constants  $k_r$  and  $k_f$  are irreversible first-order reactions. The integrated rate equation for the CL intensity versus time is:

$$I_t = \left[ \frac{Mk_r}{k_f - k_r} \right] [\exp(-k_r t) - \exp(-k_f t)] \quad (2)$$

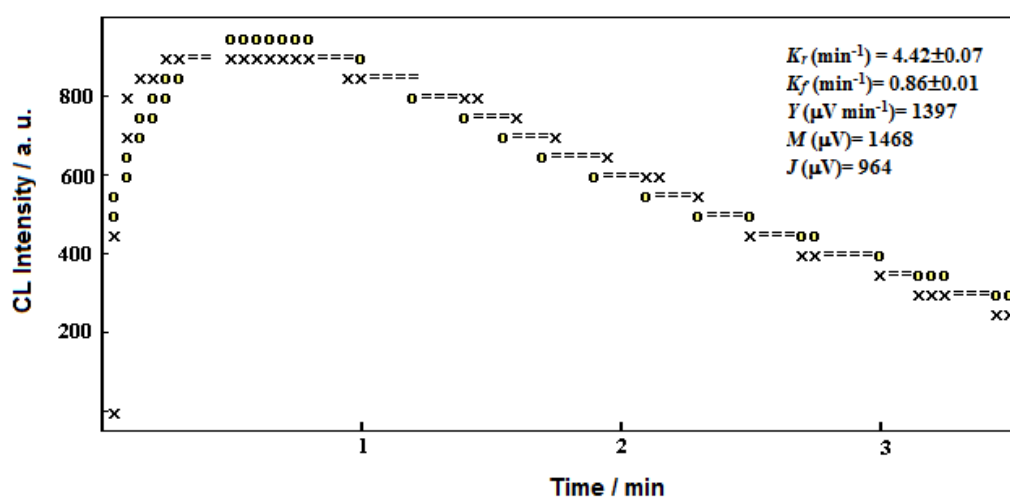
Where  $I_t$  is the CL intensity at time  $t$ ,  $M$  is a theoretical maximum level of intensity if the reactants were entirely converted to a CL-generating material, and  $k_r$  and  $k_f$  are the first-order rate constants for the rise and fall of the burst of CL, respectively. A further advantage of this model is that it not only allows the determination of parameters  $M$ ,  $k_r$  and  $k_f$ , but also it permits an estimate of the intensity at maximum level ( $J$ ), the time of maximum

intensity ( $T_{max}$ ) and the total light yield ( $Y$ ), as follows:

$$J = M \left( \frac{k_f}{k_r} \right)^{[k_f / (k_r - k_f)]} \quad (3)$$

$$T_{max} = \frac{\ln(k_f/k_r)}{k_f - k_r} \quad (4)$$

$$Y = \int_0^{\infty} I_t dt = \frac{M}{k_f} \quad (5)$$



**Fig. 2.** A typical computer fit of the CL intensity–time plot for TCPO–H<sub>2</sub>O<sub>2</sub>–fluorescer–sodium salicylate system (H<sub>2</sub>O<sub>2</sub>, 5.1×10<sup>-2</sup> mol dm<sup>-3</sup>; sodium salicylate, 1.2×10<sup>-3</sup> mol dm<sup>-3</sup>; fluorescer, 1.6×10<sup>-4</sup> mol dm<sup>-3</sup> and TCPO, 1.6×10<sup>-3</sup> mol dm<sup>-3</sup>): (×) experimental point; (o) calculated point; (=) experimental and calculated points are the same within the resolution of the plot.

In this work, a non-linear least-squares curve fitting program, KINFIT [19] was used to evaluate the  $M$ ,  $k_r$  and  $k_f$  values from the corresponding CL intensity–time plots. A typical computer fit of the CL intensity time plots is shown in Fig. 2. The theoretical values of maximum intensity ( $J$ ), and corresponding time ( $T_{max}$ ) and  $Y$  can be calculated by Eqs. 3, 4 and 5 using parameters of  $k_f$ ,  $k_r$  and  $M$  which were determined from the resulting CL intensity–time plots. All kinetic parameters are listed in Table 1. The

experimental values of maximum intensity ( $I_{max}$ ) and  $T_{max}$  were extracted from CL intensity–time plots.

Fig. 3 shows CL intensity as a function of time (intensity/time emission profile) for the PO-CL system in the presence of varying concentrations of TCPO. As is obvious from the inset of Fig. 3 there is a nice linear correlation between the CL intensity and the TCPO concentration. The basis for such linear correlation has already been discussed in literature [20, 21].

It is interesting to note that both the rate constants  $k_r$  and  $k_f$  are more or less independent of TCPO concentration (within the experimental errors), as it is the limiting reagent in the CL process (Table 1).

Such constancy of  $k_r$  and  $k_f$  with increasing TCPO concentration confirms that the reaction is pseudo first-order in TCPO when  $H_2O_2$  is present in large excess [10]. Fig. 4 shows CL intensity as a function

of time for the PO-CL system in the presence of varying concentrations of fluorescer. As it has been clearly shown before [20], there is an exponential increase in CL of the  $H_2O_2$ -TCPO-fluorescer system with increasing concentration of the fluorescer, in the concentration range studied. However, the reciprocal plot of CL intensity against fluorescer resulted in a linear calibration graph (Fig. 4).

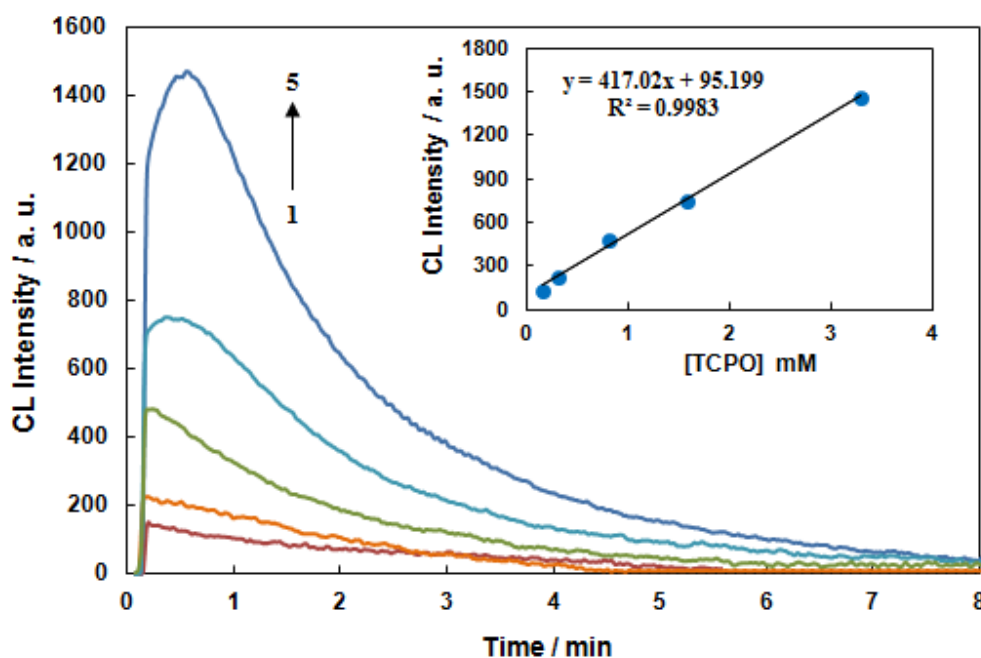


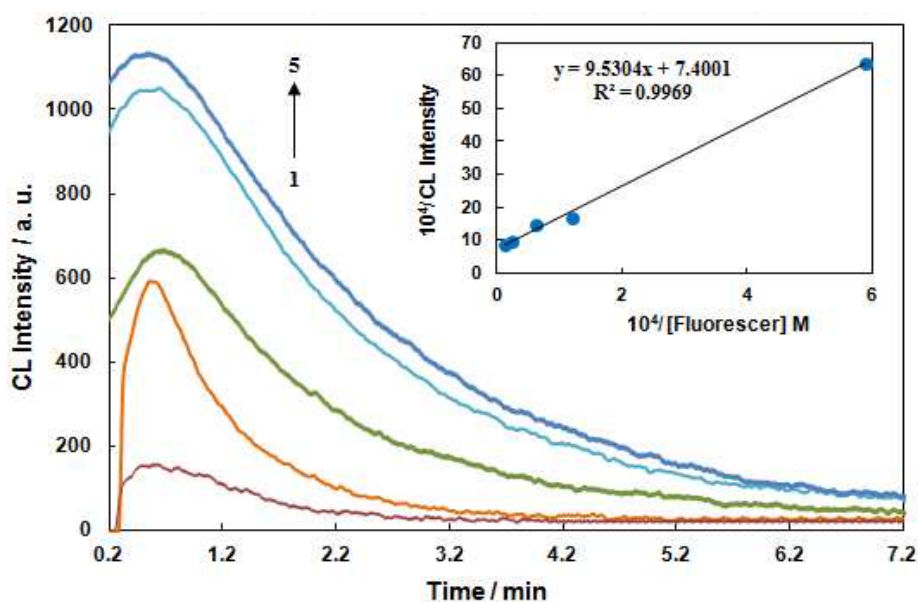
Fig. 3. CL intensity as a function of time for reaction of  $H_2O_2$  ( $5.1 \times 10^{-2} \text{ mol dm}^{-3}$ ), sodium salicylate ( $1.2 \times 10^{-3} \text{ mol dm}^{-3}$ ) and fluorescer ( $1.6 \times 10^{-4} \text{ mol dm}^{-3}$ ) in ethylacetate in the presence of varying concentrations of TCPO: (1)  $1.7 \times 10^{-4}$ , (2)  $3.3 \times 10^{-4}$ , (3)  $8.3 \times 10^{-4}$ , (4)  $1.6 \times 10^{-3}$ , (5)  $3.3 \times 10^{-3} \text{ mol dm}^{-3}$ . Corner of right hand side: correlation diagram for the CL emission with TCPO concentrations.

Table 1 reveals that although the rate constants  $k_r$  and  $k_f$  obtained for the PO-CL reaction are more or less independent the fluorescer concentration, the CL total yield increases with increasing fluorescer concentration, which is consistent with previous

reports [20, 22]. Such observations declare the fact that the high-energy cyclic intermediates (*i.e.*, dioxetane species) may transfer energy to a fluorescer via the CIEEL mechanism.

**Table 1.** CL parameters evaluated from computer fitting of the CL intensity–time plots for TCPO- H<sub>2</sub>O<sub>2</sub> - furandicarboxylate derivative – sodium salicylate system.

Parameter changed	Concentration (mol dm <sup>-3</sup> )	$k_r$ (min <sup>-1</sup> )	$k_f$ (min <sup>-1</sup> )	M (μV)	J <sub>exp</sub> (μV)	J (μV)	T <sub>exp</sub> (min)	T <sub>max</sub> (min)	Y (μV/min)
TCPO	1.7×10 <sup>-4</sup>	8.0±0.4	0.42±0.06	151.4±2.2	141	128	0.31	0.38	360
	3.3×10 <sup>-4</sup>	8.2±0.3	0.47±0.01	253.5±2.5	224	213	0.21	0.26	539
	8.3×10 <sup>-4</sup>	5.1±0.2	0.64±0.02	574.1±11.1	481	457	0.26	0.30	897
	1.6×10 <sup>-3</sup>	4.5±0.1	0.57±0.09	1061.1±9.2	753	728	0.49	0.50	1861
	3.3×10 <sup>-3</sup>	3.6±0.1	0.67±0.02	2104±24.0	1468	1429	0.59	0.57	3140
H <sub>2</sub> O <sub>2</sub>	1.7×10 <sup>-2</sup>	1.4±0.09	0.20±0.06	256.1±2.1	120	132	0.79	0.74	1423
	3.3×10 <sup>-2</sup>	2.4±0.09	0.26±0.02	393.5±4.9	380	321	0.75	0.67	1711
	5.1×10 <sup>-2</sup>	4.0±0.12	0.34±0.08	1013.3±11.2	771	790	0.61	0.63	2980
	6.7×10 <sup>-2</sup>	5.3±0.11	0.49±0.03	1710.5±18.9	1217	1248	0.46	0.46	3491
	8.4×10 <sup>-2</sup>	5.4±0.13	0.50±0.03	1920.3±21.9	1300	1428	0.43	0.40	3729
Sodium salicylate	4.0×10 <sup>-4</sup>	2.5±0.8	0.45±0.06	1253.4±9.4	921	955	0.79	0.77	2785
	8.0×10 <sup>-4</sup>	3.6±0.5	0.58±0.01	1707.5±19.8	1144	1094	0.77	0.74	2944
	1.2×10 <sup>-3</sup>	4.1±0.5	0.58±0.07	1812.4±12.7	1277	1237	0.64	0.61	3125
	1.6×10 <sup>-3</sup>	4.2±0.6	0.64±0.13	1891.2±6.3	1213	1182	0.60	0.57	2955
	2.0×10 <sup>-3</sup>	4.2±0.8	0.65±0.15	1756.3±6.5	1122	1002	0.58	0.57	2850
fluorescer	1.7×10 <sup>-5</sup>	2.7±0.1	1.08±0.38	260.8±7.5	157	143	0.51	0.55	241
	8.3×10 <sup>-5</sup>	2.9±0.2	1.51±0.08	1009.7±50.3	591	500	0.42	0.46	669
	1.6×10 <sup>-4</sup>	1.6±0.1	1.60±0.07	1704.6±10.6	669	627	0.91	0.86	1065
	4.2×10 <sup>-4</sup>	2.1±0.1	0.66±0.03	1773.5±52.1	1052	1044	0.81	0.80	2687
	8.3×10 <sup>-4</sup>	2.5±0.1	1.51±0.01	1725.6±28.6	1130	1150	0.81	0.80	3383


**Fig. 4.** CL intensity vs. fluorescer concentration with H<sub>2</sub>O<sub>2</sub> (5.1×10<sup>-2</sup> M) in the presence of sodium salicylate (1.2×10<sup>-3</sup> M) and TCPO (1.6 × 10<sup>-3</sup> M), in ethyl acetate: (1) 1.7 × 10<sup>-5</sup>, (2) 8.3 × 10<sup>-5</sup>, (3) 1.6 × 10<sup>-4</sup>, (4) 4.2 × 10<sup>-4</sup>, (5) 8.3× 10<sup>-4</sup> mol dm<sup>-3</sup>. Corner of right hand side: The bireciprocal plot of CL emission with fluorescer concentrations.

Previous kinetic works has shown that the charge-transfer steps leading to CL are fast relative to the formation of an initial intermediate and, for this reason, the final reactions leading to CL are kinetically unobservable [20-24].

The influence of  $\text{H}_2\text{O}_2$  concentration on the PO-CL was studied at constant concentration of other reagents and presented in Fig. 5 and Table 1. It was found that there is a direct linear relationship between the concentration of  $\text{H}_2\text{O}_2$  and PO-CL intensity of the

system, at the concentration ranges of  $1.7 \times 10^{-2}$ - $6.7 \times 10^{-2} \text{ mol dm}^{-3}$ . However, further increase in  $\text{H}_2\text{O}_2$  concentration (i.e.,  $6.7 \times 10^{-2} > \text{mol dm}^{-3}$ ) was found to have no significant effect on the PO-CL intensity. Even though, in the absence of sodium salicylate,  $I_t$  at each  $\text{H}_2\text{O}_2$  concentration was found to be much lower than that in the presence of the salt. The observed behavior is clearly indicative of the catalytic effect of sodium salicylate on the PO-CL system studied [25-27].

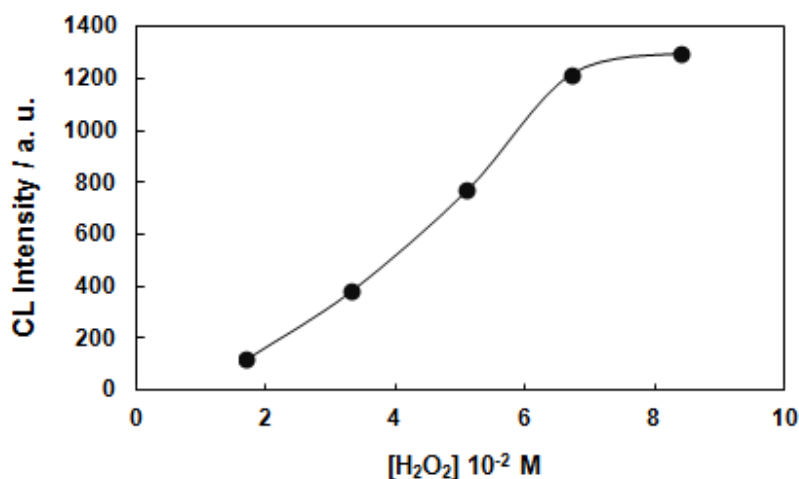


Fig. 5. Effect of  $\text{H}_2\text{O}_2$  concentration on the CL intensity of TCPO- $\text{H}_2\text{O}_2$ -fluorescer system. TCPO ( $1.6 \times 10^{-3} \text{ mol dm}^{-3}$ ), sodium salicylate ( $1.2 \times 10^{-3} \text{ mol dm}^{-3}$ ) and fluorescer ( $1.6 \times 10^{-4} \text{ mol dm}^{-3}$ ) in ethylacetate in the presence of varying concentrations of  $\text{H}_2\text{O}_2$ : (1)  $1.7 \times 10^{-2}$ , (2)  $3.3 \times 10^{-2}$ , (3)  $5.1 \times 10^{-2}$ , (4)  $6.7 \times 10^{-2}$ , (5)  $8.4 \times 10^{-2} \text{ mol dm}^{-3}$ .

It is interesting to note that, with the excess amount of  $\text{H}_2\text{O}_2$ , the pseudo-first-order fall rate constant,  $k_f$ , increases linearly with increasing  $\text{H}_2\text{O}_2$  concentration with a regression equation  $k_f = 0.095[\text{H}_2\text{O}_2] + 0.085$  (Table 1) with a relatively large intercept of about  $0.085 \text{ min}^{-1}$ , which is representative of a first-order reaction that is zero-order in concentration of  $\text{H}_2\text{O}_2$  [10, 28]. Meanwhile, the pseudo-first-order rate constant for the rise step  $k_r$  increased linearly with increasing  $\text{H}_2\text{O}_2$  concentration (Table 1). In this case,

the linear plot of  $k_r$  vs.  $\text{H}_2\text{O}_2$  concentration passes through the origin, within the experimental error, which is consistent with the previously reported mechanism proposed by Hadd *et al.* for the PO-CL reactions in the organic media [10]. The intensity/time emission profile of furandicarboxylate derivative, under the optimal constant concentrations of TCPO,  $\text{H}_2\text{O}_2$  and fluorescer indicated that the emission intensity is significantly enhanced by addition of sodium salicylate. This confirms a key role of



catalyst in the PO-CL system. In order to investigate the optimal concentration of sodium salicylate, the CL response of the  $\text{H}_2\text{O}_2$ -TCPO-fluorescer system was measured against the varying concentrations of the sodium salicylate the resulting plot is shown in Fig. 6. As seen, the PO-CL intensity rapidly increased with increasing concentration of sodium salicylate

until a concentration of  $1.2 \times 10^{-3}$  mol  $\text{dm}^{-3}$  is reached. However, further addition of sodium salicylate causes to decrease the CL intensity and in total yield,  $Y$  (Table 1). This, probably due to the quenching effect of the base at higher concentrations, which possibly it leads to decompose the intermediate, dioxetanedione, and hence reduces the PO-CL light [26-30].

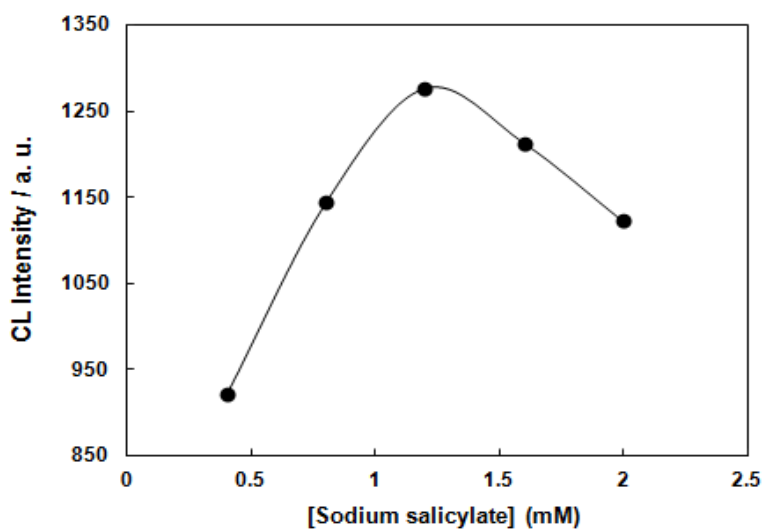


Fig. 6. Effect of sodium salicylate concentration on the CL intensity of TCPO- $\text{H}_2\text{O}_2$ -fluorescer system. TCPO ( $1.6 \times 10^{-3}$  M),  $\text{H}_2\text{O}_2$  ( $5.1 \times 10^{-2}$  M) and fluorescer ( $1.6 \times 10^{-4}$  M) in ethylacetate in the presence of varying concentrations of sodium salicylate: (1)  $4.0 \times 10^{-4}$ , (2)  $8.0 \times 10^{-4}$ , (3)  $1.2 \times 10^{-3}$ , (4)  $1.6 \times 10^{-3}$ , (5)  $2.0 \times 10^{-3}$  mol  $\text{dm}^{-3}$ .

#### 4. Conclusion

The present study describes a new CL system of  $\text{H}_2\text{O}_2$ - bis-(2,4,6-trichlorophenyl) oxalate (TCPO) using furandicarboxylate derivative as fluorescer. In this system, a blue light is produced in the present of furandicarboxylate derivative. The results indicated how concentrations of the components involved in CL, influence on the light emission. Kinetic parameters for the PO-CL of fluorescer were calculated from the corresponding CL intensity-time plots. A non-linear least-squares curve fitting program, KINFIT was used to evaluate the

theoretical maximum level of intensity ( $M$ ), the first order rate constants for the rise  $k_r$  and fall  $k_f$  of the burst of CL. The furandicarboxylate derivative is found intense and useful fluorescer compound which produces blue light emission.

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